INL/EXT-14-31642

An Analysis of Methanol and Hydrogen Production via High-Temperature Electrolysis Using the Sodium Cooled Advanced Fast Reactor

Shannon M. Bragg-Sitton Richard D. Boardman Robert S. Cherry Wesley R. Deason Michael G. McKellar Idaho National Laboratory

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March 2014

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Prepared for the U.S. Department of Energy Office of Nuclear Energy Under DOE Idaho Operations Office Contract DE-AC07-05ID14517

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ABSTRACT

Integration of an advanced, sodium-cooled fast spectrum reactor into nuclear hybrid energy system (NHES) architectures is the focus of the present study. A techno-economic evaluation of several conceptual system designs was performed for the integration of a sodium-cooled Advanced Fast Reactor (AFR) with the electric grid in conjunction with wind-generated electricity. Cases in which excess thermal and electrical energy would be reapportioned within an integrated energy system to a chemical plant are presented. The process applications evaluated include hydrogen production via high temperature steam electrolysis and methanol production via steam methane reforming to produce carbon monoxide and hydrogen which feed a methanol synthesis reactor. Three power cycles were considered for integration with the AFR, including subcritical and supercritical Rankine cycles and a modified supercritical carbon dioxide modified Brayton cycle. The thermal efficiencies of all of the modeled power conversions units were greater than 40%. A thermal efficiency of 42% was adopted in economic studies because two of the cycles either performed at that level or could potentially do so (subcritical Rankine and S-CO₂ Brayton). Each of the evaluated hybrid architectures would be technically feasible but would demonstrate a different internal rate of return (IRR) as a function of multiple parameters; all evaluated configurations showed a positive IRR. As expected, integration of an AFR with a chemical plant increases the IRR when "must-take" wind-generated electricity is added to the energy system. Additional dynamic system analyses are recommended to draw detailed conclusions on the feasibility and economic benefits associated with AFR-hybrid energy system operation.

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An Analysis of Methanol and Hydrogen Production via High-Temperature Electrolysis Using the Sodium Cooled Advanced Fast Reactor

1. INTRODUCTION

Integration of an advanced, sodium-cooled fast spectrum reactor into nuclear hybrid energy system (NHES) architectures is the focus of the current study. As previously discussed in Bragg-Sitton, et al., (2013), NHES could be a key part of the solution to achieving energy security, could provide reliable power availability even with increasing renewable energy penetration into the power grid, and could allow repurposing excess heat and electricity in times of low demand.

Multiple analyses have been performed to demonstrate the load-managing potential of small modular reactors (SMRs). The purpose of this report is to present the results of a techno-economic evaluation of several conceptual designs for the integration of a sodium-cooled Advanced Fast Reactor (AFR) with the electric grid. Selected system designs allow the reactor thermal energy to be converted to electricity and be subsequently dispatched to the grid or to be used in the production of alternative commodities as electricity demand fluctuates. The recent drive in the U.S. and Europe has been to increase the amount of renewable energy on the electrical grid in attempt to reduce overall greenhouse gas (GHG) emissions, but the variability of electricity production via renewable sources increases the need for dependable load-balancing power generation. Nuclear energy provides one option for producing low-emissions electricity. The challenge for nuclear energy is to provide cost-competitive energy in a market in which pricing is established by instantaneous demand with a "must take" priority for variable renewable power generation provided by wind and solar energy.

Nuclear reactors must be operated near their nominal design capacity to be economically viable, justifying large capital costs to build the plant and minimizing operations and maintenance costs. Integration of renewable energy with nuclear power in a hybrid energy system could supply demand-following electricity to the grid while simultaneously increasing utilization of the capital equipment through integration of additional processes that can make efficient use of excess thermal energy. Many industrial manufacturing processes can beneficially use excess reactor thermal energy and/or electrical energy that would be available in times of low grid electricity demand or high renewable-generated electricity.

This report includes analysis results for several electricity generation scenarios to begin to quantify the benefits of hybrid applications of the AFR:

- A. **Single-input, single-output (SISO)** generation of electricity from a nuclear plant (provides a traditional baseline for subsequent hybrid analyses).
- B. **Multi-input, single-output (MISO)** generation of electricity. This simplified hybrid implementation allows evaluation of integrated wind and nuclear power generation using custom Rankine and supercritical power cycles to produce electricity only.
- C. **Multi-input, multi-output (MIMO)** generation of electricity and an additional output commodity (e.g. hydrogen, methanol). For the current study, these cases include:
 - i. Integration of wind and nuclear power generation with hydrogen and oxygen production via high temperature steam electrolysis (HTSE) in addition to electricity generation.
 - ii. Integration of wind and nuclear power generation with methanol production via steam methane reforming of natural gas (produces carbon monoxide and hydrogen, which are catalytically combined to produce methanol) in addition to electricity generation.

The selected hybrid cases are useful illustrations of the art-of-the-possible. High temperature steam electrolysis (HTSE) is a process that ideally splits steam at 800°C (O'Brien, 2008). HTSE is approximately 30% more efficient than standard water electrolysis. HTSE represents a process that can be rapidly turned up or down to utilize electricity and thermal energy when it is available. Additionally, heat recuperation from the hot product streams can be used to amplify the heat provided by a nuclear reactor having intermediate-level output temperature.

Methanol production is representative of many petro-chemical manufacturing industries that must operate continuously near their design capacity for both technical and economic reasons. Methanol production requires heat, steam, and electricity that could be provided by a nuclear plant. Methanol is a primary feedstock for several chemical products, and it can also be converted into gasoline or olefins.

The current study was limited to analysis of a small modular version of the AFR technology to produce electricity and heat for the described hybrid energy systems. The examples are based on the AFR-100 design, which would produce approximately 100 megawatts electricity depending on its associated power cycle. The AFR-100 is a sodium cooled fast reactor design developed at the Argonne National Laboratory; a summary of the design parameters is provided in (Kim, Grandy, & Hill, 2012). The AFR is one of the leading advanced SMR concepts being developed by the DOE Advanced SMR (aSMR) Program. The AFR concept would use sodium for both the core cooling in the primary loop and as the working fluid in the secondary heat transfer loop. The secondary loop provides isolation of the reactor core from the power conversion unit and process heat applications.

AFR-100 Product	Product Description
Reactor Conditions	
Thermal Energy Rating	250 MWt
Reactor Outlet Temperature	550°C (sodium)
Reactor Inlet Temperature	395°C (sodium)
Reactor Heat and Power	
Steam	510°C and 17 MPa for Subcritical Rankine cycle
Steam	510°C and 24 MPa for Supercritical Rankine cycle
Carbon Dioxide	510°C and 20 MPa for Supercritical CO ₂ Brayton cycle
Electricity Production	>100 MWe Net AC or DC
	Generated by Rankine or Supercritical carbon dioxide Brayton power cycle with thermal efficiency > 40%

 Table 1. AFR-100 Design Parameters (Kim, Grandy, & Hill, 2012)

HYSYS (Aspen Technology Inc., 1995) was used to model integration of the AFR-100 reactor with the power conversion units and a high temperature steam electrolysis (HTSE) plant located in close proximity to the reactor site. The modeled power conversion units include supercritical carbon dioxide (S-CO₂) modified Brayton, supercritical steam Rankine, and subcritical steam Rankine power cycles. HYSYS allows for accurate mass and energy balances and contains all of the fundamental process components in the plant; for example, compressors, turbines, pumps, valves, and heat exchangers. HYSYS is used to support the analysis of power conversion units and HTSE because of its ease to develop and optimize detailed power conversion systems and the legacy of HYSYS models developed for HTSE at INL. This work sets the stage for future evaluation of the technical attributes of these cycles, such as their ramp rates and ability to be hybridized with manufacturing industries. Section 2.2 presents additional details on the HTSE integration and the associated results.

The integration of a methanol plant to an AFR-100 was modeled using Aspen-Plus. A detailed methanol plant based on natural gas reforming to produce the appropriate ratio of carbon monoxide and hydrogen (mixtures of CO and H_2 are often referred to as syngas) for catalytic synthesis of methanol was previously

developed for other SMR designs, as described in (Bragg-Sitton, et al., 2013). The model includes both major and minor unit operations with a full heat and electrical integration between the nuclear and chemical production plants. This study leverages the results of the earlier model to evaluate potential heat and electrical integration with the AFR-100. Section 2.3 presents additional details and the associated results for methanol plant integration.

A custom Microsoft Excel spreadsheet economic model (Gandrik A., 2011) was used to calculate the internal rate of return (IRR) of a capital investment based on a standard computation of the net present value (NPV) from discounted cash flows. The economic spreadsheet invokes typical plant economic cost estimations using scaled and factored analyses that include contingencies for engineering, piping, instruments and controls, etc. The analysis employs the HTSE technology design basis developed by the Idaho National Laboratory (INL) and preliminary plant engineering and economics completed by Dominion Engineering under subcontract to DOE-NE (Krull, Roll, & Varrin, March 2013). A limited parametric evaluation of the selling price of electricity and SMR plant size was completed to illustrate the impact of these variables on the financial indicators that can be used to measure project economic value. Hydrogen, oxygen, and methanol commodity prices may also vary according to market projections, but only historical prices were used to project revenue for purposes of this study.

A detailed evaluation of the dynamic hybrid operation of this plant with variable production of electricity and chemicals was beyond the scope of the present work. Such an analysis requires the development of a dynamic process model that accounts for transitory operations that follow market demand functions such as the time-dependent trading costs of electricity.

2. SODIUM FAST REACTOR HYBRID HEAT APPLICATIONS

2.1 Power Generation

2.1.1 General Considerations of Power Cycles

The major difference between nuclear and non-nuclear power cycles is the heat source. For conventional plants, fossil fuels are the heat source, whereas nuclear fission is the heat source for a nuclear plant. A power cycle generally consists of four stages: (1) heat addition, (2) power generation through expansion, (3) heat rejection, and (4) compression.

Thermodynamic performance of a cycle is measured by its thermal efficiency, η_{th} . The thermal efficiency is defined as the electrical power output, \dot{W}_{elec} , divided by the heat input, \dot{Q}_{in} , or:

$$\eta_{th} = \frac{\dot{W}_{elec}}{\dot{Q}_{in}} \tag{1}$$

A power cycle is based on the thermodynamic concept of a heat engine. Power may be produced from a heat engine that is placed between a high temperature source and a low temperature sink, as shown in Figure 1. The work of the heat engine, \dot{W} , is defined in Eq. (2), where $\dot{Q}_{\rm H}$ and

 \dot{Q}_L represent the heat flow from the high temperature source and the low temperature sink, respectively:

$$\dot{\mathbf{W}} = \dot{\mathbf{Q}}_{\mathrm{H}} - \dot{\mathbf{Q}}_{\mathrm{L}} \tag{2}$$

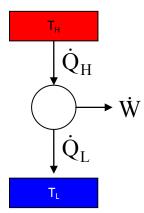


Figure 1. Heat engine between hot source and cold sink.

Heat is transferred from the high-temperature source to the heat engine and heat is rejected from the heat engine to the low temperature sink. The thermal efficiency of a heat engine can be shown as:

$$\eta_{\rm th} = \frac{\dot{Q}_{\rm H} - \dot{Q}_{\rm L}}{\dot{Q}_{\rm H}} \tag{3}$$

In real situations, a temperature difference is needed to transfer the heat from the source to the heat engine and from the heat engine to the heat sink. However, if those differences were to go to zero, an ideal or maximum efficiency could be determined. The maximum efficiency is called the Carnot efficiency, η_{Carnot} , and is a function of source and sink temperatures only, T_H and T_L :

$$\eta_{\text{Carnot}} = \frac{T_{\text{H}} - T_{\text{L}}}{T_{\text{H}}}$$
(4)

In this report, three power cycles were analyzed: supercritical Rankine steam cycle, subcritical Rankine steam cycle, and a supercritical carbon dioxide modified Brayton gas cycle. The following assumptions were made for all of the cycles analyzed:

- Cycle turbines and compressors have 90% isentropic efficiencies unless otherwise stated.
- Pumps have 75% isentropic efficiencies.
- Intermediate heat exchangers (IHX) and steam generators have minimum approach temperatures of 20°C.
- All other heat exchangers in the power cycles have minimum approach temperatures of 5.56°C.
- Pressure drops across the components are 2% of the inlet pressure to the component.
- For the Rankine power cycles, the high pressure and low pressure turbines have isentropic efficiencies of 80% and the intermediate turbine has an efficiency of 90%.

The purpose of these models is to provide a reasonable thermal efficiency for electricity production. The models are theoretical and are not developed for actual power cycle design.

2.1.2 Rankine Steam Cycle

The Rankine steam cycle is the most basic thermodynamic power cycle. The simplest cycle consists of a steam generator, turbine, condenser, and pump, as shown in Figure 2. The working fluid is water; low-pressure water is pumped to a high pressure. Heat is transferred to the water through a steam generator to produce high-pressure steam. The steam expands through the turbine to produce flow work or power which is converted to electricity in a generator. The low-pressure saturated steam/water is condensed to liquid water in the condenser.

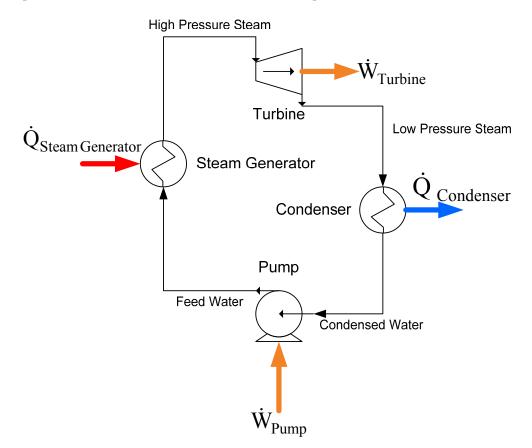


Figure 2. Basic Rankine steam cycle.

The Rankine cycle efficiency is defined as the power difference between the turbine and the pump divided by the heat input to the steam generator:

$$\eta_{th} = \frac{\dot{W}_{Turbine} - \dot{W}_{Pump}}{\dot{Q}_{Steam \,Generator}}$$
(5)

The cycle efficiency can be improved through heat recuperation in which a portion of the partially expanded streams from the turbines exchange heat with the water returning from the condenser to the steam generator, also known as feed water. These heat exchangers are called feed water heaters. The expanded streams are mixed with the exit stream of the condenser. The efficiency can also be improved by reheating the steam from the first turbine within the steam

generator before expanding the steam in the second turbine. Figure 3 shows a Rankine steam cycle with feed water heaters and a set of turbines. The power cycle is separated from the heat of the reactor through two circulation loops: the primary sodium loop and a secondary (intermediate) sodium heat transfer loop. The purpose of the intermediate loop is to prevent tritium migration to the power cycle components. The thermal efficiency of a recuperated Rankine cycle is defined as:

$$\eta_{th} = \frac{\sum \dot{W}_{Turbines} - \sum \dot{W}_{Pumps}}{\dot{Q}_{Reactor}}$$
(6)

Figure 3 is a simple representation of the actual process model. Both supercritical and subcritical Rankine cycle models for this work have 6 feed water heaters, 1 deaerating heater, and 3 feed water pumps. The supercritical Rankine cycle has a pressure exiting the steam generator that is above the critical point of steam (22.1 MPa) and the subcritical has a pressure below the critical point. The models are based on a supercritical steam cycle developed by Babcock and Wilcox (The Babcock & Wilcox Company, 2005). The process flow diagrams and stream conditions of both models are found in Appendix A.

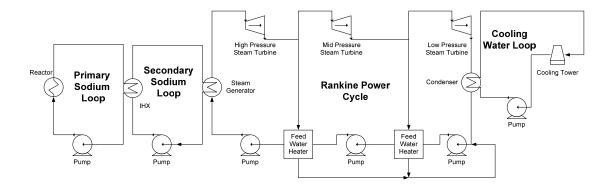


Figure 3. Rankine steam cycle with feed water heaters.

The Rankine cycle is optimized by increasing the temperature into the steam generator to as high a temperature as possible. This temperature is constrained by the minimum temperature difference between the hot side and the cold side of the steam generator. The steam generator inlet temperature establishes the maximum flow rate of water/steam through the steam generator. Next, the feed water heaters must be optimized by adjusting the fraction of steam bled from the turbines to the feed water heaters and the pressures at which those streams are bled. Those variables are adjusted so that the inlets of the pumps are saturated liquid and each feed water heater has a minimum temperature difference of 5.56 °C between the hot side and cold side fluids at the inlets and outlets. Figure 4 shows a typical temperature versus heat flow profile for an optimized feed water heater.

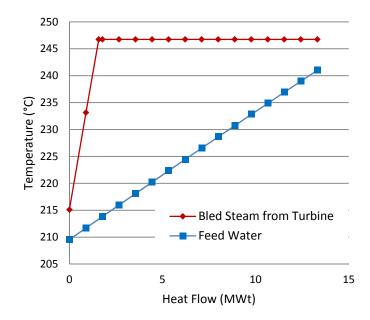


Figure 4. Typical temperature profile for an optimized feed water heater.

2.1.3 Supercritical Carbon Dioxide Modified Brayton Gas Cycle (S-CO₂)

The basic Brayton gas cycle is shown in Figure 5. The high-pressure working gas is expanded in a turbine to produce power. The low-pressure warm gas is cooled in an ambient cooler, which reduces the power of compression. The low-pressure cold gas is compressed to the high-pressure of the system. Often the turbine and the compressor are mechanically connected through a single shaft. The thermal efficiency of the cycle is presented in Eq. (7).

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{Turbine}} - \dot{W}_{\text{Compressor}}}{\dot{Q}_{\text{Gas Heater}}}$$
(7)

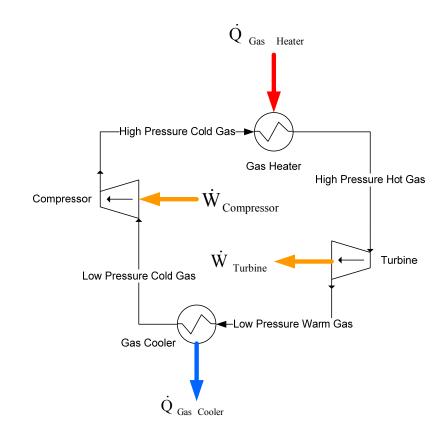


Figure 5. Simple Brayton cycle.

As with the Rankine steam cycle, the thermal efficiency is improved through recuperation. The recuperating heat exchanger heats the gas exiting the compressor and cools the gas leaving the turbine. This has a two-fold advantage of reducing the amount of cooling needed from the gas cooler and heat needed before expansion.

A modified Brayton cycle (Figure 6) was developed to take advantage of the high density of carbon dioxide at the thermodynamic critical point (Dostal, Driscoll, & Hejzlar, 2004). Compression power is reduced due to the higher density of the CO₂. High pressure (~20 MPa) CO_2 is heated from the secondary sodium heat transfer loop to the maximum temperature of the cycle through the intermediate heat exchanger (IHX). The gas is expanded in the turbine to near the critical pressure of carbon dioxide (~7.4 MPa). The high temperature recuperator (HTR) exchanges heat with the return line from the compressors. This exchange increases the temperature into the IHX which increases the flow through the turbine, resulting in higher power production. The low pressure stream is further cooled by the low temperature recuperator (LTR) by exchanging heat from the gas exiting the LTR. The flow is then split to parallel compressors. The lower mass flow fraction (~30%) enters the high temperature compressor which is expanded to the high pressure and combined with the gas from the cold temperature compressor as this flow exits the LTR. The larger fraction of flow (~70%) rejects its heat through a gas cooler before entering the low temperature compressor. The thermal efficiency for the S-CO₂ cycle as shown in Figure 6 is described by Eq.8.

$$\eta_{\rm th} = \frac{\sum \dot{W}_{\rm Turbines} - \sum \dot{W}_{\rm Pumps} - \sum \dot{W}_{\rm Compressors}}{\dot{Q}_{\rm Reactor}}$$
(8)

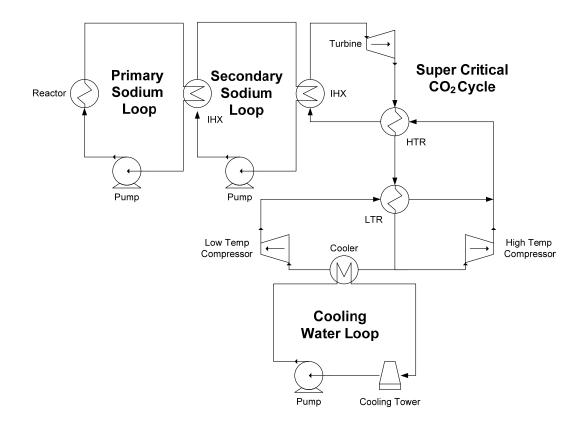


Figure 6. Supercritical CO₂ cycle.

The S-CO₂ cycle is optimized by adjusting the split between the low temperature and high temperature compressors, the outlet pressure of the turbine (a slight adjustment), and the temperature of the CO₂ into the IHX. The last adjustment has an optimal value below or above which the thermal efficiency decreases. The temperature rise across the nuclear reactor core has a strong effect on this adjustment. If the core has a large temperature rise (~150 - 400°C), the optimal value cannot be reached due to constraints imposed by the reactor inlet temperature, which in turn will result in a lower than optimal thermal efficiency. The cycle can be adjusted to its optimal efficiency if the temperature rise across the core is less than the difference between the optimal IHX inlet and outlet CO₂ temperatures. The process model developed for this study is based on the Argonne National Laboratory modelling work of the S-CO₂ cycle integrated with sodium cooled fast reactors (Chang, Finck, Grandy, & Sienicki, 2006; Sienicki, 2011).

2.1.4 Cooling Tower Model

A cooling tower model was developed to cool the condensers in the Rankine cycles and the cooler in the S-CO₂ cycle. The air in the cooling tower model has an inlet temperature of 20°C and a relative humidity of 50%. The water cooling constraints and conditions such as blowdown and entrained water are based on published information (Peters & Timmerhaus, 1991; Zhai & Rubin, 2010). The process flow diagram for the cooling tower is shown in Figure 7.

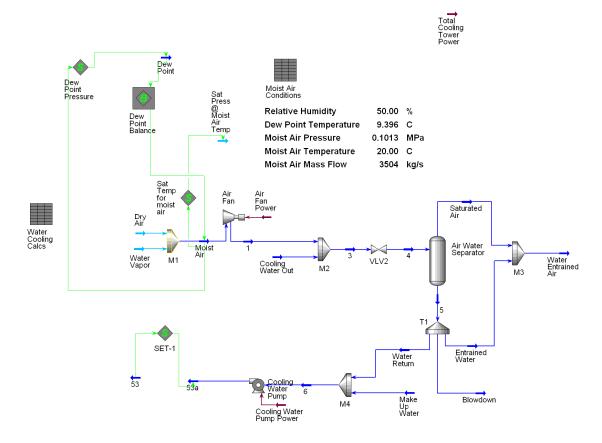


Figure 7. Water cooling tower process flow diagram.

2.1.5 Results

Detailed process flow diagrams and corresponding steam and component data are found in Appendix A. Table 2 summarizes the analysis results for the AFR-100 integration with each power cycle.

The most efficient cycle is the supercritical Rankine cycle with a thermal efficiency of 43.8%; however, this cycle also has the highest pressure of the studied power conversion cycles, 24 MPa. Both Rankine cycles have low pressures (7.43 kPa) in the condenser, which will result in large heat exchangers. The subcritical Rankine cycle has the lowest pressure difference, 17 MPa, across a heat exchanger between the secondary sodium loop and the power conversion cycle. The Rankine cycles are established cycles with many years of experience within the nuclear industry, including previous use in sodium-cooled reactors.

The S-CO₂ cycle has a low pressure of 7.40 MPa, near the critical point of carbon dioxide. The highest pressure in the cycle is 20 MPa at the outlet of the cold temperature compressor. The overall higher pressure within this cycle results in smaller components. The Rankine cycles are constrained only by the reactor outlet temperature. However, the S-CO₂ cycle is constrained by both the reactor outlet and inlet temperatures. Another analysis was performed in which the inlet temperature constant. The results of this analysis are shown in Figure 8. Figure 8 plots the cycle thermal efficiency and the temperature difference across the IHX on the CO₂ side as a function of the CO₂ temperature into the IHX. As the temperature difference across the IHX decreases from 155°C to 139°C, the thermal efficiency increases from 40% to 42%. If the temperature into the IHX is further increased, the thermal efficiency decreases.

difference across the CO_2 of the IHX has a direct relationship to the temperature difference across the reactor core. In other words the temperature difference across the reactor core constrains the temperature difference of the CO_2 across the IHX. Another means to approach the optimal CO_2 temperature difference across the IHX is to lower the allowable temperature differences between the hot side and cold side of each heat exchanger between the reactor core and the IHX. This temperature difference is referred to as the minimum approach temperature difference of the heat exchanger. For example, if the IHX inlet approach temperature difference between the sodium side and the CO_2 side is reduced from 20°C to 5°C, the S- CO_2 cycle thermal efficiency could increase to 42%. The lower efficiency of the S- CO_2 cycle in this study results from two factors: the temperature difference across the reactor core and the temperature difference constraint across the hot side and cold side of each heat exchanger between the reactor core and the IHX.

	Supercritical Rankine	Subcritical Rankine	S-CO ₂
Electric Power Generated (MWe)	109.5	106.8	100.5
Thermal Efficiency	43.8%	42.7%	40.2%
High Pressure (MPa)	25.0	17.7	20.8
Low Pressure (MPa)	0.0074	0.0074	7.40
Water Usage (kg/s)	66.9	68.2	82.1

Table 2. Results of power conversion unit analysis for AFR-100

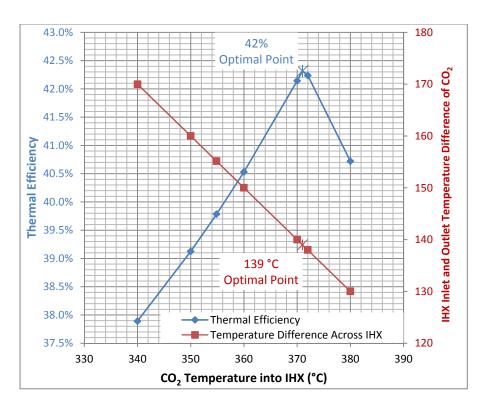


Figure 8. Thermal efficiency of S-CO₂ cycle as a function of IHX temperature difference of inlet and outlet CO₂

2.2 Hydrogen Production via HTSE

2.2.1 Introduction and model development

In 2009, an independent review team considered the integration of three hydrogen production technologies with a high temperature gas-cooled reactor (HTGR) under the Next Generation Nuclear Plant (NGNP) Project funded by the U.S. Department Energy Office of Nuclear Energy (DOE-NE) (NGNP, July 2009). The three hydrogen production processes considered were: 1) thermal-chemical water splitting based on the sulfur iodine looping reactions process, 2) the hybrid sulfur process, and 3) high-temperature steam electrolysis (HTSE). These technologies were selected over other candidate processes based on higher thermodynamic efficiencies that can be achieved at process temperatures that matched the HTGR reactor outlet temperature of approximately 850 °C. The review team recommended the HTSE process as the best choice for the NGNP Project. Most commercial and industrial hydrogen production is by steam methane forming where natural gas and steam are reacted to form syngas (hydrogen and carbon monoxide) and the carbon monoxide in the syngas is reacted with more water to create carbon dioxide and hydrogen.

The energy duty of HTSE is approximately 85-90 % electricity input. Thermal energy is used to produce and supply superheated steam combined with a gas recycle stream. With custom design of the hydrogen and oxygen separation processes, heat recuperation can be used to superheat steam that is supplied to the HTSE process from intermediate temperature steam generators.

Hydrogen can be efficiently produced using HTSE with steam temperatures up to approximately 800°C in solid oxide electrolysis cells (SOEC). The steam and associated electricity that would be produced by the AFR-100 can provide the required input to the HTSE unit operations. Heat recuperation from the product streams is used to amplify the temperature of the intermediate quality steam provided by the AFR-100. Electricity is simultaneously directed to the HTSE plant.

Figure 9 shows the detail of a custom HYSYS process model developed to simulate integration of an AFR-100 with HTSE. Steam produced by the reactor is apportioned between power generation and the HTSE plant. For this analysis, the electrolysis process is at the thermal neutral point, defined as isothermal at 800°C and adiabatic.

Table 3 shows the electrolysis cell conditions applied in the analysis. Figure 10 shows the nuclear heat integration and recuperation for the HTSE process with highlights showing low and high temperature heat recuperation, nuclear process heat integration, and topping heat. The HYSYS models for the power cycles combined with the electrolysis units are provided in Appendix A.

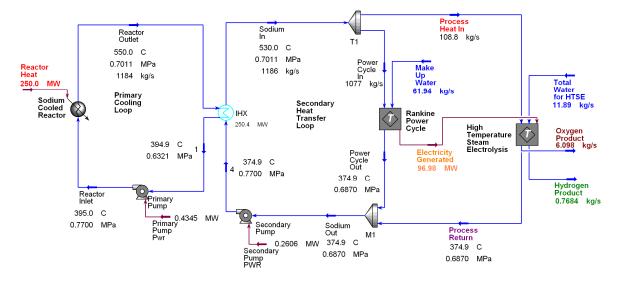


Figure 9. Process flow diagram of AFR-100/HTSE Integration

Table 3.	HTSE el	ectrolysis	cell	parameters
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	Supercritical Rankine	Subcritical Rankine	S-CO ₂
Number of cells	526,000	514,000	487,000
Cell Area (cm ²)	225	225	225
Current Density (amperes/cm ²)	0.636	0.636	0.635
Area Specific Resistance (ohms * cm ²)	0.4	0.4	0.4
Operating Voltage	1.29	1.29	1.29
Current (amperes)	143	143	143

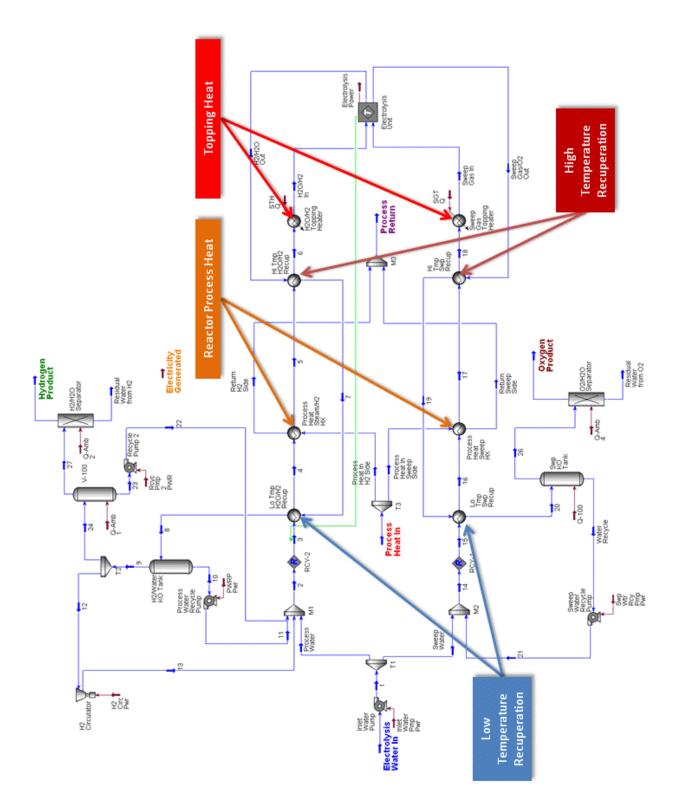


Figure 10. HTSE heat integration process flow diagram.

2.2.2 Results of the Process Model

Figure 11 summarizes the input and product streams for the integrated AFR-100/HTSE process for a single 250 MW_t nuclear reactor. The HTSE process uses approximately 90 to 100 MW_e electrical load input from the nuclear reactor and produces no carbon dioxide, as summarized in Table 4.

A secondary steam loop transfers \sim 530 °C steam from the AFR-100 to the HTSE facility where feed water is converted to steam. High temperature and low temperature recuperating heat exchangers are subsequently used to superheat the steam used in the electrolyzers. A total of 21 to 24 MW of thermal energy is needed for this purpose.

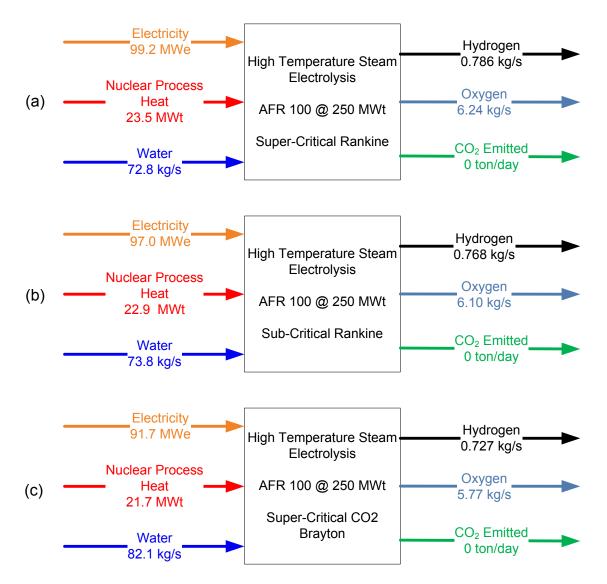


Figure 11. General energy and product flows for AFR-100 integration with HTSE using the analyzed power conversion cycles: (a) Supercritical Rankine, (b) Subcritical Rankine and (c) Supercritical CO_2 Brayton.

	Supercritical Rankine	Subcritical Rankine	S-CO ₂
Inputs			
250 MWt AFR-100	1	1	1
Outputs			
Hydrogen (kg/s)	0.786	0.768	0.727
Hydrogen Production Efficiency	44.1%	43.1%	40.8%
Power Cycle Thermal Efficiency	43.8%	42.7%	40.2%
Oxygen (kg/s)	6.24	6.10	5.77
Utility Summary			
Total Power (MWe)	99.2	97.0	91.7
Electrolyzer	97.1	95.0	89.8
Pumps	0.0826	0.0808	0.0764
Circulator	0.194	0.189	0.179
Topping Heaters	1.71	1.67	1.58
Power Needed for HTSE Cooling	0.0480	0.0468	0.0457
Process Heat			
Total Process Heat (MWt)	23.5	22.9	21.7
Water Consumption			
Total Water (kg/s)	72.8	73.8	82.1
Make-Up Cooling Water for Power Conversion Unit	60.6	61.9	70.4
Make-Up Cooling Water for Electrolysis Process	5.05	4.93	5.06
Water Consumed by Electrolysis	7.12	6.96	6.58
CO ₂ Emissions			
Emitted (ton/day CO ₂)	0	0	0

Table 4. Hydrogen production summary.

The HTSE process requires the feed mixture of steam and recycled hydrogen to be heated to approximately 800°C, which necessitates additional topping heat from an auxiliary heat source. This heat source could derive from a combustor, electric heating, or waste heat from a neighboring process. This assessment assumes that topping heat is provided by 1.6 to 1.7 MW electrical heating. The hydrogen product is approximately 99.1% pure with residual water vapor. The corresponding oxygen byproduct is also 99.1% pure with residual water vapor.

In convention with prior HTSE assessments, the hydrogen production efficiency for this process is defined as the higher-heat value (HHV) of the product hydrogen divided by the HHV of feed gas and other thermal energy input into the processes. In this case, the input energy is the sum of thermal value of the feed streams, the process heat input from the AFR-100, and the thermal equivalent of the electric power used for topping heat and the SOEC since steam is already in its base oxidation stream. The HTSE case has an overall efficiency of 41 to 44%, which, as expected, is very close to the efficiency for electrical power production. Standard electrolysis of water typically is less than 25% efficient.

2.3 Methanol Production Plant

2.3.1 Adaptation of the conventional methanol process

Methanol production in the U.S. is largely based on the chemistry of reacting CO and CO_2 with H_2 in a catalyst reactor. A simple block diagram illustrates the steps of converting natural gas to methanol, which subsequently can be converted into fuels or higher value chemicals through additional chemical processing plants.

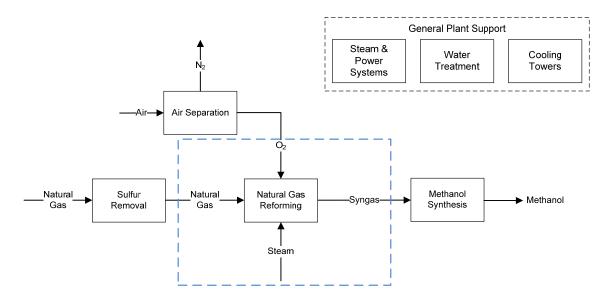


Figure 12. Steps for converting natural gas to methanol. The center section of the diagram (outlined in blue) is further described in Figure 13.

A synthesis gas mixture (or syngas) is adjusted to achieve a molar ratio (\mathbb{M}) of 2.10, as calculated by the following expression:

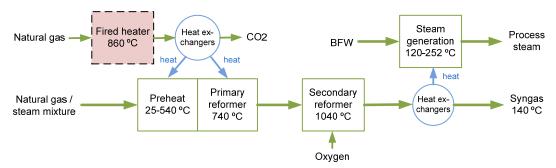
$$M = (H_2 - CO_2)/(CO + CO_2).$$

The conventional methanol process starts with reforming natural gas using steam to make syngas (see Figure 12(a), Figure 13). A feed mixture of steam and natural gas is heated to approximately 540 °C prior to entering a primary reformer that operates at 740 °C for partial conversion of the methane to syngas. A natural gas-fired process heater is used to first heat the primary reformer and then to preheat the steam-methane feed mixture through a series of counter-current heat exchangers. The partially reformed effluent of the primary reformer enters a secondary reformer where it reacts with pure oxygen to generate internal chemical reactor temperatures up to 1040 °C. Excess steam is used to control free carbon formation and deposition in the process and downstream gas feed line. These conditions also convert nearly all of the methane to syngas. The pure oxygen is obtained from a dedicated air separation plant.

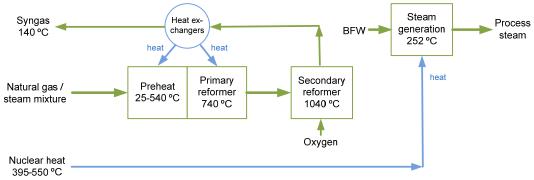
The hot secondary reformer effluent gas is used to generate steam at three successively lower pressure levels. The steam is distributed and used throughout the plant at several pressure levels; for instance, in heaters and distillation column reboilers, and for process needs, including production of steam that is blended with the natural gas feed to the reformers. Excess steam from the methanol process is generally collected and heated in a custom heat recovery and steam generation unit (HRSG) to supply steam turbines that produce electricity to power the plant auxiliary loads. The conventional steam-methane reforming process can readily substitute heat provided by a high-temperature nuclear reactor for some, if not most, of the indirect heat that is currently provided by natural gas combustion. The case for this integration was previously modeled for the fluoride salt-cooled high temperature reactor (FHR) and the high temperature gas-cooled reactor (HTGR) SMR concepts (Bragg-Sitton, et al., 2013). However, the outlet temperature of the AFR is not sufficient to provide significant benefit in raising the reformer feed stream to 740 °C. Therefore, an alternative beneficial integration scheme is needed.

By redesigning the conventional steam reforming process, as shown in Figure 13(b), an opportunity to use lower temperature process heat provided by the AFR is possible. In this case,

the heat in the hot syngas produced by the secondary reformer can be recuperated in a counter flow heat exchanger arrangement. This essentially replaces the combustion of natural gas to preheat the inflow steams and natural gas feed to the reformer. Model simulations have shown there is adequate heat in the syngas to sustain the reactions in the primary reformer. This process modification results in the need for steam generation from an external heat source. This heat source can be provided from any choice of nuclear reactor, including a light water reactor (LWR) that would have a relatively low reactor outlet temperature. This process configuration was previously modeled for a pressurized water reactor (PWR) (Bragg-Sitton, et al., 2013).



(a) Conventional steam-methane reforming process



(b) Modified arrangement that enables heat input from AFR

Figure 13. Comparison of heat management for two steam-methane reforming cases. The output syngas is a precursor to methanol, as shown in Figure 12. Note that BFW = boiler feed water.

In this study, the hybrid integration for the AFR with a methanol plant is based on the same integration scheme that was used for the previous PWR study. The engineered design for transferring the heat may be different to take advantage of the higher temperature involved with the AFR (i.e., a salt loop may be used); however, the layout of the methanol plant and the integration with the plant utilities would be identical. Consequently, the current work scaled the Aspen model feed streams and outputs of the PWR-methanol hybrid architecture that was previously studied. It is assumed that the process steam is generated by the nuclear plant; the steam is then passed to the methanol plant. When the AFR is dedicated to power production alone, the process steam is generated by a natural gas fired boiler (as depicted in Figure 14 in Section 3.1.8.2).

In either the conventional or modified steam methane reforming process, heat supplied by the nuclear reactor can directly replace the hot gas that is produced by natural gas combustion. All of the unit operations involve indirect heat transfer. Any time heat is provided by the nuclear plant, CO_2 emissions are reduced. Therefore, the benefit of providing nuclear heat to the process is two-fold: a reduction in natural gas fuel costs and a reduction in greenhouse gas emissions.

In the conventional methanol plant (Figure 13a), various grades of surplus steam are superheated in a heat recovery/steam generation (HRSG) unit. This high temperature steam is then used to produce power for the plant auxiliary equipment loads- such as compressors and pumps. The proposed plant configuration shown in Figure 13b does not result in excess steam. Consequently, electrical power must be imported from the grid to supply the electrical power required to operate the methanol plant for this case. Alternatively, the necessary electrical power can be provided by the nuclear reactor. In this study, it is assumed that AFR constantly supplies the essential electricity to the methanol plant. This results in the need to install a larger AFR that is capable of supplying up to 100 MWe to the grid while also servicing the methanol plant loads. Hence, the case for the methanol plant integration requires a larger SMR than the case for the HTSE integration.

By supplying nuclear-generated electrical power to the methanol plant, carbon dioxide emissions are lower than the integration scenarios previously modeled for the FHR and HTGR. Additionally, while the AFR is similar to the PWR integration case, the main advantage of the AFR is a higher power generation efficiency that is achieved by the higher outlet temperature of the AFR. Thus, a smaller AFR is needed compared to the previously studied PWR integration.

In summary, the present AFR integration scheme results in decreased GHG emissions by avoiding the natural gas fired heat recovery and steam generation unit. It also reduces the capital cost of the methanol plant through elimination of this unit and the power generation battery in a standard methanol production plant (Figure 13a). The complete ramifications of these costbenefit trade-offs is beyond the scope of the present study, and will be addressed in a related exergy study of the system. An exergy study could also help assess the relative merits of the various classes of SMR integration with the alternative methanol plant configurations.

2.3.2 Operation to Counterbalance Wind Generation Variability

The proposed AFR integration with the methanol plant is accomplished by fixing the size of the methanol plant on a scale that can utilize the nuclear thermal energy that is available when the wind-generation electricity is produced at any instant. When the wind farm is operating at its maximum capacity of 30 MWe, 69 MWt of additional heat is made available from the AFR-100 to be used by the methanol plant. In order to avoid turning down methanol production when this thermal energy is required for electricity production (e.g. at times of low wind input), a natural gas-fired boiler may be employed to provide the necessary steam and process heat. Natural gas boilers, along with a steam accumulator, will facilitate a smooth transition between the heat/steam provided by the AFR. The capital cost of a natural gas boiler is not substantial.

The proposed method of AFR integration results in a simple control scheme in which the natural gas boiler is dynamically adjusted in concert with wind power generation. As wind power is generated, thermal energy from the nuclear plant is proportionally diverted to the methanol plant. The natural gas boiler is thus modulated to balance the steam duty. An analysis of the dynamic load-balancing and thermal energy transfer is beyond the scope of this effort, but can be addressed through dynamic systems modeling.

3. FINANCIAL PERFORMANCE

3.1 Study Methodology and Scope

In order to assess the financial performance of AFR hybrids, it is necessary to define the methodology and scope under which they will be compared to alternatives. Similar to previous work, the goal of this analysis is to assess the value of hybridized energy systems featuring the AFR-100 sodiumcooled fast spectrum reactor with respect to other hybridized and non-hybridized energy systems. Comparative cases were selected for the present work, allowing a complete understanding of the value of the AFR hybridized system, as well as hybridized systems in general, to be reached. The applied economic evaluation closely matches that of previous work (Lee, Gribik, Maio, McKellar, Patterson, & Wood, 2010). Prior to discussing the analysis techniques, it is necessary to remind the reader of the energy system configurations that were introduced in section 1:

A. SISO

Single-Input/Single-Output (SISO) systems are the most common form of energy system present today. They represent systems that produce a single product using a single energy source, such as typical coal and nuclear plants. The current energy grid represents a network of SISO systems that operate independently to meet the grid demand. Independent systems can be impacted by one another based on how the generation from each system is accepted on the grid. For instance, if renewable-generated electricity is considered "must-take" on the grid, then other baseload SISO systems, such as a nuclear plant, may be required to reduce output to accommodate the renewable input. This scenario is represented by case 1b in the discussion below.

B. MISO

Multi-Input/Single-Output (MISO) systems include a secondary energy source within an integrated system. An example of this is a nuclear plant operating in parallel with a wind farm to produce electricity. This configuration differs from the previous scenario because the integration of the wind and nuclear subsystems occurs behind the electrical grid. When the wind farm produces electricity, the nuclear plant is still forced to turn down its energy production or sell its energy at a reduced rate to allow acceptance to the electric grid. In this configuration the available thermal energy would not be optimally used.

C. MIMO

Multi-Input/Multi-Output (MIMO) systems would integrate two or more input energy sources to produce two or more output commodities, one of which is electricity. An example of this system is a nuclear reactor that is integrated with a renewable energy system, such as a wind farm, to produce both a chemical product and electricity. When the wind farm produces electricity, the thermal output and/or electricity generation from the nuclear reactor can be reapportioned to a chemical production plant to achieve a higher overall system efficiency and a greater financial benefit through the production of multiple commodities.

The present work attempts to evaluate the relative value of MIMO versus SISO and MISO systems. Several cases have been analyzed using the methods and assumptions discussed below. The results and parameters for these cases—which focus on communicating relative financial significance rather than absolute financial significance—are provided in section 3.2 and are in accordance with previous work (Bragg-Sitton, et al., 2013).

3.1.1 Financial Figures of Merit

To allow sufficient comparison to prior work, the analysis tools were not changed. Specifically, the indices selected as financial figures-of-merit are the Net Present Value (NPV) ranking and the Internal Rate of Return (IRR) ranking. The reasons for these selections are as follows:

1) The financial risk of a hybridized SMR is similar to a standard, electricity-only SMR implementation.

Result: Discount rate for all architectures is held constant.

2) The time structure of the cash flow is identical for hybridized versus standard SMR implementation. The assumption implies an initial cash outflow followed by constant inflows for both architectures.

Result: The time structure implies there is only one IRR solution of NPV=0. Moreover, because both investments have the same time structure, the IRR between the two investments may be compared despite differences in the risk.

3) Money is a constrained resource.

Result: The absolute value of the NPV (project return) is secondary to the IRR of the project.

The standard financial figure-of-merit used to characterize the financial performance of any power plant is the levelized cost of electricity. However, due to the production of alternative commodities in advanced hybrid systems (e.g. hydrogen, methanol, etc.), this measure cannot fully assess the economic viability of a project, resulting in the adoption of NPV and IRR in the current analyses. It is additionally assumed that both architectures have the same operating lifetime.

3.1.2 Financial Analysis Theory

The economic performance analyses compute project NPV and IRR of the project. Given the cash flow seen by the project investor, CF_k , at the end of year k, the IRR is defined as such:

$$\sum_{k=0}^{N} CF_k (1 + IRR)^{-k} = 0$$
 ,

where the cash flows in the future are discounted by $(1 + IRR)^{-k}$ to account for the time value of the money. The IRR is therefore an intrinsic property of the investment. In a perfect market the investor will most often choose the investment with the higher return for a given level of risk. Consequently, if the project risk and the return r that the market will demand are known for an accepted level of risk, it is possible to define the value produced in excess of the marketrequested project return. This value is taken as the Net Present Value (NPV) of the project:

$$NPV = \sum_{k=0}^{N} CF_k (1+r)^{-k} = 0$$
.

From the above formulas it is clear that IRR and NPV depend on the cash flow seen by the investor. While a complete and exhaustive description of the internal structure of CF_k , which ultimately depends on the detailed financial management of the project, is outside the scope of this report, it is useful to present its main components.

For k = 0 the cash outflow is simply represented by the fraction α_c of the overnight capital costs financed by equity (a more complex model is described in Section 3.1.3):

$$CF_0 = C_0 \alpha_C$$

For k > 0 several contributions are present. First, the CF_k seen by the investor is the Free Cash Flow to Equity (FCFE), given that the only variation to the capital structure required by the investment analysis is the yearly reduction of debt (p_k) :

$$CF_k = FCFE_k = (Net \ Income)_k - p_k$$

The net income could be expressed by means of the Earning Before Taxes (EBT_k) and the tax rate t: Net Income = $EBT_k(1 - t)$. This leads to:

$$CF_k = EBT_k(1-t) - p_k$$
.

In a simplification of the corporate structure, EBT_k can be expressed as:

$$EBT_k = R_k - E_k - D_k - L_k i ,$$

where:

 R_k : Revenues E_k : Yearly O&M *i*: Interest on debt D_k : Depreciation L_k : Residual debt

Because some of those contributions scale with inflation, it is useful to introduce an inflationadjusting factor as $I_k = (1 + inflation rate)^k$. Thus, the final expression for CF_k is:

$$CF_k = (R_o I_k - E_o I_k - D_k - L_k i)(1-t) - p_k.$$

The yearly depreciation D_k as a function of the initial investment C_0 can be computed using the Modified Accelerated Cost Recovery System (MACRS) coefficients for an electrical utility power plant; these values are reported in Table 5 (Perry & Green, 2008). Subsequently, the yearly reduction of debt (p_k) and the residual debt (L_k) can be derived once the type of financing structure is chosen (loan type and length).

The formula reported herein for CF_k is a useful proxy of the expression for the evaluation presented, which is sufficient to illustrate the structure of the analysis performed. The complete details of the model used can be found in (Gandrik A. M., 2012).

Finally, it is important to note that the IRR can be compared with the "return on equity" (or more frequently referred as the "cost of equity") rather than the Weighted Average Cost of Capital (WACC). This is because the cash flow to the debt has been already been removed from the stream and only the free cash flow to equity has been considered.

Year	Recovery Rate	Year	Recovery Rate
1	0.05	9	0.059
2	0.095	10	0.059
3	0.0855	11	0.059
4	0.077	12	0.059
5	0.0693	13	0.059
6	0.0623	14	0.059
7	0.059	15	0.059
8	0.059	16	0.0295

Table 5. Standard 15-year MACRS depreciation schedule.

3.1.3 Capital Cash Flows during Construction

In order to properly measure the compounding and discounting that occurs for a capital investment, it is necessary to model the capital cash flow during plant construction. This is accomplished by calculating the annual fractional capital cash flow breakdown by applying a generic standard cumulative distribution, the S-Curve, as recommended by the Generation-IV

International Forum (GIF) (GIF, 2007). The capital breakdown per month, *CapF*(*month*), is calculated as follows:

$$CapF(month) = 0.5 * \left(\sin\left(\frac{\pi}{2} + \frac{\pi * month}{c_{months}}\right) + 1 \right) - CapF(month - 1),$$

where *month* is the current month in the plant construction period and *c_months* is the total number of months in the plant's construction period. The capital fraction for each year is calculated by summing the capital fraction for the corresponding months.

3.1.4 Financial Analysis Parameters and Key Assumptions

The relevant parameters applied in the current financial analysis are summarized in Table 6. These values were selected based on previous work, as reported in (Bragg-Sitton, et al., 2013).

Parameter	Value
Federal Tax Rate	35%
State Tax Rate	6%
Overall Tax Rate	38.9%
Annual Inflation Rate	3%
Economic Life	30 years
Debt/Equity Ratio	50%
Interest Rate on Debt	8%
Repayment Term	15 years
Reactor Construction Period	3 years
Startup Time	1 year
Plant Availability	90%
(nuclear and chemical)	9070

 Table 6. Assumed Economic Input Parameters used in Financial Analysis

3.1.5 Capital Cost Estimation for the AFR-100 and Wind Farm

A literature review of the capital costs for Sodium Fast Reactors (SFRs) was conducted to estimate a reasonable capital cost for the AFR-100. Applicable cost numbers were difficult to obtain due to the small number of studies that have been completed, particularly recent studies. The most complete estimate for SFRs was found in the 1988 Department of Energy (DOE) Nuclear Energy Cost Database (Delene, Williams, & Shapiro, 1988). The 1988 Cost Database numbers for SFRs (called the liquid metal reactor [LMR] in the cited report) were in 1987\$ and based on a single reactor module with an 1100 MWe power rating. The next applicable cost estimate was found in a 2000 International Conference on Nuclear Energy presentation on the S-PRISM (Super-Power Reactor Innovative Small Module) SFR developed by General Electric (GE) (Boardman 2000). The numbers presented for the S-PRISM SFR were in 1996\$ and based on a twin reactor module with a 1651 MWe power rating. Both documents break their costs down to capital and O&M components; however, the 1988 Cost Database also lists scaling exponents for specific capital cost components.

To allow determination of reasonable capital cost estimates, the two referenced estimates were scaled to the desired reactor size and applicable 2011\$ values using the Chemical Engineering Plant Cost Index (CEPCI) and an exponential scaling factor of 0.7. The result of this adjustment is shown in Table 7.

Table 7. Scaled capital cost comparisons for SFRs found in literature.

Reference Design	Reference Design Size	Target Design Size	Reference Capital Cost w/ Power Cycle	Calculated \$/kWe (2011\$)	Calculated \$/kWt (2011\$) assuming 40% efficiency
1988 Cost Database	1100 MWe	100 MWe	2270 m\$ (1987\$)	7659.2	3063.7
2000 S- PRISM	1651 MWe	100 MWe	2200 m\$ (1996\$)	4741.9	1896.8

Based on these cost estimates, a conservative capital cost of \$800M (\$8000/kWe in 2011\$) was assumed for the AFR-100. This reference capital cost provides a benchmark for scaling the AFR-100 to larger sizes.

Additionally, the estimated capital cost for a 30 MWe wind farm was assumed to be \$2150/kWe has been based on a 2012 report from the National Renewable Energy Laboratory.

3.1.6 Capital Cost Estimation for Methanol and HTSE Chemical Plants

In order to allow for direct comparison of results, similar reference costs for the methanol and HTSE plant were taken from previous work. The sole exception is a cost estimate for the methanol plant's integrated natural gas package boiler that is unique to the current work. For all plant components, an exponential scaling factor of 0.6 and the CEPCI were used to determine equipment prices in 2011\$. For the HTSE plant, a reference plant was scaled according to the required size, rather than itemization of components. It was not necessary to itemize the plant, as it requires minimal modifications for integration with the AFR-100 and is of reasonable size. The size of the itemized methanol plant components are shown in Table 12 and the final costs (including 10% engineering fee and 18% contingency fee) for those components are shown in Table 8.

System Descriptor	Cost (2011\$)
Natural Gas Package Boiler	\$12,458,584
Air Separation Unit (ASU)	\$82,137,134
AutoThermal Reforming Unit (ATR)	\$120,075,821
Methanol Synthesis Unit	\$134,477,552
Steam Turbines (Methanol plant only)	\$8,875,450
Heat-Recovery Steam Generators (HRSG)	\$1,327,247
Cooling Towers	\$3,731,341
Water Systems	\$24,894,343
Piping	\$24,894,343
Instrumentation & Controls	\$9,116,238
Electrical Systems	\$28,049,964
Buildings & Structures	\$32,257,458
Methanol Plant Total (sum of above)	\$482,295,475
HTSE Plant Total	\$17,434,306

Table 8. Capital cost estimates for chemical plant components.

3.1.7 Manufacturing Cost Estimation for the AFR-100

Manufacturing costs for the AFR-100 Hybrid Energy System were separated into two main categories: one for nuclear-related energy generation costs and one for chemical manufacturing cost, as summarized in Table 9. For nuclear related energy generation costs, the three main contributors are the Operations and Maintenance Costs (O&M), nuclear fuel costs, and decommissioning sinking fund payment costs.

Table 9. Manufacturing costs used in the models.

Specific Cost	Value
Nuclear-Related Energy Gener	ation Costs
Reactor Operations and Maintenance	\$12.05/MWt-hr
Nuclear Fuel	\$8.53/MWt-hr
Decommissioning (\$/MWt-hr)	\$0.14/MWt-hr
Chemical Plant-Related	Costs
Natural Gas (used in methanol plant)	\$6.50/MMBTU
Wastewater Treatment	$0.38/m^{3}$
Makeup Water Treatment	$0.0079/m^3$
Zinc Oxide	\$10918.73/m ³
HDS Catalyst	\$16378.09/m ³
Primary Reforming Catalyst	\$27296.82/m ³
Secondary Reforming Catalyst	\$23657.24/m ³
Methanol Catalyst	\$27296.82/m ³
Water Usage	$.013/m^{3}$
HTSE Cell Replacement	\$0.077/kg of H ₂
CO ₂ Emission Tax	\$55.12/MT

The assumed cost of natural gas is higher than present (fiscal year 2014) wholesale market prices. EIA projections suggest that natural gas will rise to between between \$6-8 per Million British Thermal Units (MMBTU) by 2035. Therefore, the average cost of \$6.50 per MMBTU seems reasonable for a project that begins operation by 2025.

Determination of manufacturing costs was different for each non-electric application studied depending on the feed source and the method of production. For methanol production, the majority of costs derive from the natural gas feed source and wastewater treatment. For HTSE, the majority of costs derive from cell replacement and maintenance costs.

3.1.8 Commodity Pricing

The pricing of commodities used in the calculations has a high impact on the estimated plant performance. These values are tabulated in Table 10. The assumed selling price of electricity is higher than the average retail market price of 0.10/kWe-hr. This value was selected to reflect both the possible selling price of electricity in the future and to be consistent with the "bid-in" price of wind and solar energy.

Table 10. Applied commodity prices.

Commodity	Price
Electricity	\$0.12/kWe-hr
Methanol	\$459.05/MT
Hydrogen	\$2.50/kg
Oxygen	\$75.52/MT
Nitrogen	\$64.95/MT

3.1.9 Nuclear and Chemical Plant Scaling

The purpose of this report is to establish the value of integrating the AFR-100 with wind power generation to produce electricity and either hydrogen via HTSE or methanol via steam methane reforming and methanol synthesis. The integration in this study differs from earlier cases involving FHR and HTGR integration as follows:

- 1. The general design for the SMR integration studies nominally targets a nuclear reactor that can provide up to 100 MWe to the grid. In this study, three power cycles were evaluated, resulting in theoretical AFR-100 designs of slightly different thermal energy generation. Of these power cycles, the subcritical Rankine cycle was selected for integration with HTSE and methanol production. Thus, heat conveyance is performed with subcritical steam. This is in contrast with earlier integrations performed for the FHR and HTGR case studies, which conveyed heat using a helium working fluid (Bragg-Sitton, et al., 2013).
- 2. The performance of the SMR with wind integration depends on the power cycle efficiencies, which differ for each of the SMRs. The current work considers the static case in which the maximum electricity production by the wind farm is 30 MWe. The capital and operating cost of the wind turbines and the associated wind power revenues were included in the NVP and IRR calculations for this study. The capacity factor for the wind farm (~30%) is not addressed in the current study but should be included in future dynamic analyses.
- 3. HTSE integration depends on the heat integration scheme that optimizes the combination of heat recuperation, topping heat, and electrical input. The ratio of heat and electrical input varies according to power cycle efficiencies and associated excess thermal heat available when the SMR power generation is turned down from 100 MWe to 70 MWe. This heat integration also depends on the temperature of heat available from the SMR. In the present study, the size of the SMR and HTSE were scaled as necessary to establish constant reactor thermal output while maintaining 100 MWe to the grid at all times via combination of all available input sources (e.g. wind and nuclear).
- 4. Integration with the methanol plant depends on the temperature level of heat associated with the SMR, which impacts the heat integration scheme. Additionally, this study assumes constant output by the methanol plant, using natural gas heaters to make up the steam or hot gas that is not available when the SMR is dedicated to power production.

As a result of these assumptions, the detailed view of the AFR-100 system integration does not allow for direct comparison with previous work (Bragg-Sitton, et al., 2013). However, various scaling factors were applied to the AFR-100 to take advantage of the previous detailed Aspen modeling that was completed for a PWR integration with a methanol plant. The scaling constraints are described below.

3.1.9.1 Scaling Constraint: Constant Grid Electricity Production

The first scaling constraint requires the system to produce 100 MWe for the grid at all times. This implies that the nuclear reactor must be able to turn down its electricity output to the grid according to the size of the integrated wind farm, in this case, 30 MWe. When reduction in wind energy generation occurs, energy that was previously directed to the chemical process must be redistributed to the electric grid.

3.1.9.2 Scaling Constraint: Chemical Process Turn-Down and Plant Size

The second scaling constraint depends on the coupled process that allows for reapportioning of nuclear-generated energy when it is not required to meet grid demand. In the case of methanol plant integration, the unit operations are difficult to cycle. Material constraints and complex plant material and energy integration flows can take many hours, or even days, to start up and stabilize. Additionally, the cash flow for the methanol plant essentially requires that the plant operate near its nameplate capacity at all times. These constraints are met by assuming that natural gas heaters will be used to provide the heat and steam when necessary to maintain plant operation at full capacity. When heat is available from the AFR, the natural gas burners are modulated accordingly. This type of a system represents a process where multiple energy inputs flexibly produce multiple outputs commodities (MIMO). Figure 14 differentiates the variable and constant energy and product flows for this hybrid process.

In the case of hydrogen (HTSE) plant integration, turn down of plant production is technically and economically feasible. The electrolysis cells can be held in hot standby and will respond nearly instantaneously to coordinated steam and electricity input. The capital cost of the electrolysis cells is relatively low, which obviates the need to run HTSE full time. Thus, a third input energy source is not required for this system. The driver for the size of the HTSE plant is only dependent on the total amount of energy that can be diverted when wind energy is available to meet grid demand. This system is depicted in Figure 15.

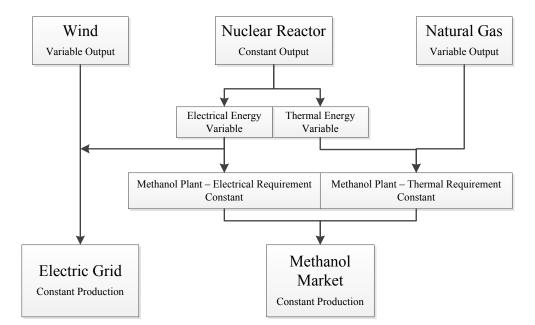


Figure 14. MIMO nuclear hybrid energy system depicting wind energy and methanol production integration.

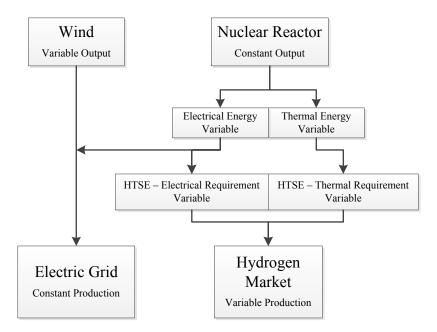


Figure 15. MIMO nuclear hybrid energy system depicting wind energy and hydrogen production integration.

3.1.9.3 Scaling Constraint: Nuclear Process Turn-Down and Plant Size

The hybrid system analyses all assume that nuclear reactor thermal energy production remains constant at all times. Thus, the nuclear reactor plant size is driven by the required electricity production when no wind-generated electricity is available. In the case of integration with HTSE, the HTSE production is scaled according to the energy available when wind offsets the demand for nuclear power generation. The energy from the nuclear plant is then apportioned between electrical power to the grid and combined electrical power and heat to the HTSE.

The methanol plant integration case requires a constant amount of electricity to support needs within the methanol plant. Therefore, the nuclear reactor must be scaled to provide 100 MWe to the grid (when wind-generation is zero) plus the electricity required by the methanol plant. This condition is necessary to maintain steady operation of the methanol plant at all times, resulting in a higher thermal power AFR than is required for the HTSE integration.

3.1.9.4 Scaling Constraint: Nuclear Hybrid Energy System Architecture

The final scaling constraint on the system is the architecture itself. In the case of a fully augmentable architecture, each plant may allocate energy differently in the system – especially for more complicated chemical plant integrations such as methanol. However, in the present work, two plant architectures are defined for analysis: one to represent HTSE integration with the AFR-100 and one to represent methanol integration with the AFR-100, scaled up to provide the constant electrical input to the methanol plant.

For the methanol case, the selected plant architecture selected was initially designed for application in a PWR hybrid energy system. Two primary changes were made: (1) a natural gas package boiler was included to provide thermal energy makeup when the nuclear reactor thermal energy is unavailable and (2) scaling was introduced to prevent reactor thermal energy from being delivered to the chemical plant when grid demand is met fully by the nuclear reactor (100 MWe; wind generation of zero) (Bragg-Sitton, et al., 2013). The equipment and utility loads for the AFR integration are derived from the detailed PWR-methanol Aspen model simulations, as shown in Tables 11 and 12.

Since the methanol plant architecture was operated in a variable manner in the PWR case (without the use of natural gas boiler makeup, the methanol plant could not be maintained at 100%), the utility loads for two plant scales provided a linear scaling formula for the present AFR-methanol integration. The *Reference #1* case in Table 11 corresponds to 100 MWe provided by the PWR to the grid (no contribution from wind generation), resulting in a turn-down of the methanol plant by just over 50% without input from wind. The *Reference #2* case corresponds to conditions in which 30 MWe is provided by wind generation and 70 MWe is provided by PWR nuclear generation to meet the 100 MWe grid demand, allowing for increased methanol production. The *Derived* AHR-integrated methanol case is then represented by the right-hand column; these values correspond to the AFR-integrated methanol plant as modeled in Aspen. The modeled methanol plant equipment from the PWR case is referred to as simply *Reference* in Table 12, as the two cases correspond to different operating modes for the same plant. The PWR-methanol plant equipment was already scaled for maximum production (as for the Reference #2 case of Table 11); a standard scaling method was used for equipment sizing.

System Descriptor	Reference #1	Reference #2	Derived Plant
Nuclear Plant Electric Output to Grid (MWe)	100	70	100
Nuclear Plant Thermal Output (MWt)	400	400	334
Methanol (MT/day)	1403	2915	3052
Nitrogen (MT/day)	2320	4817	5043
Air Separation Power (MWe)	11.5	24	25.13
Nat. Gas Reform. Power (MWe)	1.5	3.1	3.24
Fossil Power and Steam (MWe) (produced)	2.1	7.3	7.77
Methanol Power (MWe)	7.4	15.3	16.01
Water Treatment Power (MWe)	2.1	3.2	3.29
Required Process Heat Power (MWt)	32.3	67.1	70.26
Natural Gas (MMSCFD)	34.8	72.4	3052.19
Wastewater Treatment (1000-gal/day)	1080	1702	82.83
Makeup Water Treatment (1000-gal/day)	3074	4073	1758.44
Zinc Oxide (ft ³ /day)	0.18	0.37	4163.65
HDS Catalyst (ft ³ /day)	0.09	0.18	0.39
Primary Reforming Catalyst (ft ³ /day)	0.06	0.12	0.19
Secondary Reforming Catalyst (ft ³ /day)	0.04	0.08	0.13
Methanol Catalyst (ft ³ /day)	0.03	0.07	0.084

 Table 11. Methanol Plant Variable Production Scaling. "Reference 1" and "Reference 2" correspond to the earlier PWR integration study; "Derived Plant" corresponds to the AFR case.

Table 12. Methanol Plant Equipment Scaling. "Reference" corresponds to the earlier PWR integration study; "Derived" corresponds to the AFR case.

System Descriptor	Reference	Derived
Air Separation Unit (ASU) (kg/hr)	56694	59362.5
AutoThermal Reforming Unit (ATR) (m ³)	2.04×10^6	2.12×10^6
Methanol Synthesis Unit (MT/day Methanol)	2915	3052
Heat-Recovery Steam Generators (HRSG) (kg/hr Steam)	8029	8406
Cooling Towers (L/min Water)	336985	352846

For the HTSE hybrid case, the plant size was determined from the information presented in Section 2.2 of this report. The scaling values are shown in Table 13. Since the HTSE architecture has only been evaluated for the maximum power output case, all values for the HTSE case were scaled proportionally according to hydrogen output. Although a specific model for HTSE integration was developed for the AFR-100, it was necessary to scale it to accommodate wind integration. To do so, the necessary reactor size was first determined by the

total electrical output provided by the reactor when no electrical energy is displaced by wind (100 MWe). This reactor size was then used to determine the HTSE plant size that could be coupled to the plant when 30 MWe of nuclear-generated electricity is displaced by wind. The ratio of the thermal power available for HTSE between the *Reference Case* (plant design described in Section2.2) and the *Derived Case* (plant size used for economic analysis) was then used to determine the remaining attributes of the integrated HTSE plant.

Table 13. HTSE Production Scaling. "Reference" corresponds to the AFR/HTSE plant design presentedin Section 2.2 of the current report. "Derived" corresponds to the AFR/HTSE plant size usedfor economic analysis.

System Descriptor	Reference	Derived
Nuclear Plant Thermal Power (MWt)	250	235.61
Nuclear Plant Thermal Power Available to HTSE (MWt)	250	70.68
Nuclear Plant Electric Power to HTSE (MWe)	96.98	27.42
Process Heat Required for HTSE (MWt)	9.82	2.64
Hydrogen Product (kg/s)	0.7684	0.22
Oxygen Product (kg/s)	6.098	1.72
Water Required for HTSE (kg/s)	11.89	3.36
Nuclear Plant Tertiary Cooling Water (kg/s)	68.19	64.26
Nuclear Plant Tertiary Cooling Water Required for HTSE (kg/s)	61.94	58.37

3.2 Study Results

A series of cases was progressively analyzed to assess the value of hybridized energy systems featuring the AFR-100 Sodium Fast Reactor with respect to other hybridized and non-hybridized energy systems. Thus, the present work includes a number of comparative cases to clearly identify the value of system hybridization.

The selected cases are summarized in Table 14. The case numbers listed on the left-hand side serve to organize each case into families according to their purpose. The purpose of each case family and its impact to the understanding of energy systems are described below. The calculated IRR is included in this summary table to provide a snapshot of the final results. Additional details are included in the results provided in Tables 15-20.

To group the selected cases even further, Case sets 1-3 are presented in detail in Table 15. All cases presented in Table 15 are Single-Input/Single-Output (SISO), in which the AFR is only required to produce electricity.

Case 1a presents a scenario where the nuclear power plant is operating at full electric power output. Case 1b is a variant of the SISO construct in which some other input source is connected to the grid directly (not integrated into the hybrid system) and is providing 30 MWe. This case reflects the current scenario in which baseload nuclear generation is required to turn down it capacity when wind generation is available to the grid. Its purpose is to provide a baseline for comparison to the other cases evaluated in this study.

Cases 2a - 2e evaluate the impact of the selling price of electricity over the range of \$0.08 to \$0.16 per kWe-h. The results are plotted in Figure 16 to illustrate the break-even IRR. Caution should be exercised when interpreting the outcome of this trend given the set of financial and project scales that have been selected for this study.

Cases 3a – 3c examine the trend of increasing reactor size from 100 MWe to 600 MWe using a single reactor module. The results are conveyed in Figure 17. The effect of economies of scale yields an increased IRR as the reactor electric power output is increased. Note that the scaling results will differ for one large reactor (assumed here) versus building multiple reactor units to achieve the same electric power production. The latter case requires additional study.

6	0	Integrated Subsystems			Subsystems	Price of	a
Case #		Note: All configurations include the AFR-100 and Electricity Production		Included in Capital Cost	Included in Revenue	Electricity	Calculated IRR (%)
	Wind	HTSE	Methanol			(¢/kW-h)	
1a [*]				Ν	Ν	12	4.9
$1b^*$				Ν	Ν	12	0.37
2a				Ν	Ν	8	-1.68
2b				Ν	Ν	10	2.04
2c				Ν	Ν	12	4.9
2d				Ν	Ν	14	7.31
2e				Ν	Ν	16	9.47
3a [‡]				Ν	Ν	12	4.9
3b [‡]				Ν	Ν	12	8.10
3c [‡]				Ν	Ν	12	10.4
4a	yes			N, W	N, W	12	4.92
5a			yes	N, M	N, M	12	16.44
5b¢	yes		yes	N, W, M	N, W, M	12	15.79
5c [¢]	yes		yes	N, W, M	N, W, M	12	16.65
5d [§]			yes	М	М	12	36.97
6a¢	yes	yes		N, W, H	N, W, H	12	4.06
6b¢	yes	yes		N, W, H	N, W, H	12	7.62

Table 14. List of Evaluated Cases: Single-Input and Multi-Input for Electricity Production

N = Nuclear, W = Wind, M = Methanol, H = Hydrogen

*Case 1a is just a nuclear plant supplying electricity to the grid; Case 1b assumes a "hybrid grid" in which an additional input source connected to the grid forces the nuclear plant to turn down power.

[‡]Cases 3a-3c vary the nuclear plant capacity.

^eCases 5b, 5c, 6a, and 6b represent cases where wind does and does not contribute to electricity production with all other factors held constant.

[§]Case 5d does not include electricity generation. This is a baseline case in which methanol production is driven purely by natural gas. Capital cost for the natural gas plant is included in the IRR calculation.

Case Price of Electricity		Subsystems Included in Revenue (MWe)		Subsystems in Capit (Yes o	al Cost	Calculated CO ₂ Production	Calculated IRR (%)
	(¢/kW-h)	Nuclear	Wind	Nuclear	Nuclear Wind		
1a	12	100	0	Yes	No	0	4.9
1b	12	70	0	Yes	No	0	0.37
2a	8	100	0	Yes	No	0	-1.68
2b	10	100	0	Yes	No	0	2.04
2c	12	100	0	Yes	No	0	4.9
2d	14	100	0	Yes	No	0	7.31
2e	16	100	0	Yes	No	0	9.47
3a	12	100	0	Yes	No	0	4.9
3b	12	300	0	Yes	No	0	8.10
3c	12	600	0	Yes	No	0	10.4

Table 15. List of Evaluated Cases: Single-Input and Multi-Input for Electricity Production

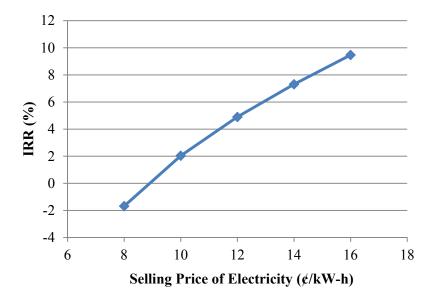


Figure 16. Results from Case 2 evaluations, indicating the variation in the IRR as a function of electricity price for Single-Input/Single-Output cases (nuclear to electricity only).

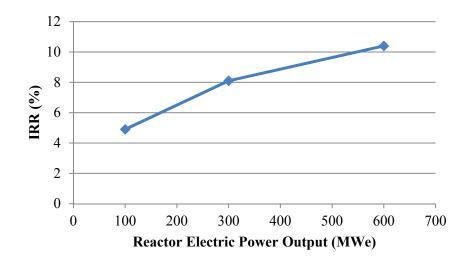


Figure 17. Results from Case 3 evaluations, demonstrating the increased IRR for larger single-unit nuclear plants (note that these results do not translate directly to the build of multiple lower power units to achieve the same total electric power).

Case 4, depicted in Table 16. a represents the closely coupled integration of the AFR and wind generation to produce a combined 100 MWe to meet grid demand. The purpose for calling out Case 4a specifically is to show that, relative to Cases 1a and 1b, the integration of wind within the system (creating a MISO system), recovers revenue that ordinarily would be lost when the plant is forced to turn down due to competition with wind-generated electricity on the grid.

Table 16. List of Evaluated Cases: Multi-Input for Electricity Production (MISO)

Case #	Price of Electricity	Sub	Subsystems Included in Revenue		Subsystems Included in Capital Cost			Calculated CO ₂ Production	Calculated IRR (%)
	(¢/kW-h)	N (MWe)	W (MWe)	M (MT/day)	Ν	W	M	(MT/day)	
4a	12	70	30	0	Yes	Yes	No	433	4.92
N = Nu	uclear, W = Wi	nd, $M = M$	[ethanol						

Cases 5a – 5d, presented in Table 17, are MIMO cases that consider various integration and operating options for integration of the AFR-100 and wind with methanol production. As was shown in case 1a, 5a results in a higher IRR when the wind plant is not integrated with the nuclear-methanol plant combination (single input scenario). However, Case 5c shows that integration with the methanol plant has prevented a large drop in IRR when wind displaces the electric power previously provided by the nuclear plant. The generally higher IRR value shown by Cases 5a -5c is explained by Case 5d, where the additional revenue from methanol results in higher overall plant revenue relative to the capital investment for the methanol plant.

Recall that the methanol cases differ from the hydrogen production cases in that the methanol plant is maintained at 100% capacity through the introduction of additional natural gas heating. This results in additional revenue from methanol production even when all of the nuclear generation is directed to

the grid electrical demand. Case 5d provides a baseline case in which only natural gas is used to drive the methanol plant (no wind or nuclear input) and no electricity is generated. This results in a high IRR but significantly higher CO_2 production than when some of the reactor thermal energy is made available to the methanol plant. For the HTSE-integrated cases that will be discussed next, hydrogen is produced only when there is excess energy available from the nuclear plant when wind-generated electricity is available.

The value of nuclear/wind integration with methanol production is a substantial decrease in CO_2 emissions. The current evaluation assumes a penalty of \$50/ton of CO_2 emitted. This illustrates the overall benefit of hybridization depending on total systems costs and benefits. Additionally, the case for hybridization is dependent on the selling price of electricity. When the market demand for electricity is low, the value of directing heat and electricity to the methanol plant will increase. Consideration of time value of products is left for future SMR hybrid assessment using dynamic analysis tools.

Case #	Price of Electricity (¢/kW-h)	Subsystems Included in Revenue		Subsystems Included in Capital Cost (Yes or No)			Calculated CO ₂ Production	Calculated IRR (%)	
	(¢/K vv -II)	N (MWe)	W (MWe)	M (MT/day)	Ν	W	М	(MT/day)	
5a*	12	100	0	3052.2	Yes	No	Yes	392.81	16.44
$5b^*$	12	100	0	3052.2	Yes	Yes	Yes	392.81	15.79
5c	12	70	30	3052.2	Yes	Yes	Yes	22.92	16.65
$5d^*$	12	0	0	3052.2	No	No	Yes	392.81	36.97

 Table 17. List of Multi-Input/Multi-Output (MIMO) Evaluated Cases Featuring Integration with a Methanol Production Plant.

N = Nuclear, W = Wind, M = Methanol

*Cases 5a, 5b and 5d are all supplemented by a natural gas plant for constant methanol production capacity.

The results relevant to previous FHR and HTGR integration evaluations are shown in Table 18, where Cases 1a and 1b provide base cases for comparison of methanol integration performance evaluated in Cases 5b and 5c. It can be seen that integration of the methanol plant greatly increases the calculated IRR; more importantly, it can be seen that integration of the methanol plant mitigates a drop in the calculated IRR when displacement from wind-generated electricity occurs. The negative Net Present Value displayed in Table 18 for Cases 1a and 1b is not of crucial concern, as the merit in the analyzed cases is in their *relative* financial figures of merit (as compared to one another) rather than the actual value calculated due to the large number of assumptions made in determining these results. However, the NPV for these cases is much lower than that of other cases, indicating that the investment is not worthwhile relative to an expected 8% return.

Analysis Case	Case 1a	Case 1b	Case 5b	Case 5c		
Reactor Electric Output (MWe)	100	70	142.5 (100 sent to grid)	112.5 (70 sent to grid)		
Wind Electric Output (MWe)	0	0	0	30		
Reactor Thermal Output (MWt)	235.61	164.93	333.7	333.7		
Natural Gas Boiler (MWt)	0	0	70.25	0		
Methanol (MT/d)	0	0	3052.2	3052.2		
Financial Indicators						
NPV @ 8% Discount Factor (million \$)	-178.9	-383.5	1123.9	1259.7		
Calculated IRR (%)	4.90	0.37	15.79	16.65		
Capital Costs (million \$)	767.5	767.5	1526.1	1526.1		
Nuclear Reactor	767.5	767.5	979.3	979.3		
Power Cycle	(included in reactor capital cost)					
Wind Turbines	0	0	64.5	64.5		
Methanol Process	0	0	482.3	482.3		
Manufacturing Costs (million \$/yr)	38.5	33.9	281.1	259.2		
Nuclear Reactor & Power Cycle	38.6	33.9	54.6	54.6		
O&M	22.4	22.4	31.7	31.7		
Fuel	15.9	11.2	22.5	22.5		
Decommissioning Fund	0.3	0.3	0.4	0.4		
Methanol Process	0	0	227.2	212.0		
Direct Costs	0	0	206.9	191.8		
Indirect Costs	0	0	20.2	20.2		
Revenues (million \$/year)	94.7	66.3	562.3	562.3		
Electricity	94.7	66.3	94.7	94.7		
Methanol	0	0	379	379		
Nitrogen	0	0	88.62	88.62		

Table 18. AFR-100 methanol hybrid energy system economic modeling results for configurations producing both electricity and methanol. In all cases the total electricity production is constant at 100 MWe.

Table 19 summarizes the outcome of nuclear-wind-HTSE-electricity hybrid plants taking the entire system capital investment into consideration (similar to Cases 5b and 5c for methanol integration). The production of hydrogen naturally increases the internal rate of return. When compared to Case 4a (nuclear-wind-electricity), it is evident that HTSE integration accomplishes its primary task in preventing a large drop in revenue when it has been displaced by wind electricity generation. Again, the current analysis does not consider the time-value of the price of electricity into consideration; the impact of variable pricing will be included in a future study using dynamic analysis tools. As discussed with respect to Table 18, the negative Net Present Value displayed in Table 20 for all cases is not of crucial concern, as the analyses are performed only to determine *relative* financial

significance. However, the NPV for these cases does signify that the investment is not of high worth relative to an expected 8% return. This result also serves to show the relatively low worth of hydrogen in comparison with methanol as a product given that the HTSE plant is operated only when excess thermal and electrical energy are available from the nuclear plant (when the wind-generated electricity is available) whereas revenue is available from the methanol plant at all times due to the additional feed from natural gas fired heaters to maintain the methanol plant at 100%.

Table 19. List of Multi-Input/Multi-Output (MIMO) Evaluated Cases Featuring Integration with a HTSE Plant

Case #	Price of Electricity		nue Contr ough Prod		Co	pital C ntribut 'es or N	tion	Calculated CO ₂ Production	Calculated IRR (%)	
	(¢/kW-h)	N (MWe)	W (MWe)	H (MT/day)	Ν	W	Н	(MT/day		
6a	12	100	0	0	Yes	Yes	Yes	0	4.06	
6b	12	70	30	26.58	Yes	Yes	Yes	0	7.62	

N = Nuclear, W = Wind, H = Hydrogen

	Case 1a	Case 1b	Case 6a	Case 6b
Reactor Electric Output (MWe)	100	70	100	97.34 (70 sent to grid)
Wind Electric Output (MWe)	0	0	0	30
Reactor Thermal Output (MWt)	235.61	164.93	235.61	235.61
Hydrogen (MT/day)	0	0	0	26.58
Financial Indicators				
NPV @ 8% Discount Factor (million \$)	-178.9	-383.5	-240.9	-25.2
Calculated IRR (%)	4.90	0.37	4.06	7.62
Capital Costs (million \$)	767.5	767.5	835.9	835.9
Nuclear Reactor	767.5	767.5	753.9	753.9
Power Cycle		(included in re	eactor capital	costs)
Wind Turbines	0	0	64.5	64.5
HTSE	0	0	17.4	17.4
Manufacturing Costs (million \$/yr)	38.5	33.9	40	40.7
Nuclear Reactor & Power Cycle	38.6	33.9	38.5	38.5
O&M	22.4	22.4	22.4	22.4
Fuel	15.9	11.2	15.9	15.9
Decommissioning Fund	0.3	0.3	0.3	0.3
HTSE	0	0	1.5	2.2
Direct Costs	0	0	.75	1.4
Indirect Costs	0	0	.73	.7
Revenues (million/year)	94.7	66.3	94.7	91.9
Electricity	94.7	66.3	94.7	66.3
Hydrogen	0	0	0	21.8
Oxygen	0	0	0	3.8

Table 20.AFR-100 HTSE hybrid energy system economic modeling results for configurations producing
both electricity and hydrogen via HTSE. In all cases the total electricity production is constant
at 100 MWe.

4. CONCLUSIONS AND RECOMMENDATIONS

Integration of an advanced, sodium-cooled fast spectrum reactor in nuclear hybrid energy system (NHES) architectures was the focus of the present study. Several power cycles were considered for integration with the Advanced Fast Reactor, including subcritical and supercritical Rankine cycles and a modified supercritical carbon dioxide modified Brayton cycle. All three power cycles were considered for electricity production and hydrogen production via high temperature steam electrolysis; only the subcritical Rankine cycle was considered for the cases that integrated methanol production. Based on the design parameters of the AFR-100 and the assumptions made for the analysis the following conclusions can be made:

- The thermal efficiencies of all of the modeled power conversion units were above 40%. The supercritical Rankine cycle achieved the highest calculated efficiency at 43.8%, followed by the subcritical Rankine at 42.7% and the S-CO₂ at 40.2%
- The Rankine cycles have the lowest pressure at the condenser (7.4 kPa), which will necessitate large equipment. The S-CO₂ system will, in general, have higher pressures throughout the cycle, reducing the physical equipment size.
- The S-CO₂ cycle could achieve a thermal efficiency of approximately 42% if the reactor inlet temperature is allowed to increase by 15°C, or if the minimum approach temperature at the low temperature end of the cycle intermediate heat exchanger is reduced by 15°C. Such a modification can be addressed via optimization of the reactor design in conjunction with the balance of plant.
- A thermal efficiency of 42% was used for the chemical plant integration studies because two of the cycles either performed at that level or could potentially do so.
- With a fixed AHR thermal output, the hydrogen production rate by HTSE is strongly dependent on the thermal efficiency of the power cycle. This is attributed to the electrical versus thermal duty of approximately 90% to 10%, respectively. Hydrogen production varies from 0.727 kg/s to 0.786 kg/s based on the power conversion unit integrated with the AFR-100 reactor.
- The cost of electricity directly correlates with IRR, as expected given the relationship with revenue generation. This result suggests the opportunity to flexibly produce multiple energy services according to the highest market value of either electricity or chemicals. During periods of high electricity demand, the AFR-generated electricity would likely be bid onto the grid. During periods of low electricity demand, the electricity and heat generated by the AFR would be dispatched to the integrated chemical plant.
- Based on a capital cost of \$8,000/kWe installed, a positive IRR is realized when the selling price of electricity is greater than approximately \$0.09/kW-h. This compares favorably to the current production cost of variable renewable power generations options (*viz.*, http://www.nrel.gov/analysis/tech_lcoe.html).
- The scale of AFR production correlates with higher IRR, as expected given the reduced capital investment per kW installed as plant sizes are increased. This may be realized by a) reducing the capital cost of the AHR based on manufacturing and permitting experience, b) building larger power units to reduce the capital cost per thermal unit production, or c) timely capital investments through phased construction of multi-module plants.
- Integration of an AFR with a chemical plant increases the internal rate of return (IRR) when "must-take" wind-generated electricity is added to the energy system.
- HTSE and methanol plant integration with a small modular AFR illustrate two models of hybridization with a chemical manufacturer in which the nuclear heat is dynamically modulated

between electricity generation and steam supply or process heating for the chemical plant. Through custom design of heat recuperation and heat exchangers, thermal energy can be dispatched from an AFR to augment chemical production. Both cases can accommodate variable heat and electricity supply.

- Integration of an AFR with methanol production in the manner modeled in this report results in a significant reduction of CO₂ emissions relative to standard methanol production methods. HTSE offsets CO₂ emissions associated with conventional production of hydrogen using steam methane reforming. The U.S. market for hydrogen used for petroleum refining and fertilizer production currently uses about 13 million tons of hydrogen each year. Hydrogen production via HTSE and substitution of nuclear energy in the methanol industry could reduce the current total U.S. greenhouse gas emissions by 3-5%. Additionally, HTSE could produce hydrogen for peaking-power fuel cells or light-duty vehicles in the transportation sector.
- HTSE represents a type of chemical manufacturing that involves a relatively small capital investment and, therefore, can economically be cycled up and down as energy is diverted from electricity production to the HTSE plant. HTSE is also capable of rapid cycling in response to the dynamic energy supply from the AFR. The IRR projections in this work could be increased if the AFR is dedicated to hydrogen production. This could be accomplished by building a larger AFR to service grid demand while maintaining a steady threshold of hydrogen generation. In this case, the surplus energy delivered to the HTSE plant during periods of wind power generation augments hydrogen production.
- Methanol production represents a chemical plant that involves a large capital investment that should be utilized to the maximum extent possible. The unit operations in a methanol plant require long time periods to start up; therefore, it is not technically feasible to modulate the plant output. Consequently, an alternative heat supply source is needed to maintain steady operation when heat from the nuclear plant is not available. This can be conveniently and economically accomplished with natural gas heaters and steam boilers.
- The NPV and IRR calculations presented in this study are based on case-specific assumptions and are not intended to discriminate hybrid options. The selection of preferred options will depend on several factors, including local and regional demand for energy services (i.e., electricity verses hydrogen or methanol), plant scale, duration of operations, and total wind penetration.

The current analysis of these hybrid system configurations leads to the following recommendations:

- 1. Accurate SMR capital and operating cost estimates are needed to increase the confidence level in the economic analysis. The present work relies on disparate and dated data in the open literature. A conservative cost of capital (\$8,000/kWe-h) was used for the financial analyses. Detailed cost estimates based on manufacturing and construction costs for a selected SMR will also help identify areas for cost improvement.
- 2. Dynamic analysis of heat diversion from SMRs for HTSE or methanol production should be completed. These analyses must consider:
 - a) Variation in wind-generated power levels (for example, ranging from 0-100 percent of rated power output of the wind farm),
 - b) Transient thermal energy delivery (including factors such as the distance to the chemical plant),

- c) Integrated controls that modulate alternative heat and steam supply using natural gasfired burners to supplement nuclear-generated heat, and
- d) Turn-down capability of the SMR in circumstances where the chemical plant is offline during maintenance activities.
- 3. Given the relative importance of hydrogen in the current chemical manufacturing industry, and likely increased importance in future markets, a comparison of SMR-based hybrid system production of hydrogen by various processes should be performed: a) HTSE, b) steam methane reforming, and c) select thermal chemical water splitting. This study should consider the time value of producing electricity versus hydrogen and the value of avoiding CO₂ emissions. The benefits of producing hydrogen using nuclear-integrated HTSE for use in peaking-power fuel cells or in the transportation section would provide valuable insight into the art-of-the-possible for significant reduction in U.S. greenhouse gas emissions.
- 4. An analysis of overall system exergy (i.e., the conversion efficiency of energy to useful work) will help clarify the value proposition for integrating SMRs with methanol plants. Two configurations have been developed: one that conveniently integrates FHR and HTGR concepts with a conventional methanol plant, and a re-engineered design that beneficially integrates the lower temperature heat that can be provided by an AFR or PWR. Factorial analysis of the exergy and other figures of merit will elucidate the cost-benefit tradeoffs for these two system configurations for the different SMR designs, plant scales, and performance under variable demand for electrical power generation.
- 5. A methodical technical, economic, and environmental assessment of U.S. hybrid energy systems is needed on a region-by-region basis. The assessment must consider resource availability, industrial and energy delivery infrastructure, population, energy demand, market factors, and regulatory controls/constraints. In order to characterize the dynamic attributes of the unique hybrid systems, a new approach for modeling the integrated energy system is necessary. It should include dynamic models of power generation, thermal energy production and delivery, and industrial applications to evaluate the technical feasibility of dynamic energy transfer within the coupled system. Rigorous analysis of markets, including state-of-the-art models of the electricity system that incorporate system management costs and value and reflect realistic market influences informed by consumer projections and macroeconomics, are also necessary.
- 6. Given the co-dependence of SMR hybrid systems on energy and material coupling, as well as market signals, advanced instrumentation and control approaches are needed to provide real-time state estimation of energy demands. Detailed consideration of the instrument types, location, and data links should be included in this study. The design of practical instrumentation and controls may impact the design of the integrated hybrid systems. Additionally, human factors must be taken into consideration for the SMR(s), wind power generation, and chemical plant operations. This effort should eventually utilize a virtual test mockup to demonstrate the feasibility of monitoring and managing integrated energy systems with electricity dispatch authorities.
- 7. New hybrid systems will fundamentally change the manner in which nuclear reactors are integrated with chemical industries, requiring safety and licensing issues to be addressed. This activity is needed early in the analysis process to provide guidance to the reactor design teams, the chemical manufacturing industry, the associated regulatory bodies (e.g. the Nuclear Regulatory Commission), and developers/providers of the SMR technology. Plant separation distance, co-dependence on utilities, and interruption in services are among key considerations that need to be addressed.

5. REFERENCES

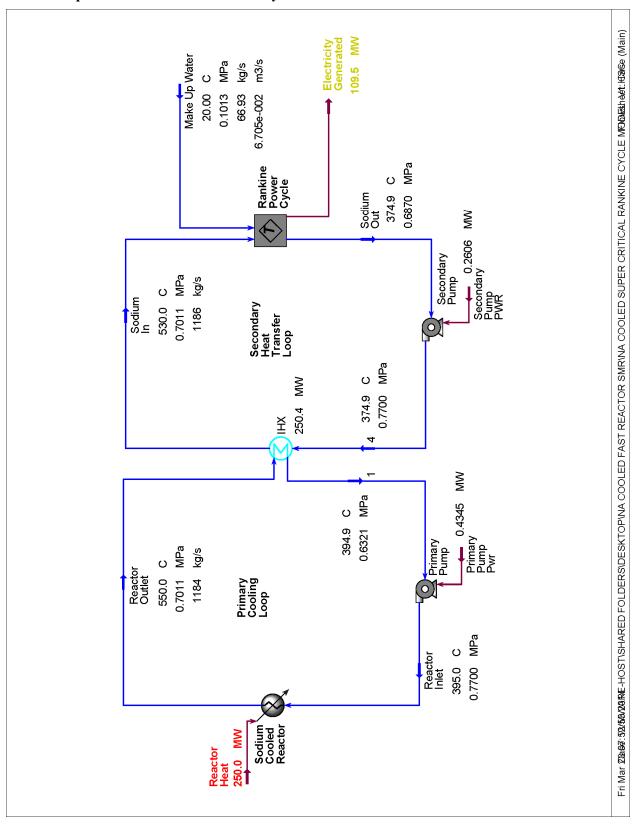
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6. APPENDIX: MODEL PROCESS FLOW DIAGRAMS AND OUTPUT

Models developed using Aspen HYSYS V7.3 on an Apple Mac Pro Mid 2010 with a 2 x 2.4 GHz Quad-Core Intel Xeon processor using VMware Fusion Version 4.1.3 emulating Windows XP.

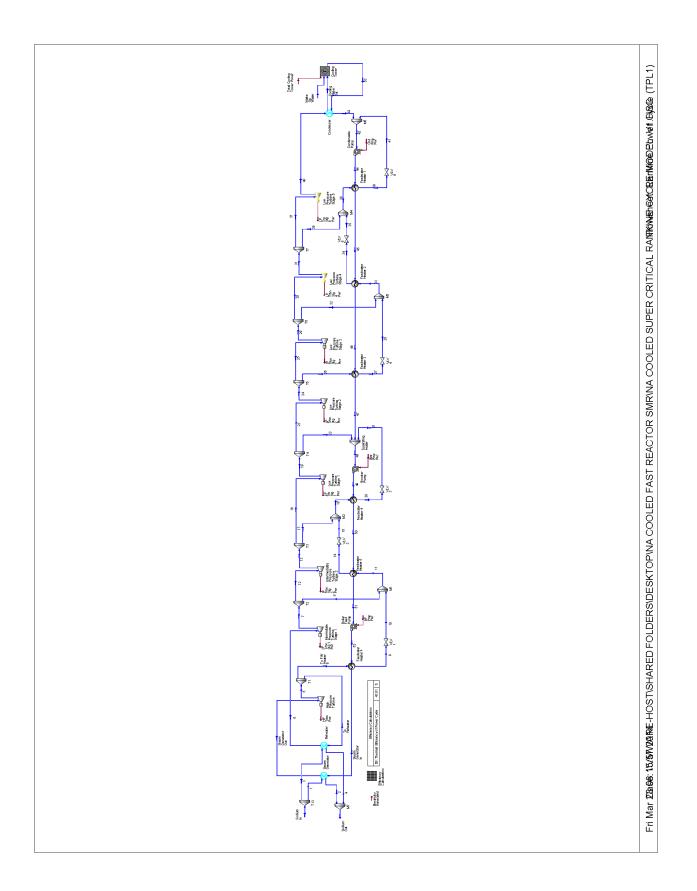


6.1 Supercritical Rankine Power Cycle Model

1				Case Name:	NA COOLED SUPER	R CRITICAL RANKINE CY	CLE MODEL V1 HSC		
2									
3	aspentech	Burlington, USA	MA	Unit Set:	AFR				
5				Date/Time:	Fri Mar 28 09:55:16 3	2014			
6	المراجع		C (14)						
8	AAOLK	(DOOK:	Case (Ma	ain)					
9				Material Stre	ams	Fluid P	kg: All		
10	Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1		
12	Vapour Fraction		0.000				0.0000		
13	Temperature	(C)	530.0				394.9 *		
14	Pressure	(MPa)	0.701	0.770	0 * 0.7011		* 0.6321		
15	Molar Flow (kgmole/h)	1.857e+00:	5 1.857e+00	5 1.854e+005	1.854e+005	1.854e+005		
16	Mass Flow	(kg/s)	118	3 118	6 1184	1184	1184		
17	Liquid Volume Flow	(m3/h)	454	454	4 4537	4537	4537		
18	Heat Flow	(MVV)	818.	568.	3 849.9	1 599.9	599.5		
19	Name		Sodium Out	Make Up Water					
20	Vapour Fraction		0.000						
21	Temperature	(C)	374.						
22	Pressure	(MPa)	0.687						
23		kgmole/h)	1.857e+00:						
24	Mass Flow	(kg/s)	118						
25	Liquid Volume Flow	(m3/h)	454			_			
26	Heat Flow	(MVV)	568.	-106	0				
28				Compositio	ns	Fluid P	kg: All		
29	Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1		
30	Comp Mole Frac (H2O)		**				***		
31	Comp Mole Frac (Nitrogen)		**	* *	* ***	* ***	***		
32	Comp Mole Frac (Oxygen)		**	* *	* ***	* ***	***		
33	Comp Mole Frac (Hydrogen)		**	* *	* ***	* ***	***		
34	Comp Mole Frac (CO2)		**	* *	* ***	* ***	***		
35	Comp Mole Frac (CO)		**	* *	* ***	* ***	***		
36	Comp Mole Frac (Sodium)		1.000) 1.000	0 * 1.0000	1.0000	* 1.0000		
37	Comp Mole Frac (Air)		**	* *	* ***	* ***	***		
38	Name		Sodium Out	Make Up Water					
39	Comp Mole Frac (H2O)		**	* 1.000	0				
40	Comp Mole Frac (Nitrogen)		**	* *	*				
41	Comp Mole Frac (Oxygen)		**						
42	Comp Mole Frac (Hydrogen)		**						
43	Comp Mole Frac (CO2)		**						
44	Comp Mole Frac (CO)		**	-					
45	Comp Mole Frac (Sodium)		1.000	,					
46 47	Comp Mole Frac (Air)					1	1		
48				Energy Strea	ms	Fluid P	kg: All		
49	Name		Reactor Heat	Electricity Generat	ed Primary Pump Pwr	Secondary Pump PV	VF		
50	Heat Flow	(MVV)	250.0)* 109.	5 0.4345	0.2606			
51				Unit Ops					
52									
53	Operation Name	Ope	ration Type	Feeds	Produc	ts Ignored	Calc Level		
54	Sodium Cooled Reactor	Heater	-	Reactor Inlet	Reactor Outlet	No	500.0 *		
55 56				Reactor Heat Sodium In	Sodium Out				
57	Rankine Power Cycle	Standard :	Sub-Flowsheet	Make Up Water	Electricity Gener	ated No	2500 *		
58	Efficiency Calcs	Spreadsh	eet		Licanoly Offici	No	500.0 *		
59				Reactor Outlet	1				
60	IHX	Heat Exch	langer	4	Sodium In	No	500.0 *		
61	Diana Dava		Í	1	Reactor Inlet				
62	Primary Pump	Pump		Primary Pump Pwr		No	500.0 *		
63	Aspen Technology Inc.		Aspe	n HYSYS Version 7.	3 (25.0.0.7336)		Page 1 of 22		
	Licensed to: BATTELLE ENERGY	ALLIANCE					* Specified by user.		

1		DATTELLES		Case Name:	NA COO	LED SUPER CRITICAL F	RANKINE CYCLE	MODEL V1.HSC
3	espentech	Burlington, M	ENERGY ALLIANCE 1A	Unit Set:	AFR			
4 5		USA		Date/Time:	Fri Mar 2	8 09:55:16 2014		
6 7	Mor	(hook)	Case /Mair)/continu	od)			
8	WOR	CDOOK:	Case (Mair	i) (conunu	ea)			
9 10			I	Unit Ops (contin	ued)			
11	Operation Name	Opera	ation Type	Feeds		Products	Ignored	Calc Level
12 13	Secondary Pump	Pump		dium Out condary Pump PWR	4		No	500.0 *
14 15								
16								
17 18								
19								
20 21								
22								
23 24								
25								
26 27								
28								
29 30								
31 32								
33								
34								
35 36								
37 38								
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40 41								
41 42								
43 44								
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46 47								
44 45 46 47 48 49 50								
51 52								
53								
54 55								
56								
57 58								
58 59								
60 61								
62 63	Aspen Technology Inc.		Acnon H	YSYS Version 7.3	(25.0.0.73	136)		Page 2 of 22
55	Licensed to: BATTELLE ENERGY	ALLIANCE	Aspenin		(20.0.0.73			* Specified by user.

1				Case Name			RANKINE CY	CLE MODEL V1.HSC
2		BATTELLE ENE	RGY ALLIANCE					
3 4	C a	spentech Burlington, MA		Unit Set:	AFR			
5				Date/Time:	Fri Mar 28 09:55:16 3	2014		
6								
7 8		Spreadsheet	t: Efficie	ency Calcs	5		U	nits Set: NuScale1
9								
10				CONNECT	IONS			
11				Imported Va	riables			
12 13	Cell	Object		•	Variable Description			Value
14	A1	Energy Stream: Reactor Hea	at I	Heat Flow				250.0 MVV
15	A4	Energy Stream: Electricity Ge	enerated I	⊃ower				109.5 MVV
16 17			Expor	ted Variables' F	ormula Results			
18	Cell	Object			Variable Description			Value
19			I	PARAMET	· · · · ·			
20				FARAIMET	ENJ			
21 22				Exportable Va	ariables			
23	Cell	Visible Name		Variable	Description	Variabl	е Туре	Value
24	A2	A2:						<empty></empty>
25 26	A3	A3: Heat to Rankine Cycle		Heat to Rankine Cycle		Energy Percent		<empty></empty>
26	A5 A6	A5: Power Cycle Efficiency A6: Reactor Heat to HTSE	i	Power Cycle Efficienc Reactor Heat to HTSE		Energy		<empty> <empty></empty></empty>
28	B1	B1:			-	Mass Flow	r	<empty></empty>
29	B2	B2:					ing Value	<empty></empty>
30 31	B3	B3: Hydrogen Production Efficiency		Hydrogen Production	Efficiency	Percent Malas Esth		<empty></empty>
31	C1 C2	C1: C2:				Molar Enth Molar Enth		<empty> <empty></empty></empty>
33	C3	C3:				Molar Flow		<empty></empty>
34	C4	C4:						<empty></empty>
35 36				User Varia	bles			
37				FORMU	40			
38		1		FORMUL	A3			1
39 40	Cell A3	=A1*A2		Formula				Result <empty></empty>
40	A5	=A1/A2 =A4/A3*100						<empty></empty>
42	A6	=A1-A3						<empty></empty>
43 44	B3 C4	=(B1*B2/1000)/A1*100						<empty></empty>
44	C4	=C3*(C2-C1)/3600000						<empty></empty>
46				Spreadsh				
47		A		B	С			D
48 49	1	250.0 MVV * <empty> *</empty>		<empty> * <empty> *</empty></empty>		<empty> * <empty> *</empty></empty>		
50	3	<empty> *</empty>		<empty> *</empty>		<empty> *</empty>		
51	4	109.5 MVV *				<empty> *</empty>		
52 53	5 6	<empty> *</empty>						
54	7	<empty> *</empty>						
55	8							
56	9							
57 58	10							
58 59								
60								
61 62								
63	Aspen '	Technology Inc.	Asper	HYSYS Version	7.3 (25.0.0.7336)			Page 3 of 22
		BATTELLE ENERGY ALLIANCE						* Specified by user.



1				Case Name:	NA COOLED SUPER C	RITICAL RANKINE CYC	LE MODEL V1.HSC	
2	aspentec	Burlington,	ENERGY ALLIANCE	Unit Set:	AFR			
4 5		USA		Date/Time:	Fri Mar 28 09:55:16 201	4		
6								
7 8	Wo	rkbook:	Rankine P	ower Cycle	(TPL1)			
9				Streams		Fluid Pkg: All		
10					T 540 - 2010			
11 12	Name Vapour Fraction		Steam Generator Out 1.0000	To Reheater @TPL1 1.0000	To FW Heater 6 @TPL 1.0000	6@TPL1 1.0000	9 @TPL1 0.0000	
13	Temperature	(C)	510.0	354.9	354.9	510.0	276.0	
14	Pressure	(C) (MPa)	24.00	8.510	8.510	8.340	8.340	
15	Molar Flow	(kgmole/h)	2.168e+004	2.018e+004	1505	2.018e+004	1505	
16	Mass Flow	(kg/s)	108.5	101.0	7.530	101.0	7.530	
17	Std I deal Liq Vol Flow	(m3/h)	391.4	364.2	27.16	364.2	27.16	
18	Heat Flow	(MVV)	-1379	-1306	-97.41	-1263	-110.8	
19	Molar Enthalpy	(kJ/kgmole)	-2.289e+005	-2.330e+005	-2.330e+005	-2.253e+005	-2.650e+005	
20	Name		52 @TPL1	Steam Generator In @	51@TPL1	8@TPL1	12@TPL1	
21	Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000	
22	Temperature	(C)	270.5	295.3	263.1	442.4	442.4	
23	Pressure	(MPa)	24.99 *	24.49	4.936	5.390	5.390	
24	Molar Flow	(kgmole/h)	2.168e+004	2.168e+004	2.168e+004	1400	1.878e+004	
25 26	Mass Flow Std I deal Liq Vol Flow	(kg/s)	108.5 391.4	108.5 * 391.4	108.5 391.4	7.007 25.28	93.96 338.9	
20	Heat Flow	(m3/h) (MVV)	-1599	-1586	-1603	-88.51	-1187	
28	Molar Enthalpy	(MVV) (kJ/kgmole)	-2.655e+005	-2.633e+005	-1603 -2.662e+005	-2.276e+005	-2.276e+005	
29	Name	(Korkginore)	11 @TPL1	16 @TPL1	18@TPL1	23 @TPL1	22@TPL1	
30	Vapour Fraction		0.6439	1.0000	0.3688	1.0000	1.0000	
31	Temperature	(C)	268.7	363.6	235.4	272.6	272.6	
32	Pressure	(MPa)	5.390	3.080	3.080	1.365	1.365	
33	Molar Flow	(kgmole/h)	2905	1.747e+004	4208	1.626e+004	1213	
34	Mass Flow	(kg/s)	14.54	87.44	21.06	81.37	6.068	
35	Std I deal Liq Vol Flow	(m3/h)	52.44	315.4	75.96	293.5	21.89	
36	Heat Flow	(MVV)	-199.3	-1117	-300.1	-1053	-78.55	
37	Molar Enthalpy	(kJ/kgmole)	-2.469e+005	-2.302e+005	-2.567e+005	-2.332e+005	-2.332e+005	
38	Name		49 @TPL1	14@TPL1	20@TPL1	47 @TPL1	48@TPL1	
39	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000	
40	Temperature	(C)	194.5	235.2	200.1	155.2	193.6	
41	Pressure	(MPa)	5.140 *	5.390	3.018	1.365	1.365	
42 43	Molar Flow	(kgmole/h)	2.168e+004	2905	4208	1.626e+004	2.168e+004	
43 44	Mass Flow Std I deal Liq Vol Flow	(kg/s) (m3/h)	108.5 391.4	14.54 52.44	21.06 75.96	81.37 293.5	108.5 391.4	
44	Heat Flow	(ma/n) (MVV)	-1638	-216.7	-317.4	-1242	-1638	
46	Molar Enthalpy	(kJ/kgmole)	-2.719e+005	-2.686e+005	-2.715e+005	-2.751e+005	-2.720e+005	
47	Name	()	21 @TPL1	25@TPL1	26 @TPL1	27 @TPL1	30@TPL1	
48	Vapour Fraction		0.0145	1.0000	1.0000	0.0000	0.9923	
49	Temperature	(C)	193.9	196.4	196.4	123.1	123.1	
50	Pressure	(MPa)	1.365	0.6210	0.6210	0.6086	0.2190	
51	Molar Flow	(kgmole/h)	4208	1.513e+004	1129	1129	1.408e+004	
52	Mass Flow	(kg/s)	21.06	75.73	5.647	5.647	70.47	
53	Std I deal Liq Vol Flow	(m3/h)	75.96	273.2	20.37	20.37	254.2	
54	Heat Flow	(MVV)	-317.4	-990.8	-73.89	-87.01	-932.3	
55	Molar Enthalpy	(kJ/kgmole)	-2.715e+005	-2.357e+005	-2.357e+005	-2.776e+005	-2.383e+005	
56								
07 60								
50								
60								
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63	Aspen Technology In	C	Aspen H	YSYS Version 7.3 (25.0.0.7336		Page 4 of 22	
_	Licensed to: BATTELLE ENE						* Specified by user.	

1				Case Name:	NA COOLED SUPER C	RITICAL RANKINE CYC	LE MODEL V1.HSC
2 3	aspentecl	Burlington,	ENERGY ALLIANCE	Unit Set:	AFR		
4 5	- aspentee	USA		Date/Time:	Fri Mar 28 09:55:16 201	4	
5							
7	Wo	rkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)	
9				Streams (continu	ed)	Fluid Pk	g: All
10 11	Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44@TPL1
12	Vapour Fraction		0.9923	0.9420	0.0000	0.0000	0.0000
13	Temperature	(C)	123.1	84.51	84.50	45.89	40.33
14	Pressure	(MPa)	0.2190	5.670e-002	0.2146	5.557e-002	1.450 *
15	Molar Flow	(kgmole/h)	1050	1.310e+004	2179	3156	1.626e+004
16	Mass Flow	(kg/s)	5.255	65.58	10.90	15.79	81.37
17	Std I deal Liq Vol Flow	(m3/h)	18.96	236.6	39.33	56.97	293.5
18	Heat Flow	(MVV)	-69.53	-879.2	-169.8	-248.5	-1282
19 20	Molar Enthalpy	(kJ/kgmole)	-2.383e+005	-2.415e+005	-2.805e+005	-2.834e+005	-2.838e+005
20	Name Vapour Fraction		40 @TPL1 0.8839	38@TPL1 0.2917	42@TPL1 0.0000	33 @TPL1 0.4783	41@TPL1 0.0100
22	Temperature	(C)	40.51	84.51	38.80	123.1	40.13
23	Pressure	(C) (MPa)	7.584e-003 *	5.670e-002	7.433e-003	0.2190	7.433e-003
24	Molar Flow	(kgmole/h)	1.310e+004	3156	1.310e+004	2179	3156
25	Mass Flow	(kg/s)	65.58	15.79	65.58	10.90	15.79
26	Std I deal Liq Vol Flow	(m3/h)	236.6	56.97	236.6	39.33	56.97
27	Heat Flow	(M <i>\</i> VV)	-893.8	-235.3	-1034	-156.5	-248.5
28	Molar Enthalpy	(kJ/kgmole)	-2.455e+005	-2.684e+005	-2.839e+005	-2.587e+005	-2.834e+005
29	Name		1 @TPL1	3 @TPL1	2 @TPL1	4@TPL1	Sodium In @TPL1
30	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
31	Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
32	Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
33	Molar Flow	(kgmole/h)	1.534e+005	3.229e+004	1.534e+005	3.229e+004	1.857e+005
34	Mass Flow	(kg/s)	979.7	206.2	979.7	206.2	1186
35	Std I deal Liq Vol Flow	(m3/h)	3754	790.0	3754	790.0	4544
36	Heat Flow	(MW)	676.4	142.4	469.3	98.78	818.8
38	Molar Enthalpy Name	(kJ/kgmole)	1.587e+004 Sodium Out @TPL1	1.587e+004 5 @TPL1	1.101e+004 10@TPL1	1.101e+004 7@TPL1	1.587e+004 13@TPL1
39	Vapour Fraction		0.0000	1.0000	0.0226	1.0000	1.0000
40	Temperature	(C)	374.9	354.9	268.7	442.4	363.6
41	Pressure	(MPa)	0.6870	8.510 *	5.390	5.390 *	3.080 *
42	Molar Flow	(kgmole/h)	1.857e+005	2.168e+004	1505	2.018e+004	1.878e+004
43	Mass Flow	(kg/s)	1186	108.5	7.530	101.0	93.96
44	Std I deal Liq Vol Flow	(m3/h)	4544	391.4	27.16	364.2	338.9
45	Heat Flow	(MVV)	568.1	-1404	-110.8	-1275	-1201
46	Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.330e+005	-2.650e+005	-2.276e+005	-2.302e+005
47	Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45@TPL1
48	Vapour Fraction		1.0000	1.0000	0.9923	0.9420	0.0000
49	Temperature	(C)	272.6	196.4	123.1	84.51	78.94
50 51	Pressure Malar Elaw	(MPa)	1.365 1.747e+004	0.6210 * 1.626e+004	0.2190 *	5.670e-002 *	1.421 1.626e+004
51 52	Molar Flow Mass Flow	(kgmole/h)	1.747e+004 87.44	81.37	1.513e+004 75.73	1.408e+004 70.47	1.6266+004 81.37
53	Std I deal Lig Vol Flow	(kg/s) (m3/h)	315.4	293.5	273.2	254.2	293.5
54	Heat Flow	(MVV)	-1132	-1065	-1002	-944.8	-1269
55	Molar Enthalpy	(kJ/kgmole)	-2.332e+005	-2.357e+005	-2.383e+005	-2.415e+005	-2.809e+005
56 57 59 60 61							
62 63	Aspen Technology In Licensed to: BATTELLE ENE		Aspen H	YSYS Version 7.3 (25.0.0.7336)		Page 5 of 22 * Specified by user.

1				Case Name:	NA COOLED SUPER C	RITICAL RANKINE CYC	LE MODEL V1.HSC
3	aspentec	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 09:55:16 201	4	
5							
7	We	orkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)	
9 10				Streams (continu	ed)	Fluid Pkį	g: All
11	Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28@TPL1
12	Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
13	Temperature	(C)	117.5	229.7	363.6	235.3	123.1
14	Pressure	(MPa)	1.393	5.037	3.080	3.080	0.2190
15 16	Molar Flow	(kgmole/h)	1.626e+004	2.168e+004	1303	2905	1129
10	Mass Flow	(kg/s)	81.37 293.5	108.5 391.4	6.521 23.52	14.54 52.44	5.647 20.37
18	Std I deal Liq Vol Flow Heat Flow	(m3/h) (MVV)	-1256	-1620	-83.33	-216.7	-87.01
19	Molar Enthalpy	(kJ/kgmole)	-2.780e+005	-2.691e+005	-2.302e+005	-2.686e+005	-2.776e+005
20	Name	()	36 @TPL1	35@TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
21	Vapour Fraction		0.9420	0.0000	0.0001		
22	Temperature	(C)	84.51	84.50	40.13		
23	Pressure	(MPa)	5.670e-002	5.670e-002	7.433e-003		
24	Molar Flow	(kgmole/h)	977.3	2179	1.626e+004		
25	Mass Flow	(kg/s)	4.891	10.90	81.37		
26	Std I deal Liq Vol Flow	(m3/h)	17.64	39.33	293.5		
27	Heat Flow	(MVV)	-65.57	-169.8	-1282	24.72	12.81
28 29	Molar Enthalpy Name	(kJ/kgmole)	-2.415e+005	-2.805e+005 LP Trb Stg 1 Pwr @TF	-2.838e+005	ID Tribin Star 3 Dury @1	I D Triba Cha C Dura @T
29	Vapour Fraction		IP Trbn Stg 2 Pwr @T	LP Ind Stg I PWr @ I P	Bstr Pmp Pwr @TPL1	LP Trbn Stg 2 Pwr @T	LP Trbn Stg 3 Pwr @T
31	Temperature	(C)					
32	Pressure	(MPa)					
33	Molar Flow	(kgmole/h)					
34	Mass Flow	(kg/s)					
35	Std I deal Liq Vol Flow	(m3/h)					
36	Heat Flow	(MVV)	13.84	14.49	0.6251	11.30	11.11
37	Molar Enthalpy	(kJ/kgmole)					
38	Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated (
39	Vapour Fraction						
40 41	Temperature	(C)					
41	Pressure Molar Flow	(MPa)					
42	Mass Flow	(kgmole/h) (kg/s)					
44	Std I deal Liq Vol Flow	(m3/h)					
45	Heat Flow	(MVV)	12.44	14.59	3.663	0.1577	109.5
46	Molar Enthalpy	(kJ/kgmole)					
47	Name		Cooling Water Out @1	53 @TPL1	Make Up Water @TPL	Total Cooling Tower P	
48	Vapour Fraction		0.0000	0.0000	0.0000		
49	Temperature	(C)	34.96	25.00	20.00		
50	Pressure	(MPa)	0.1015	0.1035	0.1013		
51	Molar Flow	(kgmole/h)	6.507e+005	6.507e+005	1.338e+004		
52	Mass Flow	(kg/s)	3256	3256	66.93		
53	Std I deal Liq Vol Flow	(m3/h)	1.175e+004	1.175e+004	241.4		
54 55	Heat Flow Molar Enthalpy	(MW)	-5.160e+004 -2.854e+005	-5.174e+004 -2.862e+005	-1060	0.6353	
55 56	wotar ∈runalpy	(kJ/kgmole)	-Z.8548+UU5	-2.862e+UU5	-2.854e+005		
57							
58							
59							
60							
61							
62							
63	Aspen Technology In		Aspen H	HYSYS Version 7.3 (25.0.0.7336)		Page 6 of 22
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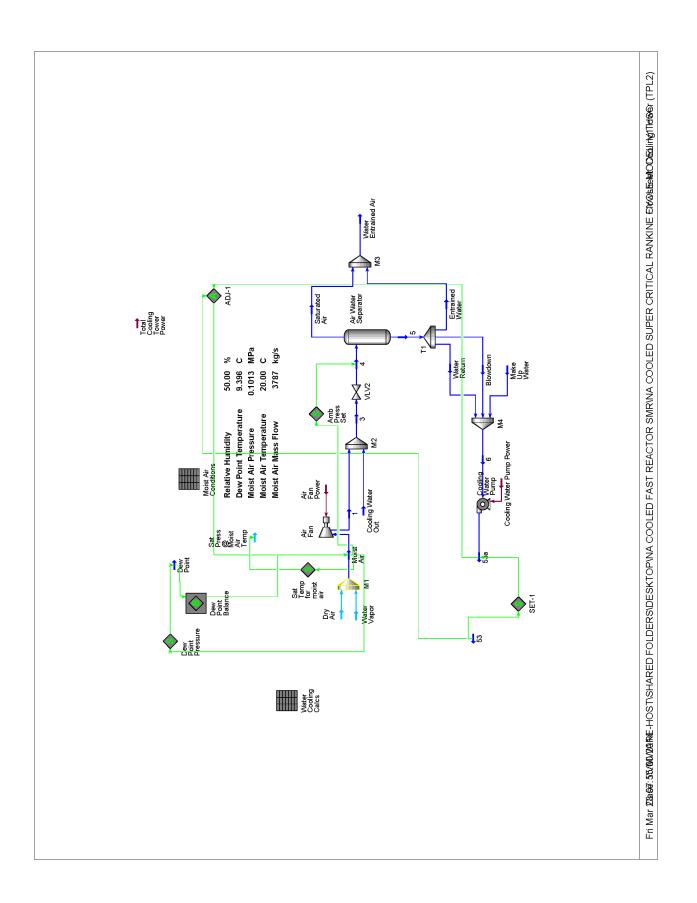
1				Case Name:		RITICAL RANKINE CYC	LE MODEL VI HSC
2			ENERGY ALLIANCE				
3 4	aspentech	Burlington, USA	, MA	Unit Set:	AFR		
5				Date/Time:	Fri Mar 28 09:55:16 201	4	
6							
7	Work	(book:	Rankine F	ower Cycle	(TPL1) (con	tinued)	
9				Expanders		Fluid Pkg	x: All
10				-			-
11	Name Power	(MVV)	High Pressure Turbin 24.72	Intermdiate Pressure 1 12.81	Intermediatte Pressure 13.84	Low Pressure Turbine 14.49	Low Pressure Turbine 11.30
13	Capacity (act feed vol flow) (A	· · · ·	4717	1.475e+004	1.951e+004	2.846e+004	5.178e+004
14	Feed Pressure	(MPa)	24.00	8,340	5.390	3.080	1.365
15	Product Pressure	(MPa)	8.510 *	5.390 *	3.080 *	1.365	0.6210 *
16	Product Temperature	(C)	354.9	442.4	363.6	272.6	196.4
17	Adiabatic Efficiency		85 *	90 *	90 *	80 *	80*
18	Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
19	Power	(MVV)	11.11	12.44	14.59		
20	Capacity (act feed vol flow) (A		9.176e+004	2.048e+005	6.407e+005		
21	Feed Pressure	(MPa)	0.6210	0.2190	5.670e-002		
22	Product Pressure	(MPa)	0.2190 *	5.670e-002 *	7.584e-003 *		
23	Product Temperature	(C)	123.1	84.51	40.51		
24	Adiabatic Efficiency		75 *	80 *	80 *		
25 26				Pumps		Fluid Pkg	g: All
20	Name		Boiler Feed Pump @	Booster Pump @TPL1	Condensate Pump @1		
28	Power	(MVV)	3.663	0.6251	0.1577		
29	Capacity(Actual Vol. Flow)	(m3/h)	501.5	447.9	715.3		
30	Feed Pressure	(MPa)	4.936	1.365	7.433e-003		
31	Product Pressure	(MPa)	24.99 *	5.140 *	1.450 *		
32	Product Temperature	(C)	270.5	194.5	40.33		
33	Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		
34				Heat Exchange	ſS	Fluid Pkg	a: All
35 36	Name		Feedwater Heater 6 @		Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
37	Duty	(MVV)	13.35	17.46	17.29	13.12	13.22
38	Tube Side Feed Mass Flow	(kg/s)	108.5	108.5	108.5	81.37	81.37
39	Shell Side Feed Mass Flow	(kg/s)	7.530	14.54	21.06	5.647	10.90
40	Tube Inlet Temperature	(C)	270.5	229.7	194.5	117.5	78.94
41	Tube Outlet Temperature	(C)	295.3	263.1	229.7	155.2	117.5
42	Shell Inlet Temperature	(C)	354.9	268.7	235.4	196.4	123.1
43	Shell Outlet Temperature	(C)	276.0	235.2	200.1	123.1	84.50
44	LMTD	(C)	15.08	15.75	15.48	18.00	17.06
45	Minimum Approach	(C)	5.556	5.555	5.556	5.556	5.556
46	UA	(kJ/C-h)	3.187e+006	3.992e+006	4.020e+006	2.625e+006	2.789e+006
47	Name		Feedwater Heater 1 @		Reheater @TPL1	Condenser @TPL1	
48	Duty	(MVV)	13.14	207.1	43.59	139.9	
49	Tube Side Feed Mass Flow	(kg/s)	81.37	979.7	206.2	3256	
50	Shell Side Feed Mass Flow	(kg/s)	15.79	108.5 *	101.0	65.58	
51	Tube Inlet Temperature	(C)	40.33	530.0	530.0	25.00	
52 53	Tube Outlet Temperature	(C)	78.94	374.9	374.9 *	34.96	
53 54	Shell Inlet Temperature Shell Outlet Temperature	(C)	84.51 45.89	295.3 510.0	354.9 510.0	40.51 38.80	
55	LMTD	(C) (C)	16.39	57.33	23.77	9.554	
56	Minimum Approach	(C) (C)	5.556	20.00	20.00	5.556	
57	UA	(C) (kJ/C-h)	2.885e+006	1.300e+007	6.603e+006	5.269e+007	
58		(Unit Ops			
59				-			
60	Operation Name	Ope	eration Type	Feeds	Products	Ignored	Calc Level
C +			_				
61 62	High Pressure Turbine @TPL	Expander	s	team Generator Out @TF		1 No	500.0 *
61 62 63	High Pressure Turbine @TPL	Expander		team Generator Out @TF	HP Trbn Pwr @TPL	_1 No	500.0 * Page 7 of 22

1			05	Case Name: N	NA COOLED SUPER CRITICAL R		MODEL V1.HSC				
3	aspentech	BATTELLE ENERGY ALLIAN Burlington , MA	UE	Unit Set: A	AFR						
4		USA		Date/Time: F	ri Mar 28 09:55:16 2014						
5 6											
7	Work	book: Rankine	e Pov	wer Cycle (TPL1) (continue	d)					
9			Un	it Ops (continue	d)						
11	Operation Name	Operation Type		Feeds	Products	Ignored	Calc Level				
12 13	Intermdiate Pressure Turbine	Expander	6 @TI	PL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *				
14	Intermediatte Pressure Turbin	E×pander	12 @	TPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *				
16	Low Pressure Turbine Stage 1	Expander	16 @	FPL1	19@TPL1	No	500.0 *				
17	Low Pressure Turbine Stage 2	Expander	23 @	FPL1	LP Trb Stg 1 Pwr @TPL1 24 @TPL1	No	500.0 *				
19 20	Low Pressure Turbine Stage 3		25 @	TPL1	LP Trbn Stg 2 Pwr @TPL1 29 @TPL1	No	500.0 *				
21	Low Fressure Turbine Stage 3	Expander			LP Trbn Stg 3 Pwr @TPL1	NU	500.0				
22 23	Low Pressure Turbine Stage 4	Expander	30 @	TPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *				
24 25	Low Pressure Turbine Stage 5	Expander	37 @	IPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *				
26 27	Feedwater Heater 6 @TPL1	Heat Exchanger	52 @ To EV	FPL1 V Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *				
28	Feedwater Heater 5 @TPL1	Heat Exchanger	50@	TPL1	51@TPL1	No	500.0 *				
30	Feedwater Heater 4 @TPL1	Heat Exchanger	11 @ ⁻ 49 @ ⁻	ſPL1	14 @TPL1 50 @TPL1	No	500.0 *				
31 32	Feedwater Heater 3 @TPL1	Heat Exchanger	18 @ 46 @		20@TPL1 47@TPL1	No	500.0 *				
33 34	_		26 @ 45 @		27@TPL1 46@TPL1						
35	Feedwater Heater 2 @TPL1	Heat Exchanger	33 @	FPL1	34 @TPL1	No	500.0 *				
36 37	Feedwater Heater 1 @TPL1	Heat Exchanger	44 @ 38 @		45@TPL1 39@TPL1	No	500.0 *				
38 39	Steam Generator @TPL1	Heat Exchanger	1 @Th Steam	PL1 Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *				
40 41	Reheater @TPL1	Heat Exchanger	3@TF	PL1 heater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *				
42	Condenser @TPL1	Heat Exchanger	53 @	rpl1	Cooling Water Out @TPL1	No	500.0 *				
43 44	Boiler Feed Pump @TPL1	Pump	40 @ 51 @	TPL1	42@TPL1 52@TPL1	No	500.0 *				
45 46			BF Pn 48 @	np Pwr @TPL1 FPL1	49@TPL1		500.0 *				
47 48	Booster Pump @TPL1	Pump	Bstr P 43 @ ⁻	mp Pwr @TPL1 「PL1	44 @TPL1	No					
49	Condensate Pump @TPL1	Pump	Cnd P	mp Pwr @TPL1		No	500.0 *				
51	M1 @TPL1	Mixer	10 @ ⁻ 8 @TF		11@TPL1	No	500.0 *				
52 53	M2 @TPL1	Mixer	17 @ 15 @		18 @TPL1	No	500.0 *				
54 55	Deaerating Heater @TPL1	Mixer	47 @ ⁻ 21 @ ⁻		48@TPL1	No	500.0 *				
56 57	· ····· · ··· · · · · ·		22 @	TPL1	38 @TPL1	-	*				
57 58	M4 @TPL1	Mixer	35 @	FPL1		No	500.0 *				
59 60	M3 @TPL1	Mixer	32 @ 28 @		33@TPL1	No	500.0 *				
61 62	M5 @TPL1	Mixer	41 @ ⁻ 42 @ ⁻	TPL1	43@TPL1	No	500.0 *				
63	Aspen Technology Inc.	Asi		SYS Version 7.3 (25	5.0.0.7336)		Page 8 of 22				
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2	\sim			A COOLED SUPER CRITICAL I	RANKINE CYCLE N	MODEL V1.HSC
3	aspentech	BATTELLE ENERGY ALLIAN Burlington, MA		AFR		
4 5	Gapontoon	USA	Date/Time: F	Fri Mar 28 09:55:16 2014		
6						
7 8	Work	book: Rankine	e Power Cycle (TPL1) (continue	ed)	
9			Unit Ops (continue	d)		
10	Operation Name	Operation Tune		,	lanarad	
12	Operation Name	Operation Type	Feeds 2@TPL1	Products Sodium Out @TPL1	Ignored	Calc Level
13	M7 @TPL1	Mixer	4@TPL1		No	500.0
14	VLV 3 @TPL1	Valve	20 @TPL1	21@TPL1	No	500.0
15	VLV 4 @TPL1	Valve	27 @TPL1	28@TPL1	No	500.0
16	VLV 5 @TPL1	Valve	34 @TPL1	35@TPL1	No	500.0
17 18	VLV 1 @TPL1	Valve	9@TPL1	10@TPL1	No	500.0
10	VLV 2 @TPL1	Valve	14 @TPL1	15@TPL1	No No	500.0 500.0
20	VLV 6 @TPL1 SG tb dP @TPL1	Valve Set	39 @TPL1	41@TPL1	NO	500.0
20	SG sh dP @TPL1	Set	1		No	500.0
22	FW6 tb dP @TPL1	Set			No	500.0
23	FW6 sh dP @TPL1	Set			No	500.0
24	FW4 tb dP @TPL1	Set			No	500.0
25	FW5 tb dP @TPL1	Set			No	500.0
26	FW5 sh dP @TPL1	Set			No	500.0
27	FW4 sh dP@TPL1	Set			No	500.0
28	Cnd sh dP @TPL1	Set			No	500.0
29	FW1 tb dP @TPL1	Set			No	500.0
30	FW1 sh dP @TPL1	Set			No	500.0
31 32	FW2 tb dP @TPL1	Set			No	500.0
32 33	FW2 sh dP @TPL1 FW3 tb dP @TPL1	Set Set			No No	500.0 ⁻ 500.0 ⁻
34	FW3 sh dP @TPL1	Set			No	500.0
35	Rht tb dP @TPL1	Set			No	500.0
36	SET-1@TPL1	Set			No	500.0
37	Cnd Tb dP @TPL1	Set	1		No	500.0
38	SET-3@TPL1	Set			No	500.0
39	SET-4@TPL1	Set			No	500.0
40	SET-5@TPL1	Set			No	500.0
41	SET-6@TPL1	Set			No	500.0
42	SET-7@TPL1	Set			No	500.0
43	SET-8 @TPL1	Set			No	500.0 1
44	T1@TPL1	Tee	5@TPL1	To FW Heater 6 @TPL1	No	500.0
45 46				To Reheater @TPL1	} − − 	
46 47	T2@TPL1	Tee	7@TPL1	8 @TPL1 12 @TPL1	- No	500.0
47			13 @TPL1	17@TPL1		
49	T3@TPL1	Tee		16@TPL1	No	500.0
50			19 @TPL1	22@TPL1		
51	T4@TPL1	Tee		23 @TPL1	No	500.0
52	TE OTDI 1	Tee	24 @TPL1	26 @TPL1	N-	500.01
53	T5@TPL1	Тее		25@TPL1	No	500.0 1
54	T6@TPL1	Тее	29 @TPL1	32 @TPL1	No	500.0
55	io WII LI	100		30@TPL1	140	000.0
56	T7 @TPL1	Tee	31 @TPL1	36 @TPL1	No	500.0
57	~			37@TPL1	┨────┤	
58	T13 @TPL1	Тее	Sodium In @TPL1	3 @TPL1	No	500.0
59 60	_	Spreadchaot		1 @TPL1	No	500.0 '
61	Efficiency Calculations@TPL	Spreadsheet	Cooling Water Out @TPL1	53@TPL1	No	500.0
	Cooling Tower @TPL1	Standard Sub-Flowsheet	Make Up Water @TPL1		No	2500 *
62						

1					Case Name:	NA CO	OLED SUPER CRIT	ICAL RAN	KINE CYCLE	MODEL V1.HSC
3	aspentech	Burlington, M	ENERGY ALLIANCE 1A	-	Unit Set:	AFR				
4 5		USA			Date/Time:	Fri Mar	28 09:55:16 2014			
6 7	Mod	hook	Pankina	Por			L1) (conti	nuad		
8	VVOIK	DOOK.	Rankine	FOV		e(IF	LT) (conu	nueu)	
9 10				Uni	it Ops (conti	nued)				
11	Operation Name		ation Type		Feeds		Products		Ignored	Calc Level
12 13	Cooling Tower @TPL1	Standard Su	ub-Flowsheet	Total C	ooling Tower Po	wer @			No	2500 *
14 15										
16										
17 18										
19										
20 21										
22										
23 24										
25										
26 27										
28 29										
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1	_			Case Name:	NA COOLED SUPER	R CRITICAL RA	ANKINE CYCLE MOD	EL V1.HSC							
2 3		aspentech Burlington, M.	NERGY ALLIANCE A	Unit Set: AFR											
4 5		USA		Date/Time:	Date/Time: Fri Mar 28 09:55:16 2014										
6															
7 8		Spreadshe	et: Efficienc	y Calcu	lations @TP	L1	Units Set:	NuScale2							
9				CONNECTI	ONS										
10 11		Imported Variables													
12	0.1			•											
13	Cel B1		Pwr@TPL1 Power		Variable Description			Value 24.72 MVV							
15	B2		tg 1 Pwr @TPL1 Power				12.81 N								
16	B3		tg 2 Pwr @TPL1 Power				13.84 N	13.84 MVV							
17	В4	Energy Stream: LP Trb St				14.49 N	IW								
18	B5	Energy Stream: LP Trbn S				11.30 N	1W								
19	В6	Energy Stream: LP Trbn S				11.11 M									
20	B7	Energy Stream: LP Trbn S				12.44 N									
21	B8 B9		g 5 Pwr @TPL1 Power				14.59 N 0.1577								
23	B1		Pwr@TPL1 Power Pwr@TPL1 Power				0.6251								
24	D1		Pwr@TPL1 Power				3.663 N								
25	D2	Energy Stream: Primary F					0.4345								
26	D3		y Pump PWR Power				0.2606								
27	D4		ling Tower Powe Power				0.6353	MVV							
28	D5	Energy Stream: Reactor H	leat Heat F	low			250.0 N	1W							
29			Exported	/ariablee' E	ormula Results										
30			Exported												
31	Ce	· · · · · · · · · · · · · · · · · · ·			Variable Description			Value							
32	D7	Electricity Generated @TPL1	Power				109.5 N	IW							
33 34	PARAMETERS														
35			Ex	portable Va	riables										
36 37	0.1	Mellele Menne		-		T	Malua.								
38	Cel D6	Visible Name D6: Total Turbine Power	Total 7		Description	Variable Type Power 115.3		Value							
39	D0	D7: Power	Power				115.3 N 109.5 N								
40	D8	D8: Thermal Efficiency of Power		ver Power ermal Efficiency of Power Cycle Percent			43.81								
41															
42				User Varia	bies										
43 44				FORMUL	AS										
45	Ce			Formula				Result							
46	D6 =B1+B2+B3+B4+B5+B6+B7+B8							IW							
47	D7 =D6-B9-B10-D1-D2-D3-D4						109.5 N	1W							
48 49	D8 =D7/D5*100 43.81														
49 50				Spreadsh	eet										
51		Α	В		С		D								
52	1	HP Trb Pwr *		24.72 MW*		Pmp Pwr*		3.663 MW*							
53	2	IP Trb Stg 1 Pwr *		12.81 MW*	Primary Pump Power *		0.4345 MVV								
54	3	IP Trb Stg 2 Pwr *		13.84 MW *	Secondary Pump Power *		0.2606 MVV *								
55	4	4 LP Trb Stg 1 Pwr *		14.49 MW *	Cooling Tower Power *			0.6353 MVV *							
56	5	LP Trb Stg 2 Pwr *		11.30 MW *	Reactor Heat *			250.0 MW *							
57 58	6	LP Trb Stg 3 Pwr *		11.11 MW *	Total Turbine Power *			115.3 MW*							
58 59	7 8	LP Trb Stg 4 Pwr * LP Trb Stg 5 Pwr *		12.44 MVV * 14.59 MVV *	Electricity Generated * Thermal Efficiency of Power Cycle *			109.5 MVV * 43.81 *							
60	9	Cnd Pmp Pwr*		0.1577 MVV *	merinar Enrotency of PU	and oyold		<empty> *</empty>							
61	10	Bstr Pmp Pwr *		0.6251 MWV*				<empty> *</empty>							
62															
63		en Technology Inc.	Aspen HYS	SYS Version	7.3 (25.0.0.7336)			age 11 of 22							
	Licens	d to: BATTELLE ENERGY ALLIANCE					* Spec	ified by user.							



				Case Name:	NA COOLED SUPER C	RITICAL RANKINE CYC	LEMODEL V1HSC		
2			E ENERGY ALLIANCE						
3 4	aspentech	Burlington, USA	, MA	Unit Set:	AFR				
5				Date/Time:	Fri Mar 28 09:55:16 201	4			
6									
7	Wo	rkbook	: Cooling To	ower (TPL2)					
9									
10				Material Stream	S	Fluid Pkg	g: All		
11	Name		Cooling Water Out @1	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2		
12 13	Vapour Fraction	(0)	0.0000	0.0000			1.0000		
13	Temperature Pressure	(C) (MPa)	34.96 0.1015	25.00 *	0.1013	0.1013	20.00 * 0.1013 *		
15	Molar Flow	(kgmole/h)	6.507e+005	6.507e+005	4.692e+005	5459	4.746e+005		
16	Mass Flow	(kg/s)	3256	3256	3760	27.32	3787 *		
17	Liquid Volume Flow	(m3/h)	1.175e+004	1.175e+004	1.565e+004	98.54	1.575e+004		
18	Heat Flow	(MVV)	-5.160e+004	-5.174e+004			-387.2		
19	Name	(Sat Press@ Moist Air	1@TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2		
20	Vapour Fraction		1.0000 *	1.0000	0.4304	1.0000 *	0.4304		
21	Temperature	(C)	20.00	20.16	25.11	9.396	25.10		
22	Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013		
23	Molar Flow	(kgmole/h)		4.746e+005	1.125e+006	4.746e+005	1.125e+006		
24	Mass Flow	(kg/s)		3787	7044	3787	7044		
25	Liquid Volume Flow	(m3/h)		1.575e+004	2.749e+004	1.575e+004	2.749e+004		
26	Heat Flow	(MVV)		-386.5	-5.198e+004	-428.0	-5.198e+004		
27	Name		Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2		
28	Vapour Fraction		1.0000	0.0000	0.0000	0.000	0.0000		
29	Temperature	(C)	25.10	25.10	25.10	25.10	25.10		
30	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013		
31	Molar Flow	(kgmole/h)	4.843e+005	6.410e+005	650.7	3031	6.374e+005		
32	Mass Flow	(kg/s)	3836	3208	3.256	15.17	3190		
33	Liquid Volume Flow	(m3/h)	1.592e+004	1.157e+004	11.75	54.71	1.151e+004		
34	Heat Flow	(MVV)	-1019 Water Entrained Air @	-5.097e+004	-51.74 6 @TPL2	-241.0	-5.067e+004		
35	Name		VVater Entrained Air (a)			53a @TPL2			
26	Veneur Freetien			Make Up Water @TPL	0				
36	Vapour Fraction	(C)	0.9987	0.0000	0.0000	0.0000			
37	Temperature	(C)	0.9987 25.10	0.0000 *	0.0000 25.00	0.0000 25.00			
37 38	Temperature Pressure	(MPa)	0.9987 25.10 0.1013	0.0000 20.00 * 0.1013	0.0000 25.00 0.1013	0.0000 25.00 0.1035			
37 38 39	Temperature Pressure Molar Flow	(MPa) (kgmole/h)	0.9987 25.10 0.1013 4.850e+005	0.0000 20.00 * 0.1013 1.338e+004	0.0000 25.00 0.1013 6.538e+005	0.0000 25.00 0.1035 6.538e+005			
37 38	Temperature Pressure Molar Flow Mass Flow	(MPa) (kgmole/h) (kg/s)	0.9987 25.10 0.1013 4.850e+005 3839	0.0000 20.00 * 0.1013 1.338e+004 66.93	0.0000 25.00 0.1013 6.538e+005 3272	0.0000 25.00 0.1035 6.538e+005 3272			
37 38 39 40	Temperature Pressure Molar Flow	(MPa) (kgmole/h)	0.9987 25.10 0.1013 4.850e+005	0.0000 20.00 * 0.1013 1.338e+004	0.0000 25.00 0.1013 6.538e+005	0.0000 25.00 0.1035 6.538e+005			
37 38 39 40 41	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow	(MPa) (kgmole/h) (kg/s) (m3/h)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004	0 0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004	- All		
37 38 39 40 41 42	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow	(MPa) (kgmole/h) (kg/s) (m3/h)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004	0.0000 25.00 0.1035 6.538+005 3272 1.180+004 -5.198e+004 Fluid Pkg			
37 38 39 40 41 42 43 44 45	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name	(MPa) (kgmole/h) (kg/s) (m3/h)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T	0 0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 C ompositions 53 @TPL2	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 5.098e+004	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2	Moist Air @TPL2		
37 38 39 40 41 42 43 44 45 46	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @1	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 Dry Air @TPL2 0.0000 *	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pke Water Vapor @TPL2 1.0000 *	Moist Air @TPL2 0.0115		
37 38 39 40 41 42 43 44 45 46 47	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 *	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809		
37 38 39 40 41 42 43 44 45 46	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 *	0.0000 25.00 0.1035 8.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pke Water Vapor @TPL2 1.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076		
37 38 39 40 41 42 43 44 45 46 47 48 49	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7800 * 0.2100 *	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000		
37 38 39 40 41 42 43 44 45 46 47 48 49 50	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @ 1.0000 0.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338±+004 66.93 241.4 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.2100 *	0.0000 25.00 0.1035 6.538+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000		
 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nydrogen Comp Mole Frac (Coygen) Comp Mole Frac (CO)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @ 1.0000 0.0000 0.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7800 * 0.2100 *	0.0000 25.00 0.1035 6.538+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000		
 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Co) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.7900 * 0.7900 * 0.2100 * 0.0000 * 0.0000 *	0.0000 25.00 0.1035 6.538+005 3272 1.180+004 -5.198e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 		
 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Sodium)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	0 0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 C ompositions 53 @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.0000 * 0.0000 * 0.0000 *	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 *** 0.0000		
 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @ 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Sat Press @ Moist Air	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1.@TPL2	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3.007PL2	0.0000 25.00 0.1035 8.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2078 0.0000 0.0000 0.0000 •••• ••• 0.0000 4 @TPL2		
 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Nom Mole Frac (CO) Nom Mole Frac (CO) Name Comp Mole Frac (H2O)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)))	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1@TPL2 0.0115	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3@TPL2 0.5831	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 •••• ••• • • • • •		
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 51 52 53 54 55	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000	0.0000 20.00 * 0.1013 1.338e+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1.@TPL2	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3.007PL2	0.0000 25.00 0.1035 8.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2078 0.0000 0.0000 0.0000 •••• ••• 0.0000 4 @TPL2		
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Ntrogen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Ari) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (H2O)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Sat Press @ Moist Air 1.0000	0.0000 20.00 * 0.1013 1.338+004 66.93 2414 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1@TPL2 1.@TPL2	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.0000 * 0.2100 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	0.0000 25.00 0.1035 6.538+005 3272 1.180+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 •••• •••• 0.0000 4 @TPL2 0.5831 0.3294		
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Cvygen) Comp Mole Frac (CQ) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Coygen)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @ 1.0000 0.00000 0.00000 0.00000 0.00000 0.000000	0 0000 20 00 * 0 1013 1.338+004 66.93 241.4 -1065 Compositions 53 @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1.0000 * 0.0000 * 0.0000 * 1.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.2100 * 0.2100 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 3 @TPL2 0.5831 0.3294 0.3294 0.0875	0.0000 25.00 0.1035 6.538+005 3272 1.180e+004 -5.198e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 •*** 0.0000 4 @TPL2 0.5831 0.3294 0.0875		
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @1 1.0000 0.00000 0.00000 0.000000	0.0000 20.00 * 0.1013 1.338+004 66.93 241.4 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1@TPL2 1.@TPL2 0.0115 0.7809 0.2076 0.0000	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7900 * 0.2100 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3 @TPL2 0.5831 0.3294 0.0875 0.0000	0.0000 25.00 0.1035 6.538+005 3272 1.180e+004 -5.198e+004 -5.198e+004 -5.198e+004 -5.198e+004 -7.198e+	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 •••• • 0.0000 4 @TPL2 0.5831 0.3294 0.0875 0.0000		
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nydrogen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV))) n)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.00000 0.000000	0 0000 2000 * 0.1013 1.338+004 66.93 241.4 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1@TPL2 1@TPL2 1.0000 *	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 0.0000 * 0.7800 * 0.2100 * 0.2100 * 0.0000 * 0.0000 * 3@TPL2 0.5831 0.3294 0.3294 0.0875 0.0000	0.0000 25.00 0.1035 8.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pke Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 ••••• 0.0000 4 @TPL2 0.5831 0.3294 0.0875 0.0000 0.0000		
377 38 39 40 41 42 43 44 45 46 47 48 49 50 51 51 52 53 54 55 56 55 56 57 58 59 60	Temperature Pressure Nolar Flow Mass Flow Liquid Volume Flow Heat Flow Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (Air) Name Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV))) n)) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.00000 0.00000 0.000000	0.0000 20.00 * 0.1013 1.338+004 6.633 2414 -1065 Compositions 53@TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1@TPL2 1@TPL2 1@TPL2 1@TPL2 1@TPL2 0.0115 0.7809 0.2078 0.0000 0.00	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 -5.198e+004 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3@TPL2 0.5831 0.3294 0.0875 0.0000 0.0000 0.0000 ****	0.0000 25.00 0.1035 6.538e+005 3272 1.180e+004 -5.198e+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 4 0.0000 4 @TPL2 0.5831 0.3294 0.0875 0.0000 0.0000 0.00000 0.00000 0.00000		
377 38 39 40 41 42 43 44 45 46 47 48 49 50 51 51 52 53 54 55 56 55 56 57 58 59 60	Temperature Pressure Molar Flow Mass Flow Liquid Volume Flow Heat Flow Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Qiry) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO)	(MPa) (kgmole/h) (kg/s) (m3/h) (MVV))) n) n)	0.9987 25.10 0.1013 4.850e+005 3839 1.593e+004 -1071 Cooling Water Out @T 1.0000 0.00000 0.00000 0.000000	0.0000 20.00 20.00 1.338e+004 1.338e+004 66.93 241.4 -1065 Compositions 63@TPL2 1.0000 0.0000	0.0000 25.00 0.1013 6.538e+005 3272 1.180e+004 -5.198e+004 -5.198e+004 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 3@TPL2 0.5831 0.3294 0.0875 0.0000 0.0000 0.0000 ****	0.0000 25.00 0.1035 6.538+005 3272 1.180+004 -5.198+004 Fluid Pkg Water Vapor @TPL2 1.0000 * 0.0000 *	Moist Air @TPL2 0.0115 0.7809 0.2076 0.0000 0.0000 0.0000 0.0000 4 @TPL2 0.5831 0.3294 0.0875 0.0000 0.0000 0.0000 0.0000		

1				Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC				
2			ENERGY ALLIANCE				SEE MODEL THIOS	
3	aspentech	Burlington, USA	MA	Unit Set:	AFR			
4	•	55A		Date/Time:	Fri Mar 28 09:55:16 201	4		
6								
7	Work	book:	Cooling To	ower (TPL2)	(continued)			
8 9			_	•	-			
9 10			Co	mpositions (conti	ositions (continued) Fluid Pkg:			
11	Name		Saturated Air @TPL2	5@TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2	
12	Comp Mole Frac (H2O)		0.0313	1.0000	1.0000	1.0000	1.0000	
13	Comp Mole Frac (Nitrogen)		0.7653	0.0000	0.0000	0.0000	0.0000	
14	Comp Mole Frac (Oxygen)		0.2034	0.0000	0.0000	0.000.0	0.0000	
15	Comp Mole Frac (Hydrogen)		0.0000	0.0000	0.0000	0.0000	0.0000	
16 17	Comp Mole Frac (CO2) Comp Mole Frac (CO)		0.0000	0.0000 0.0000	0.0000 0.0000	0.000.0	0.0000	
18	Comp Mole Frac (CO)		***	***	***	***	***	
19	Comp Mole Frac (Air)		0.0000	0.0000	0.0000	0.000	0.0000	
20	Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2		
21	Comp Mole Frac (H2O)		0.0326	1.0000 *	1.0000	1.0000		
22	Comp Mole Frac (Nitrogen)		0.7643	0.0000 *	0.0000	0.0000		
23	Comp Mole Frac (Oxygen)		0.2032	0.0000 *	0.0000	0.0000		
24 25	Comp Mole Frac (Hydrogen) Comp Mole Frac (CO2)		0.0000	0.0000 * 0.0000 *	0.0000 0.0000	0.000.0		
20	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000	0.0000		
27	Comp Mole Frac (Sodium)		***	***	***	***		
28	Comp Mole Frac (Air)		0.0000	0.0000 *	0.0000	0.000		
29				Energy Streams		Fluid Pk	g: All	
30						Traid Th		
31 32	Name Heat Flow	(MVV)	Air Fan Power@TPL2 0.6259	Cooling Water Pump F 9.430e-003	Total Cooling Tower P 0.6353			
33	Theat Thom	(101 0 3)	0.0238	•	0.0333			
34				Unit Ops				
35								
00	Operation Name	Ope	ration Type	Feeds	Products	Ignored	Calc Level	
36			Dr	y Air @TPL2	Products Moist Air @TPL2			
36 37	Operation Name M1 @TPL2	Ope Mixer	Dr. Wa	y Air @TPL2 ater Vapor @TPL2	Moist Air @TPL2	Ignored No	Calc Level 500.0 *	
36			Dr Wa 1 @	y Air @TPL2 ater Vapor @TPL2 @TPL2	- i			
36 37	M1 @TPL2 M2 @TPL2	Mixer Mixer	Dr Wa 1 @ Co	y Air @TPL2 ater Vapor @TPL2 @TPL2 ooling Water Out @TPL2	Moist Air @TPL2 3 @TPL2	No No Mo Mo	500.0 * 500.0 *	
36 37	M1@TPL2	Mixer	Dr Wa 1 @ Co Sa	y Air @TPL2 ater Vapor @TPL2 @TPL2	Moist Air @TPL2	No No	500.0 *	
36 37 38 39 40	M1 @TPL2 M2 @TPL2	Mixer Mixer	Dr Wa 1 (Co Sa En	y Air @TPL2 ater Vapor @TPL2 @TPL2 Joling Water Out @TPL2 turated Air @TPL2	Moist Air @TPL2 3 @TPL2	No No Mo Mo	500.0 *	
36 37 38 39 40 41 42 43	M1 @TPL2 M2 @TPL2	Mixer Mixer	Dr Wa Co Sa En Wa Blo	y Air @TPL2 ater Vapor @TPL2 @TPL2 ololing Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 wodown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air	No No Mo Mo	500.0 *	
36 37 38 39 40 41 42 43 44	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2	Mixer Mixer Mixer Mixer	Dr Wa Co Sa En Wa Bio Bio Ma	y Air @TPL2 ater Vapor @TPL2 @TPL2 ooling Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air		500.0 * 500.0 * 500.0 * 500.0 *	
36 37 38 39 40 41 42 43	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Moist Air Conditions @TPL2	Mixer Mixer Mixer Mixer Spreadshe	Dr Wa Co Sa En Wa Bit Ma eet	y Air @TPL2 ater Vapor @TPL2 @TPL2 ololing Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 wodown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air	@TPL2 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *	
36 37 38 39 40 41 42 43 44 45	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2	Mixer Mixer Mixer Mixer	Dr Wa Co Sa En Wa Bit Ma eet	y Air @TPL2 ater Vapor @TPL2 @TPL2 ololing Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 wodown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air		500.0 * 500.0 * 500.0 * 500.0 *	
36 37 38 39 40 41 42 43 44 45 46	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Moist Air Conditions @TPL2 Water Cooling Calcs @TPL2	Mixer Mixer Mixer Mixer Spreadshe Spreadshe	Dr Wa Co Sa En Wa Bit Ma eet	y Air @TPL2 ater Vapor @TPL2 @TPL2 ololing Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 wodown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air	@TPL2 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *	
36 37 38 39 40 41 42 43 44 45 46 47 48 49	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Mater Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Mixer Mixer Mixer Mixer Spreadshe Set Set Set	Dr Wa Co Sa En Wa Bit Ma eet	y Air @TPL2 ater Vapor @TPL2 @TPL2 ololing Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 wodown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air	No @TPL2 No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Moist Air Conditions @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2	Mixer Mixer Mixer Mixer Spreadshe Set Set	Dr Wa Co Sa En Bit Bit Bit Bit Bit Bit Bit Bit Bit Bit	y Air @TPL2 ater Vapor @TPL2 @TPL2 Joling Water Out @TPL2 turated Air @TPL2 trained Water @TPL2 ater Return @TPL2 awdown @TPL2 wdown @TPL2 wke Up Water @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2	No @TPL2 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *	
36 37 38 39 40 41 42 43 44 45 46 47 48 49	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Mater Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Mixer Mixer Mixer Mixer Spreadshe Set Set Set	Dr. 1 @ Co Sa En Bit Bit Bit Bit Bit Bit Bit Co Bit Bit	y Air @TPL2 ater Vapor @TPL2 @TPL2 @TPL2 turated Air @TPL2 turated Air @TPL2 tarianed Water @TPL2 ater Return @TPL2 awdown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air	No @TPL2 No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 Moist Air Conditions @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2	Mixer Mixer Mixer Spreadshe Spreadshe Set Set Set Set Set	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 @TPL2 turated Air @TPL2 turated Air @TPL2 tarianed Water @TPL2 ater Return @TPL2 awdown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2 widown @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2	@TPL2 No @TPL2 No @TPL2 No No No No No No No No No No No No No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Set Set Compress	Dr. 1 @ Co En Wa Bit Ma set set or Air	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 1 @TPL2	No QTPL2 No No No	500.0 ° 500.0 °	
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	M1 @TPL2 M2 @TPL2 M3 @TPL2 M4 @TPL2 M4 @TPL2 Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2 SET-1 @TPL2 Air Fan @TPL2	Mixer Mixer Mixer Spreadshe Set Set Set Compress Valve	Dr 1 @ Co Sa En Blc Blc Blc Gamma Blc Ma Sa Go Ma Sa	y Air @TPL2 ater Vapor @TPL2 @TPL2 oloing Water Out @TPL2 trained Water @TPL2 trained Water @TPL2 ater Return @TPL2 widdown @TPL2 wike Up Water @TPL2 wist Air @TPL2 Fan Power @TPL2	Moist Air @TPL2 3 @TPL2 Water Entrained Air 6 @TPL2 1 @TPL2 4 @TPL2	No QTPL2 No No No	500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 ° 500.0 °	

1		Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC						
3	aspentech Burling	Unit Set:	AFR					
4 5			Date/Time:	Fri Mar 28 09:55:	16 2014			
6 7	٨							
8	A	ajust: A	ADJ-1 @	IPLZ				
9	Adjuste	d Variable				Measured	Variable	
11	OBJECT		VARIABLE		OBJECT		VARIABLE	
12 13	Moist Air		Mass Flow		53a		Temperature	
14				olving Parame				
15 16	Source for Target Value: Value Solving Method:	e from Object Secant	Object: Tolerance:		53@TPL2 1.000e-003 C *	Offset: Maximum Ite	0.0000 erations: 100	00 *
17	Step Size:	10.00 kg/s *	Maximum:			Minimum:		
18 19				User Variable	es			
20								
21 22								
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24 25								
25 26								
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28 29								
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62 63	Aspen Technology Inc.		Aspen HYS	SYS Version 7.3	(25.0.0.7336)		Page 14 of 2	22
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aspentech Battelle energy alliance Unit Set: AFR Unit Set: AFR									
4 USA Date/Time: Fri Mar 28 09:55:16 2014									
6									
Set: Amb Press Set @TPL2									
9 10 Target									
11 OBJECT VARIABL	E								
12 4 Pressur 13 -	2								
14 Source									
15 OBJECT VARIABL 16 Moist Air Pressur									
17 Equation Parameters									
18 Equation Finance of Contract of Contrac	r								
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21 22 User Variables									
23 24 NOTES									
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63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Licensed to: BATTELLE ENERGY ALLIANCE	Page 15 of 22 * Specified by user.								

1			Case N	ame:	NA COOLED SU	PER CRITICAL RANKIN	IE CYCLE MODEL V1.HSC
2		E ENERGY ALLIANCE	Unit Set	:	AFR		
4			Date/Tir	me:	Fri Mar 28 09:55:	16 2014	
5 6			Datorra			10 2011	
7	Bala	nce: Dew Po	oint Ba	lance	@TPL2		
8 9							
10			CONNE	CTIONS			
11 12	Dew Point @TPL2	REAMS		Moist Ai	r @TPL2	OUTLET STREAMS	
13	Down onlight 12			IN DISE 74			
14 15			PARAN	IETERS			
16		Not a	general balanc	e - no ratio	s required		
17 18			User Va	ariables			
18				TIONO			
20				ITIONS			
21	Name	Dew F	oint @TPL2	M	oist Air @TPL2		
22	Vapour Temperature	(C)	<u>1.0000 *</u> 9.3960		1.0000 20.0000 *		
24	Pressure	(MPa)	0.1013		0.1013 *		
25			174622.3797		474622.3797		
26	Mass Flow	(kg/s)	3787.1761		3787.1761 *		
27	Std I deal Liq Vol Flow	(m3/h)	15745.5782		15745.5782		
28	Molar Enthalpy (k	:J/kgmole)	-3246		-2937		
29	Molar Entropy (kJ/	kgmole-C)	150.9		152.0		
30	Heat Flow	(MVV) -	4.2798e+02		-3.8716e+02		
31 32			PROPE	ERTIES			
33	Name	Dew Point @TPL2	Moist Air @	DTPI2			
34	Molecular Weight	28.73	in bloc / in (c	28.73			
35	Molar Density (kgmole/m3)	4.317e-002	4.1	60e-002			
36	Mass Density (kg/m3)	1.240		1.195			
37	Act. Volume Flow (m3/h)	1.099e+007	1.14	1e+007			
38	Mass Enthalpy (kJ/kg)	-113.0		-102.2			
39	Mass Entropy (kJ/kg-C)	5.253		5.290			
40	Heat Capacity (kJ/kgmole-C)	29.16		29.22			
41	Mass Heat Capacity (kJ/kg-C)	1.015		1.017			
42	LHV Vol Basis (Std) (MJ/m3)	0.0000		0.0000			
43 44	HHV Vol Basis (Std) (MJ/m3) HHV Mass Basis (Std) (kJ/kg)	471.7		471.7 16.42			
44	HHV Mass Basis (Std) (kJ/kg) CO2 Loading	16.42		16.42			
45	CO2 Apparent Mole Conc. (kgmole/m3)						
47	CO2 Apparent Wt. Conc. (kgmol/kg)						
48	LHV Mass Basis (Std) (kJ/kg)						
49	Phase Fraction [Vol. Basis]	1.000		1.000			
50	Phase Fraction [Mass Basis]	1.000		1.000			
51	Phase Fraction [Act. Vol. Basis]	1.000		1.000			
52	Partial Pressure of CO2 (MPa)	0.0000		0.0000			
53	Cost Based on Flow (Cost/s)	0.0000		0.0000			
54	Act. Gas Flow (ACT_m3/h)	1.099e+007	1.14	1e+007			
55	Avg. Liq. Density (kgmole/m3)	30.14		30.14			
56 57	Specific Heat (kJ/kgmole-C)	29.16	4 4 6	29.22			
58	Std. Gas Flow (STD_m3/h) Std. Ideal Lig. Mass Density (kg/m3)	1.122e+007 865.9	1.14	2e+007 865.9			
59	Std. Ideal Liq. Mass Density (kg/m3) Act. Liq. Flow (m3/s)	0.0000		865.9			
60	Z Factor			0.9992			
61	Watson K	6.042		6.042			
62	User Property						
63	Aspen Technology Inc.	Aspen H	IYSYS Vers	ion 7.3 (2	5.0.0.7336	•	Page 16 of 22
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1			Case N	ame:	NA COOLED SU	JPER CRITICAL RAN	VKINE CYCLE MODEL V1.HSC	
2 3 4	Surlington Burlington	E ENERGY ALLIANCE , MA	Unit Set		AFR			
4 5			Date/Tir	ne:	Fri Mar 28 09:55	:16 2014		
6	_ .							
7 8	Bala	nce: Dew Po	oint Ba	lance	e@TPL2	(continue	ed)	
9			PROPE	RTIES				
10 11	Name	Dew Point @TPL2	Moist Air @					
12	Partial Pressure of H2S (MPa)	0.0000		0.0000				
13	Cp/(Cp - R)	1.399		1.398				
14	Cp/Cv	1.403		1.401				
15	Heat of Vap. (kJ/kgmole)	3770		3770				
16	Kinematic Viscosity (cSt)	14.44		15.42				
17	Liq. Mass Density (Std. Cond) (kg/m3)	1.216		1.216				
18	Liq. Vol. Flow (Std. Cond) (m3/h)	1.121e+007	1.12	1e+007				
19	Liquid Fraction	0.0000		0.0000				
20	Molar Volume (m3/kgmole)	23.16		24.04				
21	Mass Heat of Vap. (kJ/kg)	131.2		131.2				
22	Phase Fraction [Molar Basis]	1.0000		1.0000				
23	Surface Tension (dyne/cm)							
24	Thermal Conductivity (Wm-K)	2.471e-002		48e-002				
25	Viscosity (cP)	1.790e-002	1.84	42e-002				
26 27	Cv (Semi-Ideal) (kJ/kgmole-C)	20.85		20.91				
28	Mass Cv (Semi-Ideal) (kJ/kg-C) Cv (kJ/kgmole-C)	0.7258 20.79		0.7279 20.86				
29	Cv (kJ/kgmole-C) Mass Cv (kJ/kg-C)	0.7238		0.7261				
30	Cv (Ent. Method) (kJ/kgmole-C)	0.7230		0.7201				
31	Mass Cv (Ent. Method) (kJ/kg-C)							
32	Cp/Cv (Ent. Method)							
33	Reid VP at 37.8 C (MPa)							
34	True VP at 37.8 C (MPa)							
35	Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.121e+007	1.12	1e+007				
36	Viscosity Index	-6.592		-5.996				
37 38			COMPO	SITION				
30 39	Name	Dew P	oint @TPL2					
40	Hydrogen		0.0000		0.0000	1		
41	H2O		0.0115		0.0115			
42	Oxygen		0.2076		0.2076			
43	Nitrogen		0.7809		0.7809			
44	CO2		0.0000		0.0000			
45 46	CO Air		0.0000		0.0000			
40	81		0.0000		0.0000		I	
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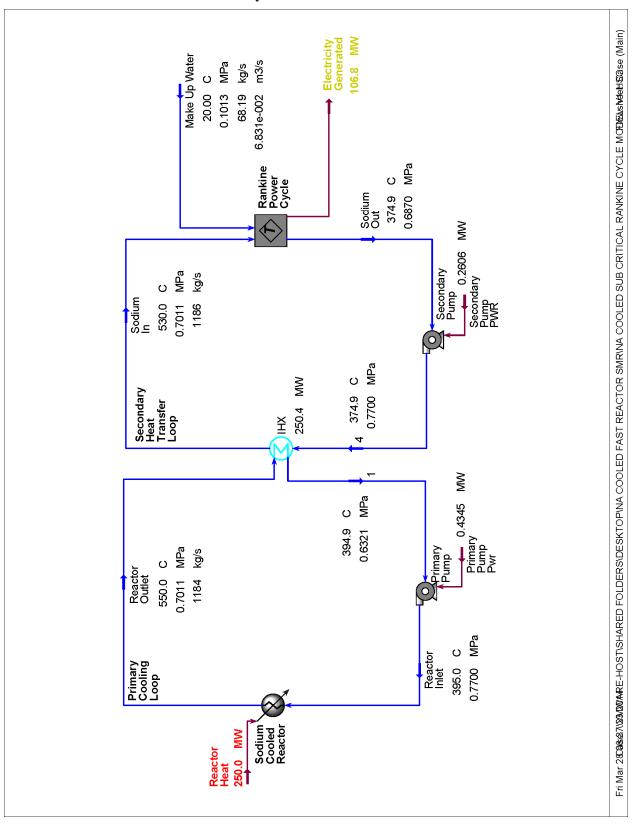
1			Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC						
3	Burlington, MA	NERGY ALLIANCE	Unit Set:	AFR						
4 5			Date/Time:	Fri Mar 28 09:55:16 2014						
6 7	C.		nt Droco							
8	Set: Dew Point Pressure @TPL2									
9 10			Target							
11	OBJECT			VARIABLE						
12 13	Dew Point			Pressure						
14			Source							
15 16	OBJECT Moist Air			VARIABLE Pressure						
17	MONTAN	Ec	uation Param							
18 19	MULTIPLIER			OFFSET						
20	1.000	``````````````````````````````````````		0.0000 kPa						
21 22			User Variabl	es						
23			NOTES							
24 25										
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Extract Endrev Allabot Barrelle Endrev Barrelle	1				Case Name:						
Construction Use 5" Interface Fit Mar 28 09.85 18 2014 Convectors Units 6" None1 Convectors Convectors None1 Convectors Imported Variables 0 0 Convectors 0 0 2 0 0 B Material Stream Saf Pross & Molet Al TTP Pressure 0 0 0 B Material Stream Saf Pross & Molet Al TTP Pressure 0		(alle	BATTELLE EI	IERGY ALLIANCE	Case Marile.						
Data Private 2006 55.05.2014 Units Steel MOUNT Image: Steel Stee		C		1	Unit Set:	Unit Set: AFR					
Spreadsheet: Moist Air Conditions @TPL2 Unesser NCMP1 CONNECTIONS Imported Variables Imported Variables 2.338-6303 MPs B Cell Variable Description 2.338-6303 MPs 0.113 MPs B Material Stream: Sat Pross (Moles Ar TO Pressure 0.113 MPs 1.882 B Material Stream: Nach Ar GTTL2 Pressure 0.113 MPs 1.882 B B Material Stream: Note Ar GTTL2 Material Weight 2.885 3.373 Hps B B Material Stream: Mote Ar GTTL2 Temperature 2.030-010 Hps 2.886 B B Material Stream: Mote Ar GTTL2 Temperature 2.030-02 2.886 Cell Check Variable Description 2.030-03 Hps 2.030 Hps Cell Check Variable Description Variable Description Variable Description Variable Mps Cell Value Material Stream: Develop Mps Value 3.930 Hps Cell Value Name Value Name Value Name Name B B B </th <th></th> <th></th> <th>• 03A</th> <th></th> <th>Date/Time:</th> <th>Fri Mar 28 09:55:16 2</th> <th>2014</th> <th></th>			• 03A		Date/Time:	Fri Mar 28 09:55:16 2	2014				
CONNECTIONS Imported Variables Connections B2 Material Stream: Set Press & Meint Ar Tel Pressure 0.1018 March B3 B4 Material Stream: Set Press & Meint Ar Tel Pressure 0.1018 March B4 Material Stream: Set Press & Meint Ar Tel Pressure 0.1018 March 0.1018 March B5 Pure Component: Ar Amesia Ar Stream: Material Stream: 0.2018 March 0.1018 March B9 Material Stream: Mids Ar oft PTL2 Mase Flow 2.308 cl 30 March 2.308 cl 30 March Cell D1 Material Stream: Mids Ar oft PTL2 Mase Flow 2.300 cl 30 March Cell D2 Material Stream: Mids Ar oft PTL2 Mase Flow 2.300 cl 30 March Cell D1 Dry Air oft PTL2 Mase Flow 2.300 Ll 30 March Cell Divertion Value Value 2.300 Ll 30 March Cell Divertion Value Value 2.300 Ll 30 March Cell Divertion Value Value 2.300 Ll 30 March B3 <					•						
3 CONNECTIONS 3 Imported Variables 3 Clipic: Variable Description Variable Secreption 0 D1 Material Straws, Maat Ark (2TPL 2) Temperature 2000 C 2000 C 0 D2 Material Straws, Maat Ark (2TPL 2) Temperature 2000 C 2000 C 0 D2 Material Straws, Maat Ark (2TPL 2) Temperature 2000 C 2000 C 0 D2 Material Straws, Maat Ark (2TPL 2) Mase New Variable Description Variable Mark 0 D1 Material Straws, Maat Ark (2TPL 2) Mase New Pressure 10000 MPa 0	7		Spreadshee	et: Moist	Air Conditi	ions @TPL2		Units Set: NGNP1			
CONNECTONS Imported Variables Solution Variable Description Value Solution Solution of the GPL of the source Value Value Solution Parts Component: NO More classifier of the source Value Value B Pure Component: NO More classifier of the source Value Value B Pure Component: Not Art (GPL-2) Mass Flow Satter of the source Value D D Material Stream: Most Art (GPL-2) Temperature 2.200 C Value Value D D Material Stream: Most Art (GPL-2) Temperature Variable Description Value Value D D Mass Flow Variable Variables Value Value D D Order of Variable Network Percent 5000 Value Value D D Mass Flow Variable Description Variable Tage Value Value <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>											
Cell Object Variable Variable Variable Variable Variable 12 B4 Material Stream Sat Press (@ Moist Ar Terr Pressure 0.101 MPa 13 B4 Material Stream Not Ark (@TPL2 Pressure 0.101 MPa 14 B6 Pure Component: Air Molecular Weight 18 02 15 B9 Material Stream Most Ark (@TPL2 Tempenture 200 C 15 D1 Material Stream Most Ark (@TPL2 Tempenture 200 C 16 B9 Material Stream Most Ark (@TPL2 Tempenture 200 C 17 Exported Variables 9380 C 9380 C 18 B10 Dry Ark (@TPL2 Mase Flow 9780 Mogr 19 B11 B11 Relsher Humstaly Relsher Humstaly Pressure 700 Ma 19 B3 B3 Valser Vapor Pressure Ark Pessure 700 Ma 3780 MgF 10 B10 B11 Relsher Humstaly Relsher Humstaly Prestert 5000 MF <th>10</th> <th></th> <th></th> <th></th> <th>CONNECTIO</th> <th>NS</th> <th></th> <th></th>	10				CONNECTIO	NS					
Cell Object Variable Variable Variable Variable Variable 12 B4 Material Stream Sat Press (@ Moist Ar Terr Pressure 0.101 MPa 13 B4 Material Stream Not Ark (@TPL2 Pressure 0.101 MPa 14 B6 Pure Component: Air Molecular Weight 18 02 15 B9 Material Stream Most Ark (@TPL2 Tempenture 200 C 15 D1 Material Stream Most Ark (@TPL2 Tempenture 200 C 16 B9 Material Stream Most Ark (@TPL2 Tempenture 200 C 17 Exported Variables 9380 C 9380 C 18 B10 Dry Ark (@TPL2 Mase Flow 9780 Mogr 19 B11 B11 Relsher Humstaly Relsher Humstaly Pressure 700 Ma 19 B3 B3 Valser Vapor Pressure Ark Pessure 700 Ma 3780 MgF 10 B10 B11 Relsher Humstaly Relsher Humstaly Prestert 5000 MF <th>11</th> <th></th> <th></th> <th></th> <th>Imported Varia</th> <th>ables</th> <th></th> <th></th>	11				Imported Varia	ables					
B P2 Material Stream: Stream (Stream: Stream) 2 338-003 MPa IS B4 Material Stream: Molax Aur Tell Fressure 0.1013 MPa IS B4 Fure Component: H20 Molecular Weight 16.02 IS B9 Material Stream: Molax Aur (2011) Mass Flow 3787 Agis IS B9 Material Stream: Molax Aur (2011) Mass Flow 3787 Agis IS D2 Material Stream: Molax Aur (2011) Mass Flow 3787 Agis IS D2 Material Stream: Molax Aur (2011) Mass Flow 3787 Agis IS D2 Material Stream: Molax Aur (2011) Temperature 2000 C IS Material Stream: Molax Flow Variables 2000 C 3787 Agis IS Material Stream: Molax Flow Variable Description Value 3787 Agis IS Mass Flow Mass Flow Variable Description Value Value IS Exportable Variables Pre		Call	Object		portou tur			Malua			
5 P4 Material Straam, Most Air (2)TPL2 Pressure 0.1013 MPa 10 Pare Component. Air Molecular Weight 28.95 10 B9 Material Straam, Most Air (2)TPL2 Temperature 20.00 C 20 D2 Material Straam, Most Air (2)TPL2 Temperature 3.98 C 21 Exported Variables' Formula Results 3.98 C 3.98 C 22 Exported Variables' Formula Results 3.98 Lgs 3.78 kgs 23 Cell Op, Air (2) TPL2 Mass Flow 3.78 kgs 24 Exportable Variables Description Value 3.78 kgs 25 Exportable Variable Description Value 3.78 kgs 26 It is is is in the strain the strai			- i	@ Moist Air Ter P	ressure	Valiable Description					
17 B7 Pure Component: Air Material Stream: Molit Air@TPL2 Marge Flow 3787 rg/s 10 D1 Material Stream: Molit Air@TPL2 Temperature 20.00 C 20 D2 Material Stream: Molit Air@TPL2 Temperature 20.00 C 21 Exported Variables' Formula Results 22 Cell Value 23 Cell Value 24 B10 Dry Air@TPL2 Material Stream: Molit Air@TPL2 Material Stream: Molit Air@TPL2 Streptable Variables' Formula Results Cell Value Streptable Variable Stream Value	15			-				0.1013 MPa			
B9 Material Stream: Moigt Air (@TFL2) Mase Flow 3737 fug's D1 Material Stream: Mask Air (@TFL2) Temperature 2000 C D2 Material Stream: Mask Air (@TFL2) Temperature 2000 C 21 Exported Variables' Formula Results 2000 C 9386 C 22 Exported Variables' Formula Results 2000 C 23 PARAMETERS 2000 C 24 B10 Dry Air (@TFL2) Mass Flow 2700 Log's 25 PARAMETERS 2000 C Value 2700 Log's 26 Exportable Variable Description Variable Type Value 27 B1 B1 Relative Humidity Relative Humidity Persure 1168e-003 MPa 28 B5 B5 Air Pressure Air Pressure Pressure 0.1002 MPa 29 Edit Variable Resolut Mass Flow 3700 Log's 29 B1 B10 <		B6	Pure Component H2O	N	lolecular Weight			18.02			
D1 Material Stream: Mout: Air @TPL2 Temperature 20.00 C D2 Material Stream: Dew Point @TPL2 Temperature 0.386 C 22 Exported Variables' Formula Results 23 Cell Object Variable Description Value 24 B10 Dev Arr @TPL2 Mass Flow 3760 hg/s 25 PARAMETERS 26 Cell Value 28 Cell Value 29 Cell Value 29 Cell Value 29 Cell Value 20 B4 B5 B5 Arr Possure 20 B4 B4 Value 20 Cell Value Portessure Pressure 1106::00.00 Solspan="2">Formula Result <td c<="" th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></td>	<th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>										
D2 Material Stream: Dew Point @ TPL2 Temperature 9.386 C 21 Exported Variables' Formula Results Value Value 22 Cell Object Variable Description Value 23 Exported Variables 3700 kg/s 3700 kg/s 24 B10 Dry Air @TPL2 Mass Flow 3700 kg/s 25 Factorial Variable Variables Pactorial Variable Type Value 26 Exportable Variables Perestre 50.00 27 Exportable Variable Pacersize Pressure 0.1002 MPa 28 B1 B1: Relative Humidity Relative Humidity Perestre 0.1002 MPa 28 B5 B6 Air Pressure Jar Pressure 0.1002 MPa	18										
21 Exported Variables' Formula Results 22 Cell Object Value 23 Cell Object Value 24 B10 Dry Air (@TPL2 Mass Flow 3760 kg/s 25 PARAMETERS 27 Exportable Variables 27 Exportable Variables 20 0 Value 28 B3 B3 B4 181 181 Relative Humidity Percent 50.00 29 B5 B5 Air Pressure Avalue Avalue Yagor Pressure 1188-003 MPa 29 B5 B5 Air Pressure Avalue Yagor Pressure Pressure 1188-003 MPa 30 B10 B10 Mass Flow Mass Flow Mass Flow 3780 kg/s 31 B5 -B41 FORMULAS 3780 kg/s 3780 kg/s 32 Cell Formula Result 0.1002 MPa 32 B3 -B41 0.1002 MPa 3780 kg/s 33 Cell Formula Result 0.1002 MPa<	19										
Cell Object Variable Description Value 24 B10 Dry Air @TPL2 Mass Flow 3760 kg/s 25 PARAMETERS 27 Exportable Variables 28 Exportable Variable Description Variable Type Value 29 Cell Value 29 Cell Value 20 B1 B1 Pressure Value 29 Cell Value Value 20 B3 B3 State Flow Value 20 B4 B4 B4 B4 B4 B4 B4 B4 Value 21 B5 B5 B5 Cell Cell Cell Cell Cell Formula Resulthead	20	02	Material Stream: Dew Poin	@IFL2	emperature			9.390 C			
St B10 Dry Air @TPL2 Mass Flow 3760 kg/s 25 PARAMETERS 27 Exportable Variables 28 Exportable Variables 29 Diry Air @TPL2 29 Cell Visible Name 20 B1 B1 Resure 20 B1 B1 Visible Name Visible Name Variable Description Variable Type Value 30 B1 B1 Resure Pressure Pressure 0.1002 MPa Start Colspan="2">Visiter Vapor Pressure Pressure 0.1002 MPa Spreadsheet Spreadsheet OD (00 C Visiter Vapor Pressure 1.168e-003 MPa Spreadsheet Spreadsheet Spreadsheet Pre	22			Export	ed Variables' Fo	rmula Results					
PARAMETERS Exportable Variables Sportable Variable Description Variable Type Value Sportable Variable Description Variable Type Value Sportable Variable Description Variable Description Variable Type Value Sportable Variables Pressure 1.168-003 MPa Sportable Variables 7.268-003 B8 B9 B8 B9 Cell Variables FORMULAS Sportadsheet Of the B9/100*B2 1.168-003 MPa B8 B9 -988 -98738(87*65) 7.268-003 Spreadsheet Spreadsheet Open=300 Maint Air Temperature * 0.000 C* Spreadsheet Open=303 3780 kg/s Spreadsheet Open=3	23	Cell	Object			Variable Description		Value			
PARAME TERS Exportable Variables 27 Exportable Variables 28 Variable Variable Description Variable Type Value 39 B1 B1: Relative Humidty Relative Humidty Percent 50.00 30 B3 B3: Water Vagor Pressure Variable Pressure 0.1002 MPa 32 B5 B5: Humidty, Rato Humidty Rato Pressure 0.1002 MPa 33 B8 B8: Humidty, Rato Humidty Rato Market Flaw 34 B10 B10 B10 B10 B10 B2 FORMULAS 35 Cell Formula Result 37 Spreadsheet 38 B8 e8/B3 0 0.00 C 37 A Relative Humidity Cell Formula Result 37 <th colspant="" prescop<="" t<="" th=""><th>24</th><th>B10</th><th>Dry Air @TPL2</th><th>N</th><th>lass Flow</th><th></th><th></th><th>3760 kg/s</th></th>	<th>24</th> <th>B10</th> <th>Dry Air @TPL2</th> <th>N</th> <th>lass Flow</th> <th></th> <th></th> <th>3760 kg/s</th>	24	B10	Dry Air @TPL2	N	lass Flow			3760 kg/s		
Exportable Variables Cell Visible Name Variable Description Variable Type Value 90 B1 B1: Relative Humidity Percent. 50.00 31 B3 33 Vater Vapor Pressure Water Vapor Pressure Pressure 11.898-003 MPa 32 B5 65 Air Pressure Air Pressure Pressure 0.1002 MPa 33 B8 B2 Humidity Ratio Humidity Ratio 7.268e-003 34 B10 B10. Mass Flow Mass Flow Mass Flow Mass Flow 3760 kg/s 36 Cell FORMULAS 37 FORMULAS 38 Estimation of the state					PARAMETE	RS					
Exportable Variables 28 Cell Visible Name Variable Description Value Value 18 B3 B3 <th< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></th<>											
28 Cell Variable Description Variable Type Value 30 B1 B1: Relative Humidity Relative Humidity Percent \$0.00 31 B3 B3: Valer Vapor Pressure Water Vapor Pressure Pressure Pressure 0.1002 MPa 32 B5 B5: Air Pressure Air Pressure Pressure 0.1002 MPa 33 B8 B8: Humidity Ratio 7.266e-003 34 B10 B10. Mass Flow Mass Flow Mass Flow 3780 kg/s 36 Cell FORMULAS 7.266e-003 37 Variable Size 11.169e-003 MPa 0.1002 MPa 38 Cell FORMULAS 0.1002 MPa 0.1002 MPa 39 Cell Formula Result 0.1002 MPa 41 B5 +84-83 0.1002 MPa 0.1002 MPa 42 B8 +86*B3/(87765) 7.266e-003 3780 kg/s 44 SpreadSheet 0.1002 MPa 0.1002 MPa 0.000 C *					Exportable Var	iables					
B1 B1 B1 B2 B3 Cell FORMULAS 33 B3 Cell Formula Result 1168e-003 MPa 0.1002 MPa 44 B4 Formula Result 0.1002 MPa 7.266e-003 3780 kg/s 44 B10 -98/18786 Mass Flow 3780 kg/s 0.1002 MPa 20.00 C* 45 A	29	Cell	Visible Name		Variable D	lescription	Variable Type	Value			
Sp. B5. Air Pressure Air Pressure Pressure 0.1002 MPa 33 B8 B8. Humidity Ratio Humidity Ratio 7.266e-003 34 B10 B10: Mass Flow Mass Flow Mass Flow 3760 kg/s 35 User Variables 37 FORMULAS 38 Cell Result Result 4 FORMULAS Solution of the second of the se	30										
33 B8 B8. Humidity Ratio Humidity Ratio 7.268e-003 34 B10 B10. Mass Flow Mass Flow 3760 kg/s 36 User Variables 37 FORMULAS 38 FORMULAS 39 Cell Formula Result 40 B3 7.268e-003 39 Cell Formula Result 40 B3	31	B3	B3: Water Vapor Pressure			er Vapor Pressure Pressure					
34 B10 B10. Mass Flow Mass Flow Mass Flow 3780 kg/s 35 User Variables 37 FORMULAS 38 Cell Result 39 Cell Result 41 B5 eStreadSmart 42 B8 -B6*B3/(B7*B5) 38	32	B5	B5: Air Pressure	A	Air Pressure Pressure			0.1002 MPa			
35 User Variables 37 FORMULAS 38 FORMULAS 39 Cell Result 40 B3	33	B8	B8: Humidity Ratio	н	lumidity Ratio			7.266e-003			
User Variables FORMULAS FORMULAS 1.168e-003 MPa 41 Result 41 Result 1.168e-003 MPa 41 B5		B10	B10: Mass Flow	N	lass Flow		Mass Flow	3760 kg/s			
S7 FORMULAS 33 Cell Formula Result 40 B3 =81/100*B2 11.168e-003 MPa 41 B5 =84-B3 0.1002 MPa 42 B8 =86*B3/(B7*B5) 7.266e-003 43 B10 =89/(1+88) 3760 kg/s 44 Spreadsheet 44 Spreadsheet 0.100 C* 44 Spreadsheet 0.00 C* 45 A B C D 44 Spreadsheet 0.00 C* 0.00 C* 44 Spreadsheet 0.00 C* 0.00 C* 45 A B C D 46 A B C D 47 1 Relative Humidity * 50.00 * Moist Air Temperature * 9.308 C* 49 3 Water Vapor Pressure * 0.1013 MPa * 51 5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Vater * 18.02 * 53 7					User Variab	les					
Bit Formula Result 39 Cell Formula 1.169e-003 MPa 41 B5 =84-B3 0.1002 MPa 42 B6 =86*B3/(B7*B5) 7.268e-003 44 Spreadsheet 3760 kg/s 44 Spreadsheet 9.300 kg/s 44 Spreadsheet 9.300 kg/s 44 Spreadsheet 9.300 kg/s 45 C D 46 A B C D 47 1 Relative Humidity * 50.00 * Moist Air Temperature * 20.00 C * 48 2 ter Vapor Sat Pres @ Moist Air Temp * 2.338e-003 MPa * Dew Point Temperature * 9.398 C * 49 3 Water Vapor Pressure * 0.1102 MPa *						_					
40 B3 =B1/100*B2 1.189e-003 MPa 41 B5 =B4-B3 0.1002 MPa 42 B8 =B8*B3(B7*B5) 7.266e-003 43 B10 =B9/(1+B8) 3780 kg/s 44 Spreadsheet 45 Spreadsheet 46 A B C D 47 1 Relative Humidity 50.00 Moist Air Temperature * 20.00 C * 49 3 Water Vapor Sat Pres @ Moist Air Temp * 2.339e-003 MPa * Dew Point Temperature * 9.396 C * 49 3 Water Vapor Pressure * 0.1013 MPa * 50 4 Moist Air Pressure * 0.1002 MPa * 51 5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Vater * 18.02 * 53 7 Molecular Weight of Air * 2.895 * 54 8 Humidity Ratio * 7.2	38				FURIMULA	5					
41 B5 =B4-B3 0.1002 MPa 42 B8 =B6*B3/(B7*B5) 7.286e-003 43 B10 =B8/(1+B8) 3760 kg/s 44 Spreadsheet 45 Spreadsheet 46 A B C D 47 1 Relative Humidity* 60.00 * Moist Air Temperature* 20.00 C * 48 3 Water Vapor Pressure * 1.188e-003 MPa * Dew Point Temperature* 9.3986 C* 49 3 Water Vapor Pressure * 0.1002 MPa * 50 4 Moist Air Pressure * 0.1002 MPa * 51 5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Water * 18.02 * 52 7 Molecular Weight of Air * 29.95 * 54 8 Humidity Ratio * 7.266e-003 * 54 9 Moist Air Mass Flow * 3760 kg/s * 57 9 <					Formula						
42 B8 =B8*B3/(B7*B5) 7.268-003 43 B10 =B9/(1+B8) 3760 kg/s 44 Spreadsheet 3760 kg/s 44 B C D 45 A B C D 46 A B C D 20.00 C* 47 1 Relative Humidity * 50.00 * Moist Air Temperature * 20.00 C* 43 3 Water Vapor Pressure * 0.1013 MPa * 50 4 Moist Air Pressure * 0.1013 MPa * 51 5 Air Pressure * 0.1002 MPa *											
ad B10 =B8/(1+B8) 3760 kg/s ad Spreadsheet C D 46 A B C D 47 1 Relative Humidity * 60.00 * Moist Air Temperature * 20.00 C * 47 1 Relative Humidity * 60.00 * Moist Air Temperature * 9.396 C * 48 2 ter Vapor Sat Pres @ Moist Air Temp * 2.339e-003 MPa * Dew Point Temperature * 9.396 C * 49 3 Water Vapor Pressure * 0.1013 MPa * Dew Point Temperature * 9.396 C * 50 4 Moist Air Pressure * 0.1013 MPa * Dew Point Temperature * 9.396 C * 51 5 Air Pressure * 0.10102 MPa * Dew Point Temperature * 9.396 C * 52 6 Molecular Weight of Vater * 1802 * Dew Point Temperature * 9.396 C * 53 7 Molecular Weight of Air * 28.95 * Dew Point Temperature * 9.376 kg/s * 54 8 Humidity Ratio * 7.266e-003 * S S </th <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>											
Ad Spreadsheet 44 Spreadsheet 46 A B C D 47 Relative Humidity * 50.00 * Moist Air Temperature * 20.00 C * 48 2 ter Vapor Sat Pres @ Moist Air Temp * 2.339e-003 MPa * Dew Point Temperature * 9.396 C * 49 3 Water Vapor Pressure * 1.169e-003 MPa * Dew Point Temperature * 9.396 C * 49 4 Moist Air Pressure * 0.1013 MPa * Dew Point Temperature * 9.396 C * 40 4 Moist Air Pressure * 0.1013 MPa * Dew Point Temperature * 9.396 C * 50 4 Moist Air Pressure * 0.1002 MPa * Dew Point Temperature * 9.396 C * 51 5 Air Pressure * 0.1002 MPa * Dew Point Temperature * 9.396 C * 52 6 Molecular Weight of Air * 28.95 * Dew Point Temperature * Point * 53 7 Molecular Weight of Air * 28.95 * Dew Point * Point * 54 8 Humidit											
46 A B C D 46 A B C D 47 1 Relative Humidity* 50.00* Moist Air Temperature* 20.00 C* 48 2 ter Vapor Sat Pres @ Moist Air Temp* 2.339e-003 MPa* Dew Point Temperature* 9.396 C* 49 3 Water Vapor Pressure* 1.169e-003 MPa* 50 4 Moist Air Pressure* 0.1013 MPa* 51 5 Air Pressure* 0.1002 MPa* 52 6 Molecular Weight of Vater * 18.02* 53 7 Molecular Weight of Air * 28.95* 54 8 Humidity Ratio* 7.266e-003* 56 9 Moist Air Mass Flow* 3760 kg/s* 57 58 57 61 10 Dry Air Mass Flow * 3760 kg/s * <th></th> <th>010</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>0100 kg/3</th>		010						0100 kg/3			
47 1 Relative Humidity* 50.00* Moist Air Temperature* 20.00 C* 48 2 ter Vapor Sat Pres @ Moist Air Temp* 2.339e-003 MPa* Dew Point Temperature* 9.396 C* 49 3 Water Vapor Pressure* 1.169e-003 MPa* 50 4 Moist Air Pressure* 0.1013 MPa* 51 5 Air Pressure* 0.1012 MPa* 52 6 Molecular Weight of Water* 18.02* 53 7 Molecular Weight of Air * 28.95* 54 8 Humidity Ratio* 7.266e-003* 56 10 Dry Air Mass Flow* 3760 kg/s* 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22	45				Spreadshe	et					
46 2 ter Vapor Sat Pres @ Moist Air Temp * 2.339e-003 MPa * Dew Point Temperature * 9.386 C * 49 3 Water Vapor Pressure * 1.169e-003 MPa * 50 4 Moist Air Pressure * 0.1013 MPa * 51 5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Vater * 18.02 * 53 7 Molecular Weight of Air * 28.95 * 54 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3760 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 56 60 61 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22				E							
49 3 Water Vapor Pressure * 1.169e-003 MFa * 50 4 Moist Air Pressure * 0.1013 MPa * 51 5 Air Pressure * 0.1013 MPa * 52 6 Molecular Weight of VVater * 18.02 * 53 7 Molecular Weight of Air * 2.895 * 54 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 58 9 Moist Air Mass Flow * 3760 kg/s * 59 8 Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 56 61 61 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336): Page 19 of 22		_					· · · · · · · · · · · · · · · · · · ·				
60 4 Moist Air Pressure * 0.1013 MPa * 51 5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Water * 18.02 * 53 7 Molecular Weight of Air * 28.95 * 54 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 58 9 Moist Air Mass Flow * 3760 kg/s * 59 8 Humidity Ratio * 3760 kg/s * 59 9 Dry Air Mass Flow * 3760 kg/s * 59 60 10 Dry Air Mass Flow * 3760 kg/s * 59 61 61 62 53 54 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336): Page 19 of 22						Dew Point Ter	nperature *	9.396 C *			
5 Air Pressure * 0.1002 MPa * 52 6 Molecular Weight of Water * 18.02 * 53 7 Molecular Weight of Air * 28.95 * 54 8 Hurridity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3780 kg/s * 58 59 61 59 61 61 59 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.7336) 63 Aspen 120 Mpt Inc. Aspen HYSYS Version 7.3 (25.0.7336) Page 19 of 22											
52 6 Molecular Weight of Water * 18.02 * 53 7 Molecular Weight of Air * 28.95 * 54 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 58 60 60 60 61 62 53 54 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22											
53 7 Molecular Weight of Air * 28.95 * 54 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3780 kg/s * 56 10 Dry Air Mass Flow * 3780 kg/s * 58 59 Image: State St	52										
64 8 Humidity Ratio * 7.266e-003 * 55 9 Moist Air Mass Flow * 3787 kg/s * 56 10 Dry Air Mass Flow * 3760 kg/s * 57 37 3760 kg/s * 4 60 60 4 5	53										
55 9 Moist Air Mass Flow* 3787 kg/s* 56 10 Dry Air Mass Flow* 3760 kg/s* 57 38 3760 kg/s* 40 58 59 50 50 60 60 50 50 50 61 62 53 54 55 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22	54										
56 10 Dry Air Mass Flow* 3760 kg/s* 57 58 59 58 59 59 60 60 60 61 62 63 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22	55										
58 59 60 61 62 63 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22											
53 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 19 of 22											
	58										
	59										
	6U 61										
	62										
	63	Aspe	n Technology Inc.	Aspen	HYSYS Version 7.	3 (25.0.0.7336)		Page 19 of 22			

1		Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
3	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Unit Set:	AFR
4 5		Date/Time:	Fri Mar 28 09:55:16 2014
6	Satu Sat Tam.	o for moi	
8	Set: Sat Tem		
9 10		Target	
11	OBJECT		VARIABLE
12 13	Sat Press @ Moist Air Temp		Temperature
14		Source	
15 16	OBJECT Moist Air		VARIABLE Temperature
17		uation Param	
18	MULTIPLIER		OFFSET
20	1.000		0.0000 C
21 22		User Variable	·····
23 24		NOTES	
25			
26 27			
28			
29 30			
31			
32			
33 34			
35			
36 37			
38			
38 39 40 41			
41			
42 43			
44			
45 46			
47			
44 45 46 47 48 49 50			
50			
51 52			
53			
54			
55 56			
56 57			
58 59			
60			
61 62			
63		SYS Version 7.3	(25.0.0.7336) Page 20 of 22
	Licensed to: BATTELLE ENERGY ALLIANCE		* Specified by user.

1		Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
2 3 4	BATTELLE ENERGY ALUANCE Burlington, MA USA	Unit Set: AFR
4 5		Date/Time: Fri Mar 28 09:55:16 2014
6 7		
8	Set: SET-1 @	UTPL2
9 10		Target
11	OBJECT	VARIABLE
12 13	53a	Pressure
14		Source
15 16	OBJECT 53	VARIABLE Pressure
17		quation Parameters
18 19	MULTIPLIER	OFFSET
20	1.000	0.0000 kPa
21 22		User Variables
23 24		NOTES
25		
26 27		
28		
29 30		
31		
32 33		
34		
35 36		
37		
38 39		
40		
41 42		
43		
44 45		
46		
44 45 46 47 48 49		
49 50		
5U 51		
52		
53 54		
55 56		
56 57 58 59		
58		
60		
61 62		
62 63	Aspen Technology Inc. Aspen HY	(SYS Version 7.3 (25.0.0.7336) Page 21 of 22
_	Licensed to: BATTELLE ENERGY ALLIANCE	* Specified by user.

1	Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC											
2			IERGY ALLIANCE	Unit Set:	AFR							
4	C	aspentech Burlington, MA										
5				Date/Time:	Fri Mar 28 09:55:16 2	2014						
6		Spreadshee	t. Water Co	ooling C	alcs @TPL2		Units Set: NGNP1					
8		Opreadured										
9 10				CONNECTIO	ONS							
11			Ir	nported Vari	ables							
12	Cell	Object		·	Variable Description		Value					
14	B1		ater Out @TPL: Mass F	Flow			3256 kg/s					
15	B5	Material Stream: Moist Air @	TPL2 Actual	Volume Flow			3169 m3/s					
16	B3	Material Stream: Saturated	Air@TPL2 Master	r Comp Mass Flo	w (H2O)		75.8339 kg/s					
17	B7	Material Stream: Water Retu		Flovv			3190 kg/s					
18	D1	Energy Stream: Cooling W	ater Pump Power				9.430 kW					
19 20			Exported V	Variables' Fo	ormula Results							
21	Cel	Object			Variable Description		Value					
22	B2	Entrained Water @TPL2	Mass F	Flow			3.256 kg/s					
23	B6	Air Fan Power @TPL2	Power				625.9 kW					
24	B4	Blowdown @TPL2	Massi				15.17 kg/s					
25	B8	Make Up Water @TPL2	Massi				66.93 kg/s					
26	D2	Total Cooling Tower Power @TPL	2 Power				635.3 kW					
27				PARAMETE	RS							
29												
30			Ex	portable Va	riables							
31	Cel	Visible Name		Variable [Description	Variable Type	Value					
32	B2	B2: Mass Flow	Mass F	Flow		Mass Flow	3.256 kg/s					
33	B6	B6: Power	Power			625.9 kW						
34	B4	B4: Mass Flow	Massi	Flow		Mass Flow	15.17 kg/s					
35	B8	B8: Mass Flow	Mass	Flow		Mass Flow	66.93 kg/s					
36	B9	B9:					<empty></empty>					
37	D2	D2: Power	Power			Power	635.3 kW					
38 39	D7	D7:					<empty></empty>					
40				User Variab	oles							
41 42				FORMULA	s							
42	Cel			Formula			Result					
44	B2	=.001*B1		onnara			3.256 kg/s					
45	B4	=.20*B3					15.17 kg/s					
46	B6	=B5/5.063					625.9 kW					
47	B8	=81-87					66.93 kg/s					
48	D2	=D1+B6					635.3 kW					
49 50				Spreadshe	eet							
51		А	В		С		D					
52	1	Cooling Water Mass Flow *		3256 kg/s *	Cooling Water Pur	mp Power *	9.430 KW *					
53	2	Entrained Water Mass Flow *		3.256 kg/s *	Total Cooling Tow		635.3 kW *					
54	3	Evaporated Water Mass Flow *	-	75.8339 kg/s *								
55	4	Blowdown Mass Flow *	15.17 kg/s *									
56 57	5	Moist Air Volume Flow *										
58	6 7	Fan Power * Water Return Flow *		625.9 kVV * 3190 kg/s *			<empty> *</empty>					
59	8	Make Up Water Flow *		66.93 kg/s *			~empty~					
60	9			<empty> *</empty>		1						
61	10			<empty> *</empty>								
62												
63		en Technology Inc.	Aspen HYS	SYS Version 7	.3 (25.0.0.7336)		Page 22 of 22					
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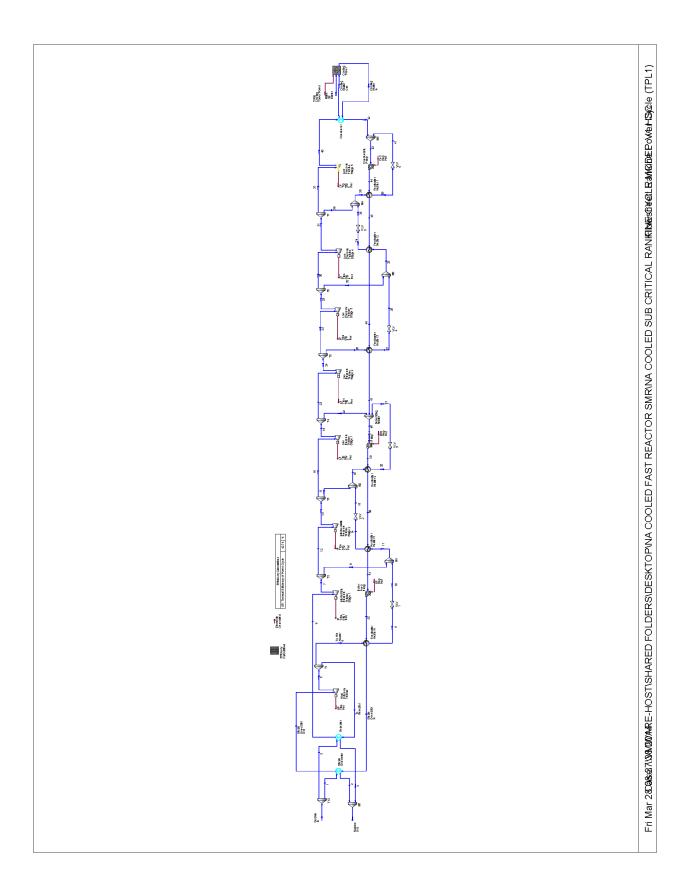


6.2 Subcritical Rankine Power Cycle Model

1				6	se Name:	NA COOLED SUB CRI	FICAL RANK	INE CYCLE	MODEL V1	ISC
2			ENERGY ALLIANC	-						
3 4	Sector	Burlington, USA	MA	Un	it Set:	AFR				
5				Da	te/Time:	Fri Mar 28 10:00:36 201	4			
6			o (14	• 、						
8	VVOrk	(DOOK:	Case (Ma	ain)						
9				Mate	Aaterial Streams Fluid Pkg:				All	
10	N 1		0.11.1	_	nai Stream					All
11	Name Vapour Fraction		Sodium In 0.000	4	0.0000	Reactor Outlet 0.0000	Reactor Ir	nlet 0.0000	1	0.0000
13	Temperature	(C)	530.		374.9	550.0 *		395.0		394.9 *
14	Pressure	(MPa)	0.701		0.7700 *	0.7011		0.7700 *		0.6321
15	Molar Flow ((kgmole/h)	1.857e+00	5	1.857e+005	1.854e+005	1.	854e+005	1.8	54e+005
16	Mass Flow	(kg/s)	118	6	1186	1184		1184		1184
17	Liquid Volume Flow	(m3/h)	454		4544	4537		4537		4537
18	Heat Flow	(MVV)	818.		568.3	849.9		599.9		599.5
19	Name		Sodium Out	1	p Water					
20 21	Vapour Fraction Temperature	(C)	0.000 374.		0.0000					
22	Pressure	(O) (MPa)	0.687		0.1013					
23		(kgmole/h)	1.857e+00		1.363e+004					
24	Mass Flow	(kg/s)	118		68.19					
25	Liquid Volume Flow	(m3/h)	454	4	246.0					
26	Heat Flow	(MVV)	568.	1	-1080					
27				Co	npositions			Fluid Pkg		All
28	Nerre		Ondiver la		<u> </u>		Desetes la		4	
29 30	Name Comp Mole Frac (H2O)		Sodium In	4	***	Reactor Outlet	Reactor Ir	1IET ***		***
31	Comp Mole Frac (Nitrogen)		**	*	***	***		***		***
32	Comp Mole Frac (Oxygen)		#7	*	***	***		***		***
33	Comp Mole Frac (Hydrogen)		**	*	***	***		***		***
34	Comp Mole Frac (CO2)		*7	*	***	***		***		***
35	Comp Mole Frac (CO)		*7		***	***		***		***
36	Comp Mole Frac (Sodium)		1.000		1.0000 *	1.0000		1.0000 *		1.0000
37	Comp Mole Frac (Air)		**		***	***		***		***
38 39	Name Comp Mole Frac (H2O)		Sodium Out		p Water 1.0000					
40	Comp Mole Frac (Nitrogen)		**	*	1.0000					
41	Comp Mole Frac (Oxygen)		#7	*	***					
42	Comp Mole Frac (Hydrogen)		**	*	***					
43	Comp Mole Frac (CO2)		**	*	***					
44	Comp Mole Frac (CO)		*7	*	***					
45	Comp Mole Frac (Sodium)		1.000		***					
46 47	Comp Mole Frac (Air)		**		***					
48				Ene	rgy Stream	S		Fluid Pkg	:	All
49	Name		Reactor Heat	Electric	ity Generated	Primary Pump Pwr	Secondar	y Pump PWF		
50	Heat Flow	(MVV)	250.	0 *	106.8	0.4345		0.2606		
51					Jnit Ops					
52										
53 54	Operation Name	Ope	ration Type	Reactor Inle	eeds t	Products Reactor Outlet		Ignored	Calc	Level
55	Sodium Cooled Reactor	Heater		Reactor He		Reactor Outlet		No		500.0 *
56		Sodi		Sodium In		Sodium Out				
57	Rankine Power Cycle	Standard S	Sub-Flowsheet	Make Up W	ater	Electricity Generate	d	No		2500 *
58	Efficiency Calcs	Spreadshe	eet					No		500.0 *
59	IHX	Heat Exch	anger	Reactor Out	llet	1		No		500.0 *
60	11.123		angu	4		Sodium In		140		000.0
61	Primary Pump	Pump		1		Reactor Inlet		No		500.0 *
62	Aspen Technology Inc.	· ·	Acres	Primary Pur		25.0.0.7336)			Dage	
03	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	ALLIANCE	ASDE	101313 ¹	/ 10/11/.3 (.	23.0.0.1336			* Specified I	1 of 14 by user.

1				Case Name: NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC					
2 3 4	espentech	Burlington, MA		Unit Set:	AFR				
4 5		USA		Date/Time:	Date/Time: Fri Mar 28 10:00:36 2014				
6 7	Mort	chook:	Case (Main		4)				
8	VVOIR	DOOK.	Case (Main						
9 10			U	nit Ops (continue	ed)				
11 12	Operation Name	Opera	tion Type Sodiu	Feeds um Out	Products 4	Ignored	Calc Level		
13	Secondary Pump	Pump		ndary Pump PWR	1	No	500.0 *		
14 15									
16 17									
18									
19 20									
21									
22 23									
24 25 26 27									
26									
28									
29 30									
31 32									
33									
34 35									
36 37									
38									
39 40									
40 41 42									
43									
44 45									
46									
45 46 47 48 49 50									
49 50									
51									
52 53									
54 55									
56									
57 58									
59 60									
61									
62 63	Aspen Technology Inc.		Aspen HY	SYS Version 7.3 (2	5.0.0.7336		Page 2 of 14		
	Licensed to: BATTELLE ENERGY	ALLIANCE					* Specified by user.		

1				Case Name:	NA COOLED SUB C	RITICAL RANK	KINE CYCLI	E MODEL V1.HSC
2 3			NERGY ALLIANCE	Unit Set:	AFR			
4	C a	spentech ^{Burlington, M/}	1					
5				Date/Time:	Fri Mar 28 10:00:36 2	2014		
6 7		Spreadshee	et [.] Efficie	ency Calcs			U	nits Set: NuScale1
8		opreadones		ency care				
9 10				CONNECT	ONS			
11 12				Imported Va	iables			
13	Cell	Object			Variable Description			Value
14	A1	Energy Stream: Reactor H	eat	Heat Flow				250.0 MVV
15	A4	Energy Stream: Electricity	Generated	Power				106.8 MVV
16 17			Expor	ted Variables' F	ormula Results			
18	Cell	Object			Variable Description			Value
19 20				PARAMET	ERS			
21				Exportable Va	riablee			
22				-				
23 24	Cell A2	Visible Name A2:		Variable	Description	Variable	Туре	Value <empty></empty>
25	A5	A5: Power Cycle Efficiency		Power Cycle Efficienc	(Percent		<empty></empty>
26	A6	A6: Reactor Heat to HTSE		Reactor Heat to HTSE		Energy		<empty></empty>
27	B1	B1:				Mass Flow		<empty></empty>
28	B2	B2:				Mass Heatir	ng Value	<empty></empty>
29	B3	B3: Hydrogen Production Efficient	ay I	Hydrogen Production I	Efficiency	Percent		<empty></empty>
30	C1	C1:				Molar Entha		<empty></empty>
31	C2	C2:				Molar Entha	ilpy	<empty></empty>
32	C3	C3:				Molar Flow		<empty></empty>
33	C4	C4:						<empty></empty>
34 35	A3	A3: Heat to Rankine Cycle		Heat to Rankine Cycle		Energy		<empty></empty>
36 37				User Varia	bies			
38		1		FORMUL	AS			
39	Cell			Formula				Result
40 41	A3	=A1*A2						<empty></empty>
41	A5 A6	=A4/A3*100 =A1-A3						<empty> <empty></empty></empty>
43	B3	=(B1*B2/1000)/A1*100						<empty></empty>
44	C4	=C3*(C2-C1)/3600000						<empty></empty>
45 46				Spreadsh	eet			
47		Α		В	С			D
48	1	250.0 MVV *		<empty> *</empty>		<empty> *</empty>		
49	2	<empty> *</empty>		<empty> *</empty>		<empty> *</empty>		
50	3	<empty> *</empty>		<empty> *</empty>		<empty> *</empty>		
51	4	106.8 MW *				<empty> *</empty>		
52	5	<empty> *</empty>						
53	6	<empty> *</empty>						
04 55	7							
56	9							
57	10							
58								
59								
60								
61								
62	۸ -	T						D 0.44
63		Technology Inc. :: BATTELLE ENERGY ALLIANCE	Aspei	n HYSYS Version	7.3 (25.0.0.7336)			Page 3 of 14 * Specified by user.
	LUCE ISBU II	DATIELLE ENERGY ALLIANCE						apecined by user.



1				Case Name:	NA COOLED SUB CRIT	ICAL RANKINE CYCLE	MODEL V1.HSC
2 3	aspentec	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 10:00:36 201	4	
6							
7 8	Wo	orkbook:	Rankine P	ower Cycle	(TPL1)		
9				Streams		Fluid Pk	a: All
10 11	Nerre		01	To Reheater @TPL1	T- DAUL-H- COTD		
12	Name Vapour Fraction		Steam Generator Out 1.0000	1.0000	To FW Heater 6 @TPL 1.0000	6@TPL1 1.0000	9 @TPL1 0.0000
13	Temperature	(C)	510.0	354.8	354.8	510.0	251.1
14	Pressure	(MPa)	17.00	5.850	5.850	5.733	5.733
15	Molar Flow	(kgmole/h)	2.008e+004	1.888e+004	1207	1.888e+004	1207
16	Mass Flow	(kg/s)	100.5	94.46	6.040	94.46	6.040
17	Std I deal Liq Vol Flow	(m3/h)	362.5	340.7	21.79	340.7	21.79
18	Heat Flow	(MVV)	-1268	-1215	-77.70	-1178	-89.59
19	Molar Enthalpy	(kJ/kgmole)	-2.272e+005	-2.318e+005	-2.318e+005	-2.247e+005	-2.672e+005
20	Name		52 @TPL1	Steam Generator In @	51@TPL1	8@TPL1	12@TPL1
21	Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
22	Temperature Pressure	(C) (MPa)	245.6 17.70 *	270.4 17.35	241.0 3.409	445.6 3.760	445.6 3.760
23	Molar Flow	(MPa) (kgmole/h)	2.008e+004	2.008e+004	2.008e+004	1134	1.774e+004
24	Mass Flow	(kg/s)	100.5	100.5 *	100.5	5.677	88.78
26	Std I deal Liq Vol Flow	(m3/h)	362.5	362.5	362.5	20.48	320.3
27	Heat Flow	(MVV)	-1493	-1481	-1496	-71.53	-1119
28	Molar Enthalpy	(kJ/kgmole)	-2.677e+005	-2.655e+005	-2.681e+005	-2.270e+005	-2.270e+005
29	Name		11 @TPL1	16 @TPL1	18@TPL1	23 @TPL1	22@TPL1
30	Vapour Fraction		0.6368	1.0000	0.3742	1.0000	1.0000
31	Temperature	(C)	246.7	365.7	215.4	274.7	274.7
32	Pressure	(MPa)	3.760	2.120	2.120	0.9299	0.9299
33	Molar Flow	(kgmole/h)	2341	1.668e+004	3408	1.567e+004	1002
34	Mass Flow	(kg/s)	11.72	83.45	17.05	78.43	5.015
35	Std I deal Liq Vol Flow	(m3/h)	42.27	301.0	61.51	282.9	18.09
36	Heat Flow	(MVV)	-161.1	-1064	-243.8	-1014	-64.83
37	Molar Enthalpy	(kJ/kgmole)	-2.477e+005	-2.298e+005	-2.576e+005	-2.329e+005	-2.329e+005
38 39	Name		49 @TPL1 0.0000	14@TPL1 0.0000	20 @TPL1 0.0000	47 @TPL1 0.0000	48@TPL1 0.0000
40	Vapour Fraction Temperature	(C)	177.2	215.1	182.7	142.0	176.6
40	Pressure	(C) (MPa)	3.550 *	3.760	2.078	0.9299	0.9299
42	Molar Flow	(kgmole/h)	2.008e+004	2341	3408	1.567e+004	2.008e+004
43	Mass Flow	(kg/s)	100.5	11.72	17.05	78.43	100.5
44	Std I deal Liq Vol Flow	(m3/h)	362.5	42.27	61.51	282.9	362.5
45	Heat Flow	(MVV)	-1525	-175.8	-258.3	-1202	-1525
46	Molar Enthalpy	(kJ/kgmole)	-2.733e+005	-2.703e+005	-2.729e+005	-2.761e+005	-2.734e+005
47	Name		21 @TPL1	25@TPL1	26 @TPL1	27 @TPL1	30@TPL1
48	Vapour Fraction		0.0132	1.0000	1.0000	0.0000	1.0000
49	Temperature	(C)	176.8	202.0	202.0	113.9	126.4
50	Pressure Malar Flaw	(MPa)	0.9299	0.4380	0.4380	0.4292	0.1660
51 52	Molar Flow	(kgmole/h)	3408	1.473e+004	942.0	942.0	1.385e+004
52 53	Mass Flow Std I deal Liq Vol Flow	(kg/s) (m3/h)	17.05 61.51	73.72 265.9	4.714	4.714	69.29 249.9
54	Heat Flow	(MVV)	-258.3	-962.9	-61.57	-72.81	-914.7
55	Molar Enthalpy	(kJ/kgmole)	-2.729e+005	-2.353e+005	-2.353e+005	-2.783e+005	-2.378e+005
56 57 58 60 61							
63	Aspen Technology In	IC.	Asnen H	YSYS Version 7.3 (2	25.0.0.7336		Page 4 of 14
03	Licensed to: BATTELLE ENE		Aspent	11010 Version 7.3 (.	23.0.0.1330		* Specified by user.

1				Case Name:	NA COOLED SUB CRI	TICAL RANKINE CYCLE	MODEL V1.HSC
2 3	aspentec	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4		USA		Date/Time:	Fri Mar 28 10:00:36 201	4	
5 6					10.00.001201		
7	Wo	rkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)	
8 9				-	, ,,	,	
9 10				Streams (continu	ed)	Fluid Pk	g: All
11	Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1
12	Vapour Fraction		1.0000	0.9633	0.0000	0.000.0	0.0000
13	Temperature	(C)	126.4	80.22	79.77	45.74	40.18
14 15	Pressure Malas Elaur	(MPa)	0.1660	4.780e-002	0.1627	4.684e-002	0.9880 *
15	Molar Flow Mass Flow	(kgmole/h)	885.3 4.430	1.301e+004 65.12	1827 9.144	2659 13.31	1.567e+004 78.43
17	Std I deal Liq Vol Flow	(kg/s) (m3/h)	15.98	234.9	32.99	48.01	282.9
18	Heat Flow	(MVV)	-58.49	-870.4	-142.6	-209.4	-1236
19	Molar Enthalpy	(kJ/kgmole)	-2.378e+005	-2.408e+005	-2.809e+005	-2.834e+005	-2.838e+005
20	Name		40 @TPL1	38@TPL1	42 @TPL1	33 @TPL1	41@TPL1
21	Vapour Fraction		0.9072	0.3009	0.0000	0.4895	0.0098
22	Temperature	(C)	40.51	80.22	38.92	114.4	40.13
23	Pressure	(MPa)	7.584e-003 *	4.780e-002	7.433e-003	0.1660	7.433e-003
24	Molar Flow	(kgmole/h)	1.301e+004	2659	1.301e+004	1827	2659
25	Mass Flow	(kg/s)	65.12	13.31	65.12	9.144	13.31
26	Std I deal Liq Vol Flow	(m3/h)	234.9	48.01	234.9	32.99	48.01
28	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-883.9 -2.445e+005	-198.2 -2.683e+005	-1026 -2.839e+005	-131.3 -2.587e+005	-209.4 -2.834e+005
29	Name	(Korkginore)	1 @TPL1	3@TPL1	2 @TPL1	4@TPL1	Sodium In @TPL1
30	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
31	Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
32	Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
33	Molar Flow	(kgmole/h)	1.585e+005	2.725e+004	1.585e+005	2.725e+004	1.857e+005
34	Mass Flow	(kg/s)	1012	174.0	1012	174.0	1186
35	Std I deal Liq Vol Flow	(m3/h)	3877	666.8	3877	666.8	4544
36	Heat Flow	(MVV)	698.6	120.2	484.7	83.37	818.8
37	Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004
38 39	Name Vanaur Fraction		Sodium Out @TPL1 0.0000	5@TPL1 1.0000	10@TPL1 0.0122	7@TPL1 1.0000	13@TPL1 1.0000
40	Vapour Fraction Temperature	(C)	374.9	354.8	246.7	445.6	365.7
41	Pressure	(MPa)	0.6870	5.850 *	3.760	3.760 *	2.120 *
42	Molar Flow	(kgmole/h)	1.857e+005	2.008e+004	1207	1.888e+004	1.774e+004
43	Mass Flow	(kg/s)	1186	100.5	6.040	94.46	88.78
44	Std I deal Liq Vol Flow	(m3/h)	4544	362.5	21.79	340.7	320.3
45	Heat Flow	(MVV)	568.1	-1293	-89.59	-1190	-1132
46	Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.318e+005	-2.672e+005	-2.270e+005	-2.298e+005
47	Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45@TPL1
48	Vapour Fraction	(0)	1.0000	1.0000	1.0000	0.9633	0.0000
49 50	Temperature Pressure	(C) (MPa)	274.7	202.0 0.4380 *	126.4 0.1660 *	80.22 4.780e-002 *	74.22
51	Molar Flow	(Mra) (kgmole/h)	1.668e+004	1.567e+004	1.473e+004	1.385e+004	1.567e+004
52	Mass Flow	(kg/s)	83.45	78.43	73.72	69.29	78.43
53	Std I deal Liq Vol Flow	(m3/h)	301.0	282.9	265.9	249.9	282.9
54	Heat Flow	(MVV)	-1079	-1024	-973.2	-926.0	-1225
55	Molar Enthalpy	(kJ/kgmole)	-2.329e+005	-2.353e+005	-2.378e+005	-2.408e+005	-2.813e+005
56							
57							
58							
59							
ъU 61							
01							
62							
62 63	Aspen Technology In	c.	Aspen H	HYSYS Version 7.3 (25.0.0.7336		Page 5 of 14

1	_			Case Name:	NA COOLED SUB CRIT	TICAL RANKINE CYCLE	MODEL V1.HSC
2 3			ENERGY ALLIANCE	Unit Set:	AFR		
4	aspented	USA USA		Date/Time:	Fri Mar 28 10:00:36 201	4	
5 6				Date/Time.	111110012010.00.00 201	-	
7	W	orkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)	
9				Streams (continu	ed)	Fluid Pkg	g: All
11	Name		46 @TPL1	50 @TPL1	17@TPL1	15 @TPL1	28@TPL1
12	Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
13	Temperature	(C)	108.4	209.6	365.7	215.2	1 14.0
14	Pressure	(MPa)	0.9489	3.479	2.120	2.120	0.1660
15	Molar Flow	(kgmole/h)	1.567e+004	2.008e+004	1066	2341	942.0
16	Mass Flow	(kg/s)	78.43	100.5	5.336	11.72	4.714
17	Std I deal Liq Vol Flow	(m3/h)	282.9	362.5	19.25	42.27	17.00
10	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-1213 -2.787e+005	-1510 -2.707e+005	-68.06 -2.298e+005	-175.8 -2.703e+005	-72.81 -2.783e+005
20	Name	(Korkginole)	36 @TPL1	35 @TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
21	Vapour Fraction		0.9633	0.0000	0.0000		
22	Temperature	(C)	80.22	79.80	40.07		
23	Pressure	(MPa)	4.780e-002	4.780e-002	7.433e-003		
24	Molar Flow	(kgmole/h)	832.1	1827	1.567e+004		
25	Mass Flow	(kg/s)	4.164	9.144	78.43		
26	Std I deal Liq Vol Flow	(m3/h)	15.02	32.99	282.9		
27	Heat Flow	(MVV)	-55.65	-142.6	-1236	25.37	11.85
28	Molar Enthalpy	(kJ/kgmole)	-2.408e+005	-2.809e+005	-2.838e+005		
29	Name		IP Trbn Stg 2 Pwr @T	LP Trb Stg 1 Pwr @TF	Bstr Pmp Pwr @TPL1	LP Trbn Stg 2 Pwr @T	LP Trbn Stg 3 Pwr @
30 31	Vapour Fraction	(0)					
32	Temperature Pressure	(C) (MPa)					
33	Molar Flow	(kgmole/h)					
34	Mass Flow	(kg/s)					
35	Std I deal Liq Vol Flow	(m3/h)					
36	Heat Flow	(MVV)	13.70	14.28	0.3937	10.65	10.28
37	Molar Enthalpy	(kJ/kgmole)					
38	Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated (
39	Vapour Fraction						
40	Temperature	(C)					
41	Pressure	(MPa)					
42	Molar Flow	(kgmole/h)					
43 44	Mass Flow	(kg/s)					
44 45	Std I deal Liq Vol Flow Heat Flow	(m3/h) (MVV)	11.37	13.52	2.335	0.1033	106.8
46	Molar Enthalpy	(MVV) (kJ/kgmole)			2.335		
47	Name	(Cooling Water Out @1	Cooling Water In @TF	Make Up Water @TPL	Total Cooling Tower P	
48	Vapour Fraction		0.0000	0.0000	0.0000		
49	Temperature	(C)	34.96	25.00	20.00		
50	Pressure	(MPa)	0.1015	0.1035	0.1013		
51	Molar Flow	(kgmole/h)	6.631e+005	6.631e+005	1.363e+004		
52	Mass Flow	(kg/s)	3318	3318	68.19		
53	Std I deal Liq Vol Flow	(m3/h)	1.197e+004	1.197e+004	246.0		
04 55	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-5.258e+004 -2.854e+005	-5.272e+004 -2.862e+005	-1080 -2.854e+005	0.6472	
56	motar Entitallyy	(nonginue)	-2.00487000	-2.00287000	-2.00487000		
57							
58							
59							
60							
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63	Aspen Technology I		Aspen H	HYSYS Version 7.3 (25.0.0.7336)		Page 6 of 14
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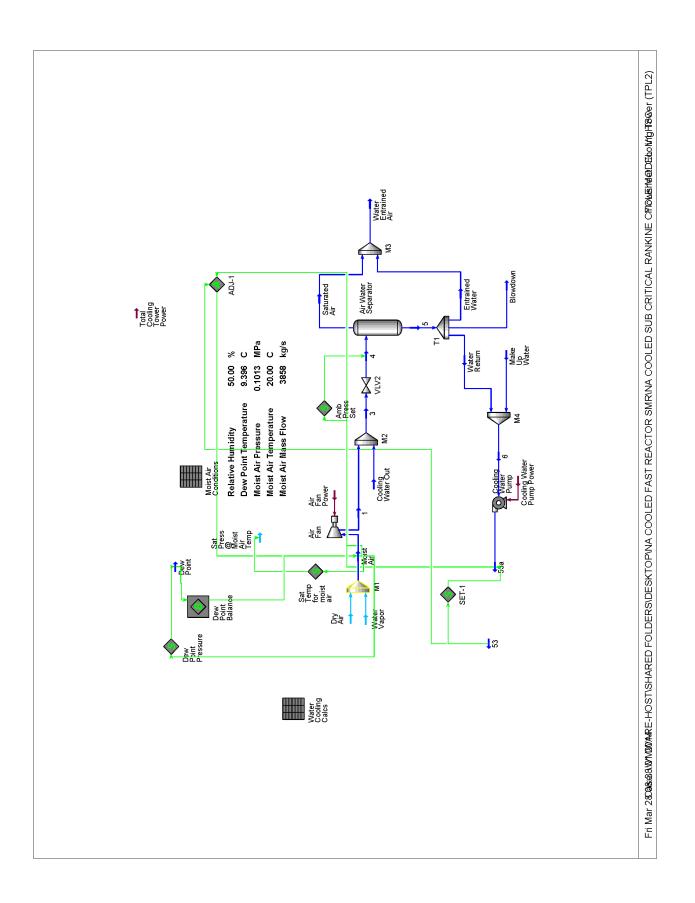
1				Case Name:	NA COOLED SUB CRIT	ICAL RANKINE CYCLE	MODEL V1.HSC
2 3		BATTELLE Burlington,	ENERGY ALLIANCE	Unit Set:	AFR		
4	Caspentech	USA		Date/Time:	Fri Mar 28 10:00:36 201	4	
5 6							
7 8	Work	(book:	Rankine F	Power Cycle	(TPL1) (con	tinued)	
9				Expanders		Fluid Pkg	c All
10	Name		High Pressure Turbin	-	Intermediatte Pressure	Low Pressure Turbine	Low Pressure Turbine
12	Power	(MVV)	25.37	11.85	13.70	14.28	10.65
13	Capacity (act feed vol flow) (A		6648	2.052e+004	2.709e+004	4.032e+004	7.463e+004
14	Feed Pressure	(MPa)	17.00	5.733	3.760	2.120	0.9299
15	Product Pressure	(MPa)	5.850 *	3.760 *	2.120 *	0.9299	0.4380 *
16	Product Temperature	(C)	354.8	445.6	365.7	274.7	202.0
17	Adiabatic Efficiency		85 *	90 *	90 *	80 *	80 *
18	Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
19	Power	(MVV)	10.28	11.37	13.52		
20	Capacity (act feed vol flow) (A	.CT_m3/h)	1.298e+005	2.720e+005	7.634e+005		
21	Feed Pressure	(MPa)	0.4380	0.1660	4.780e-002		
22	Product Pressure	(MPa)	0.1660 *	4.780e-002 *	7.584e-003 *		
23	Product Temperature	(C)	126.4	80.22	40.51		
24	Adiabatic Efficiency		75 *	80 *	80 *		
25				Pumps		Fluid Pkg	c All
26				Fullips		Fiulu Fky	j. Ali
27	Name		Boiler Feed Pump @	Booster Pump @TPL1	Condensate Pump @1		
28	Power	(MVV)	2.335	0.3937	0.1033		
29	Capacity(Actual Vol. Flow)	(m3/h)	445.5	406.2	284.6		
30	Feed Pressure	(MPa)	3.409	0.9299	7.433e-003		
31	Product Pressure	(MPa)	17.70 *	3.550 *	0.9880 *		
32	Product Temperature	(C)	245.6	177.2	40.18		
33	Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		
34 35				Heat Exchange	ſS	Fluid Pkg	r All
36	Name		Feedwater Heater 6 @	a Feedwater Heater 5 @	Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
37	Duty	(MVV)	11.89	14.66	14.48	11.24	11.26
38	Tube Side Feed Mass Flow	(kg/s)	100.5	100.5	100.5	78.43	78.43
39	Shell Side Feed Mass Flow	(kg/s)	6.040	11.72	17.05	4.714	9.144
40	Tube Inlet Temperature	(C)	245.6	209.6	177.2	108.4	74.22
41	Tube Outlet Temperature	(C)	270.4	241.0	209.6	142.0	108.4
42	Shell Inlet Temperature	(C)	354.8	246.7	215.4	202.0	114.4
43	Shell Outlet Temperature	(C)	251.1	215.1	182.7	113.9	79.77
44	LMTD	(C)	15.17	15.61	15.24	17.42	16.65
45	Minimum Approach	(C)	5.556	5.556	5.556	5.556	5.556
46	UA	(kJ/C-h)	2.821e+006	3.382e+006	3.420e+006	2.322e+006	2.436e+006
47	Name		Feedwater Heater 1 @	3 Steam Generator @TF	Reheater @TPL1	Condenser @TPL1	
48	Duty	(MVV)	11.16	213.9	36.79	142.5	
49	Tube Side Feed Mass Flow	(kg/s)	78.43	1012	174.0	3318	
50	Shell Side Feed Mass Flow	(kg/s)	13.31	100.5 *	94.46	65.12	
51	Tube Inlet Temperature	(C)	40.18	530.0	530.0	25.00	
52	Tube Outlet Temperature	(C)		374.9	374.9 *	34.96	
53	Shell Inlet Temperature	(C)	80.22	270.4	354.8	40.51	
54	Shell Outlet Temperature	(C)	45.74	510.0	510.0	38.92	
55	LMTD	(C)	16.02	78.05	22.07	9.555	
56	Minimum Approach	(C)	5.555	20.00	20.00	5.556	
57	UA	(kJ/C-h)	2.509e+006	9.866e+006	6.001e+006	5.369e+007	
58				Unit Ops			
59							
59 60	Operation Name	One	eration Type	Feeds	Products	Innored	Calc Level
60	Operation Name		eration Type	Feeds iteam Generator Out @TF	Products PL1 5@TPL1	Ignored	Calc Level
	Operation Name High Pressure Turbine @TPL	Ope Expander	5	Feeds iteam Generator Out @TF	1	No	Calc Level 500.0 *
60 61	· · · · · · · · · · · · · · · · · · ·		S		PL1 5 @TPL1 HP Trbn Pwr @TPL	No	

1		BATTELLE ENERGY ALLIANCE		Case Name:	NA COOLED SUB CRITICAL RAN	KINE CYCLE MO	DEL V1.HSC		
2 3	aspentech	BATTELLE ENERGY ALLIAN Burlington, MA	0E	Unit Set:	AFR				
4		USA		Date/Time:	Fri Mar 28 10:00:36 2014				
5 6									
7	Work	book: Rankine	e Pov	wer Cycle (TPL1) (continue	d)			
9			Un	it Ops (continue	ed)				
10	Operation Name	Operation Type		Feeds	Products	Ignored	Calc Level		
12	Intermdiate Pressure Turbine	Expander	6@TF	PL1	7 @TPL1	No	500.0 *		
13	Intermediatte Pressure Turbin	Expander	12 @1	FPL1	IP Trbn Stg 1 Pwr @TPL1 13 @TPL1	No	500.0 *		
15 16	Low Pressure Turbine Stage 1	Expander	16 @1	FPL1	IP Trbn Stg 2 Pwr @TPL1 19 @TPL1	No	500.0 *		
17 18	Low Pressure Turbine Stage 2	Expander	23 @1	FPL1	LP Trb Stg 1 Pwr @TPL1 24 @TPL1	No	500.0 *		
19 20			25 @1	TPL1	LP Trbn Stg 2 Pwr @TPL1 29 @TPL1				
21	Low Pressure Turbine Stage 3 Expander				LP Trbn Stg 3 Pwr @TPL1	No	500.0 *		
22 23	Low Pressure Turbine Stage 4	Expander	30 @1	TPL1	31@TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *		
24 25	Low Pressure Turbine Stage 5	Expander	37 @1	TPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *		
26 27	Feedwater Heater 6 @TPL1	Heat Exchanger	52 @1	FPL1 V Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *		
28 29	Feedwater Heater 5 @TPL1	Heat Exchanger	50 @1 11 @1	TPL1	51@TPL1 14@TPL1	No	500.0 *		
30	Feedwater Heater 4 @TPL1	Heat Exchanger	49 @1	TPL1	50 @TPL1	No	500.0 *		
31 32	Feedwater Heater 3 @TPL1	Liest Evekenger	18 @1 46 @1		20@TPL1 47@TPL1	No	500.0 *		
33 34		Heat Exchanger	26 @1 45 @1		27@TPL1 46@TPL1				
35	Feedwater Heater 2 @TPL1	Heat Exchanger	33 @T	FPL1	34 @TPL1	No	500.0 *		
37	Feedwater Heater 1 @TPL1	Heat Exchanger	44 @1 38 @1	TPL1	45@TPL1 39@TPL1	No	500.0 *		
38 39	Steam Generator @TPL1	Heat Exchanger	1 @TF Stearr	PL1 1 Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *		
40 41	Reheater @TPL1	Heat Exchanger	3@TF To Re	PL1 heater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *		
42	Condenser @TPL1	Heat Exchanger	Coolin	g Water In @TPL1	Cooling Water Out @TPL1	No	500.0 *		
43	Boiler Feed Pump @TPL1	Pump	40 @1 51 @1	TPL1	42@TPL1 52@TPL1	No	500.0 *		
45 46	Booster Pump @TPL1	Pump	48 @1		49@TPL1	No	500.0 *		
47 48	. –		Bstr P 43 @1	mp Pwr@TPL1 FPL1	44 @TPL1				
49 50	Condensate Pump @TPL1	Pump	Cnd P 10 @1	mp Pwr @TPL1	11@TPL1	No	500.0 *		
51	M1 @TPL1	Mixer	8@TF	PL1		No	500.0 *		
52 53	M2 @TPL1	Mi×er	17 @1 15 @1	FPL1	18@TPL1	No	500.0 *		
54 55	Deaerating Heater @TPL1	Mixer	47 @1 21 @1		48@TPL1	No	500.0 *		
56 57			22 @1 36 @1	FPL1	38 @TPL1				
58	M4 @TPL1	Mixer	35 @T	FPL1		No	500.0 *		
59 60	M3 @TPL1	Mixer	32 @1 28 @1		33 @TPL1	No	500.0 *		
61 62	M5 @TPL1	Mixer 41@T			43@TPL1	No	500.0 *		
60	2 –			42 @TPL1 10 100 100 100 100 100 100 100 100 10					

1 2			05	Case Name:	NA COOLED SUB CRITICAL R	ANKINE CYCLE MO	DEL V1.HSC
3	(aspentech	BATTELLE ENERGY ALLIAN Burlington, MA	CE	Unit Set:	AFR		
4 5	- aspontoon	USA		Date/Time:	Fri Mar 28 10:00:36 2014		
6			_				
7	Work	book: Rankine	e Pov	wer Cycle ((TPL1) (continu	ied)	
9			1.1m	it Ops (continue			
10	0				,	<u>т</u> т	
11 12	Operation Name	Operation Type	2 @TI	Feeds PL1	Products Sodium Out @TPL1	Ignored	Calc Level
13	M7 @TPL1	Mixer	4@TI			No	500.0 *
14	VLV 3 @TPL1	Valve	20 @		21@TPL1	No	500.0 *
15 16	VLV 4 @TPL1	Valve	27@		28@TPL1 35@TPL1	No	500.0 *
17	VLV 5 @TPL1 VLV 1 @TPL1	Valve Valve	34 @ 9 @ TF		10@TPL1	No	500.0 * 500.0 *
18	VLV 2 @TPL1	Valve	14 @		15@TPL1	No	500.0 *
19	VLV 6 @TPL1	Valve	39 @		41@TPL1	No	500.0 *
20	SG tb dP @TPL1	Set				No	500.0 *
21	SG sh dP @TPL1	Set				No	500.0 *
22	FW6 tb dP @TPL1	Set Set			+	No	<u>500.0 *</u> 500.0 *
23	FW6 sh dP @TPL1 FW4 tb dP @TPL1	Set				No	500.0 *
25	FW5 tb dP @TPL1	Set	L			No	500.0 *
26	FW5 sh dP @TPL1	Set				No	500.0 *
27	FW4 sh dP @TPL1	Set				No	500.0 *
28	Cnd sh dP @TPL1	Set				No	500.0 *
29 30	FW1 tb dP @TPL1	Set Set				No	500.0 * 500.0 *
31	FW1 sh dP @TPL1 FW2 tb dP @TPL1	Set				No	500.0 *
32	FW2 sh dP @TPL1	Set				No	500.0 *
33	FW3 tb dP @TPL1	Set				No	500.0 *
34	FW3 sh dP@TPL1	Set				No	500.0 *
35	Rht tb dP @TPL1	Set				No	500.0 *
36 37	SET-1@TPL1 Cnd Tb dP@TPL1	Set Set				No No	500.0 * 500.0 *
38	SET-3@TPL1	Set				No	500.0 *
39	SET-4@TPL1	Set				No	500.0 *
40	SET-5@TPL1	Set				No	500.0 *
41	SET-6@TPL1	Set				No	500.0 *
42 43	SET-7@TPL1	Set				No	500.0 *
43 44	SET-8@TPL1	Set	5 @ TF	의 1	To FW Heater 6 @TPL1	No	500.0 *
45	T1@TPL1	Тее			To Reheater @TPL1	No	500.0 *
46	T2@TPL1	Тее	7 @ T	PL1	8 @TPL1	No	500.0 *
47	12 W I L I	100			12@TPL1	UN	500.0
48	T3@TPL1	Tee	13 @	TPL1	17@TPL1	No	500.0 *
49 50			19 @	FPI 1	16@TPL1 22@TPL1	+ +	
51	T4 @TPL1	Tee	100		23@TPL1	No	500.0 *
52		Tao	24 @	TPL1	26 @TPL1	Nie	500.0 *
53	T5@TPL1	Тее			25@TPL1	No	500.0
54	T6@TPL1	Tee	29 @	TPL1	32 @TPL1	No	500.0 *
55 56			31 @	FPI 1	30 @TPL1 36 @TPL1	++	
57	T7 @TPL1	Tee	5100	rr wit	37@TPL1	No	500.0 *
58		т	Sodiu	m In @TPL1	3 @TPL1	N	500 0 t
59	T13 @TPL1	Tee			1 @TPL1	No	500.0 *
60	Efficiency Calculations@TPL	Spreadsheet				No	500.0 *
61 62	Cooling Tower @TPL1	Standard Sub-Flowsheet		g Water Out @TPL1 Up Water @TPL1	Cooling Water In @TPL1	No	2500 *
63	Aspen Technology Inc.	Asi		SYS Version 7.3 (2	5.0.0.7336)		Page 9 of 14
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1		PATTCUC		_	Case Name:	NA C	DOLED SUB CRIT	ICAL RAN	KINE CYCLE M	ODEL V1.HSC
3	aspentech Work	Burlington, M	ENERGY ALLIANC 1A	=	Unit Set:	AFR				
4 5		USA			Date/Time:	Fri Ma	ar 28-10:00:36-201	4		
6	Mort	chook	Rankine	Por		а (ТЕ		tinuc	ط) 	
8	VUIN	UUUK.	Rankine	FU		е(1 г		unue	u)	
9 10				Un	it Ops (conti	nued)				
11	Operation Name		ition Type	T 1 1 6	Feeds		Products		Ignored	Calc Level
12 13	Cooling Tower @TPL1	Standard Su	ub-Flowsheet	l otal C	Cooling Tower Pov	ver (2)			No	2500 *
14 15										
16										
17 18										
19										
20 21										
22 23										
23 24 25										
25 26										
27										
28 29										
30										
31 32										
33 34										
35										
36 37										
38 39										
40										
41 42										
42 43										
44 45 46 47										
46										
47 48 49										
49 50										
51										
52 53										
54										
55 56										
57 58										
58 59										
60 61										
62 63	Aspen Technology In-		0		Vo Varian 7	1/05 0 0	7336)			Dogo 40 of 44
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	ALLIANCE	Aspe	ai HYS	SYS Version 7.3	0 (20.0.0	.1330			Page 10 of 14 * Specified by user.

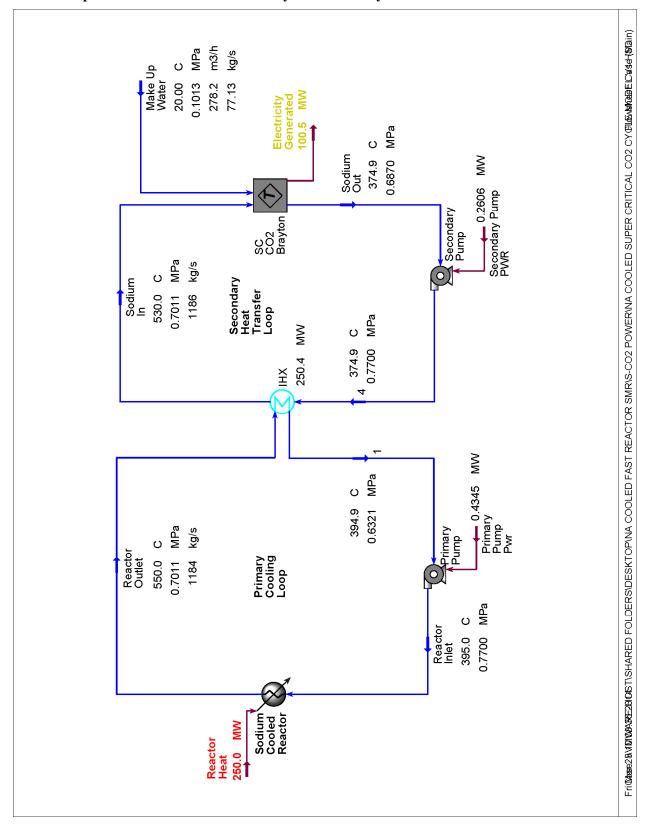
1				Case Name:	NA COOLED SUB C	RITICAL RAN	KINE CYCLE MODEL	V1.HSC					
2		aspentech Burlington, MA	NERGY ALLIANCE	Unit Set:	AFR								
4 5		USA USA		Date/Time:	Fri Mar 28 10:00:36 3	2014							
6													
7 8		Spreadshee	et: Efficienc	y Calcu	lations @TP	L1	Units Set:	NuScale2					
9					ONS								
10 11			Im	ported Var	iables								
12	Ce	Object			Variable Description			/alue					
14	B1	1	Pwr@TPL1 Power				25.37 M						
15	B2		g 1 Pwr @TPL1 Power				11.85 M						
16	B3	Energy Stream: IP Trbn St	g 2 Pwr @TPL1 Power				13.70 M	W					
17	B4	Energy Stream: LP Trb Stg	g 1 Pwr@TPL1 Power				14.28 M	W					
18	BS	Energy Stream: LP Trbn S	tg 2 Pwr @TPL1 Power				10.65 M	W					
19	BB		tg 3 Pwr @TPL1 Power				10.28 M						
20	B7		tg 4 Pwr @TPL1 Power				11.37 M						
21	BE		g 5 Pwr@TPL1 Power				13.52 M						
22	BS		Pwr@TPL1 Power				0.1033 N						
23 24	B1	*/	Pwr@TPL1 Power				0.3937 N						
	D1						2.335 M						
25 26	D2 D3		ump Pwr Power y Pump PWR Power				0.4345 M 0.2606 M						
26	D3		ling Tower Power Power				0.6472 M						
28	D4 D5			2387			250.0 M						
29	Du	Ellergy Stream. Reactor H	•				200.0 14	VV					
30		Exported Variables' Formula Results											
31	Ce	Object			Variable Description			/alue					
32	D7		Power				106.8 M						
33			•										
34				PARAMETI	EKS								
35 36			Exp	oortable Va	riables								
37	Ce	Visible Name		Variable	Description	Variable	Type	/alue					
38	DE		Cycle Therma	I Efficiency of F		Percent	42.74						
39	D7		Power			Power	106.8 M	w					
40	De	D6: Total Turbine Power	Total Tu	urbine Power		Power	111.0 M	w					
41				User Varial	oles								
42 43				FORMUL									
44							1						
45	Ce		F	ormula				Result					
46	De						111.0 M						
47 48	D7	=D6-B9-B10-D1-D2-D3-D4 =D7/D5*100					106.8 M	VV					
40 ∕19	DB	U =U / /Uo" 100					42.74						
50				Spreadsh	eet								
51		А	В		С		D						
52	1	HP Trb Pwr *		25.37 MW*		Pmp Pwr *		2.335 MW*					
53	2	IP Trb Stg 1 Pwr *		11.85 MW *	Primary Pur			0.4345 MW*					
54	3	IP Trb Stg 2 Pwr *		13.70 MW *	Secondary Pur	mp Power *		0.2606 MW*					
55	4	LP Trb Stg 1 Pwr *		14.28 MW *	Cooling Tov			0.6472 MW*					
56	5	LP Trb Stg 2 Pwr *		10.65 MW *		actor Heat *		250.0 MW *					
57	6	LP Trb Stg 3 Pwr *		10.28 MW *	Total Turbi			111.0 MW *					
58	7	LP Trb Stg 4 Pwr *		11.37 MW*	Electricity G	1		106.8 MW*					
59	8	LP Trb Stg 5 Pwr *		13.52 MVV *	Thermal Efficiency of Po	wer Cycle *		42.74 *					
60 61	9	Cnd Pmp Pwr *		0.1033 MVV *				<empty> *</empty>					
62	10	Bstr Pmp Pwr *		0.3937 MVV *				<empty> *</empty>					
63	Asp	en Technology Inc	Aspen HYS	YS Version 7	7.3 (25.0.0.7336)		Pa	ae 11 of 14					
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1				Case Name:	NA COOLED SUB CRIT	TICAL RANKINE CYCLE	MODEL V1.HSC
3	aspentech	BATTELLE Burlington,	E ENERGY ALLIANCE , MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 10:00:36 201	4	
6							
7	Wor	kbook:	Cooling To	ower (TPL2))		
9				Material Stream	15	Fluid Pkg	; All
11	Name		Cooling Water Out @1	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
12	Vapour Fraction		0.0000	0.0000			1.0000
13	Temperature	(C)	34.96	25.00 *			20.00 *
14	Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
15	Molar Flow	(kgmole/h)	6.631e+005	6.631e+005	4.779e+005	5561	4.835e+005
16	Mass Flow	(kg/s)	3318	3318	3830	27.83	3858 *
17	Liquid Volume Flow	(m3/h)	1.197e+004	1.197e+004	1.594e+004	100.4	1.604e+004
18	Heat Flow	(M <i>VV</i>)	-5.258e+004	-5.272e+004			-394.4
19	Name		Sat Press@ Moist Air	1@TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
20 21	Vapour Fraction		1.0000 * 20.00	1.0000	0.4303	1.0000 *	0.4303
21	Temperature	(C) (MDo)		20.16	25.11 0.1015	9.396	25.11
12	Pressure Malas Elau	(MPa)	2.339e-003		1.147e+006	0.1013	0.1013 1.147e+006
23	Molar Flow Mass Flow	(kgmole/h)		4.835e+005 3858	7176	4.835e+005 3858	7176
24	Liquid Volume Flow	(kg/s) (m3/h)		1.604e+004	2.801e+004	1.604e+004	2.801e+004
26	Heat Flow	(MVV)		-393.7	-5.297e+004	-436.0	-5.297e+004
27	Name	(101 + 4)	Saturated Air @TPL2	5@TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
28	Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
29	Temperature	(C)	25.11	25.11	25.11	25.11	25.11
30	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
31	Molar Flow	(kgmole/h)	4.934e+005	6.533e+005	663.1	3088	6.495e+005
32	Mass Flow	(kg/s)	3907	3269	3.318	15.45	3250
33	Liquid Volume Flow	(m3/h)	1.622e+004	1.179e+004	11.97	55.74	1.172e+004
34	Heat Flow	(MVV)	-1038	-5.194e+004	-52.72	-245.5	-5.164e+004
35	Name		Water Entrained Air @	Make Up Water @TPl	6 @TPL2	53a @TPL2	
36	Vapour Fraction		0.9987	0.0000	0.0000	0.0000	
37	Temperature	(C)	25.10	20.00 *	25.00	25.00	
38	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1035	
39	Molar Flow	(kgmole/h)	4.940e+005	1.363e+004	6.631e+005	6.631e+005	
40	Mass Flow	(kg/s)	3911	68.19	3318	3318	
41	Liquid Volume Flow	(m3/h)	1.623e+004	246.0	1.197e+004	1.197e+004	
42	Heat Flow	(MVV)	-1091	-1085	-5.272e+004	-5.272e+004	
43 44				Compositions	;	Fluid Pkg	e All
45	Name		Cooling Water Out @	53@TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
46	Comp Mole Frac (H2O)		1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115
47	Comp Mole Frac (Nitrogen)		0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
48	Comp Mole Frac (Oxygen)		0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
49	Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	* 0.0000	0.0000
50	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000 *	* 0.0000 *	0.0000
51	Comp Mole Frac (CO)		0.0000	0.0000 *	0.0000 *	* 0.0000 *	0.0000
52	Comp Mole Frac (Sodium)		***	***	***	***	***
53	Comp Mole Frac (Air)		0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
54	Name		Sat Press@ Moist Air	1@TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
55	Comp Mole Frac (H2O)		1.0000 *	0.0115	0.5832	0.0115	0.5832
56 57	Comp Mole Frac (Nitrogen)		***	0.7809	0.3293	0.7809	0.3293
57	Comp Mole Frac (Oxygen)	<u>,</u>	***	0.2076	0.0875	0.2076	0.0875
58 59	Comp Mole Frac (Hydrogen)	***	0.0000	0.0000	0.0000	0.0000
59 60	Comp Mole Frac (CO2) Comp Mole Frac (CO)		***	0.0000	0.0000 0.0000	0.0000	0.0000
61	Comp Mole Frac (CO) Comp Mole Frac (Sodium)		***	U.UUUU	0.0000		***
62	Comp Mole Frac (Sodium)		***	0.0000	0.0000	0.0000	0.0000
63	Aspen Technology Inc.			IYSYS Version 7.3 (0.000	Page 12 of 14
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1					Case Name:	NA COOLED SUB CRIT	TICAL RAN	KINE CYCLE	MODEL V1.HSC
3		BATTELLE Burlington,	ENERGY ALLIANCE MA		Unit Set:	AFR			
4	aspentech	USA			Date/Time:	Fri Mar 28 10:00:36 201	4		
5 6					Bato, Hinto.	11111111120 10:00:00 201			
7 8	Work	book:	Cooling	Towe	er (TPL2)	(continued)		
9				Compositions (continued)				Fluid Pk	a: All
10 11	Name		Saturated Air @TPL		TPL2	Entrained Water @TP	Blowdow	m@TPL2	Water Return @TPL2
12	Comp Mole Frac (H2O)		0.0313	- <u>i</u>	1.0000	1.0000	Dioridori	1.0000	1.0000
13	Comp Mole Frac (Nitrogen)		0.7653		0.0000	0.0000		0.0000	0.0000
14	Comp Mole Frac (Oxygen)		0.2034	1	0.0000	0.0000		0.0000	0.0000
15	Comp Mole Frac (Hydrogen)		0.0000)	0.0000	0.0000		0.0000	0.0000
16	Comp Mole Frac (CO2)		0.000)	0.0000	0.0000		0.0000	0.0000
17	Comp Mole Frac (CO)		0.0000		0.0000	0.0000		0.0000	0.0000
18	Comp Mole Frac (Sodium)		***		***	***		***	***
19	Comp Mole Frac (Air)		0.0000		0.0000	0.0000	50 OT	0.0000	0.0000
20	Name Comp Mole Frac (H2O)		Water Entrained Air 0.0326		e Up Water @TPL 1.0000 *	6 @TPL2 1.0000	53a @TF	1.0000	
21			0.7643		0.0000 *	0.0000		0.0000	
22	Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		0.2032		0.0000 *	0.0000		0.0000	
24	Comp Mole Frac (Oxygen)		0.0000		0.0000 *	0.0000		0.0000	
25	Comp Mole Frac (CO2)		0.0000		0.0000 *	0.0000		0.0000	
26	Comp Mole Frac (CO)		0.0000		0.0000 *	0.0000		0.0000	
27	Comp Mole Frac (Sodium)		***		***	***		***	
28	Comp Mole Frac (Air)		0.0000)	0.0000 *	0.0000		0.0000	
29	· · · · ·					_			
30				E	nergy Streams	6		Fluid Pk	g: All
31	Name		Air Fan Power @TF	PL2 Coo	ling Water Pump F	Total Cooling Tower P			
32	Heat Flow	(MVV)	0.6376	6	9.565e-003	0.6472			
33 34					Unit Ops				
35	Operation Name	Ope	ration Type		Feeds	Products		Ignored	Calc Level
36	M1 @TPL2	Mixer		Dry Air @	-	Moist Air @TPL2		No	500.0 *
37	0				apor @TPL2				
38	M2 @TPL2	Mixer		1@TPL		3 @TPL2		No	500.0 *
39 40					Water Out @TPL2 d Air @TPL2	Water Entrained Air			
40	M3 @TPL2	Mi×er			d Water @TPL2	water Entraineu Ali	@IFL2	No	500.0 *
42					eturn @TPL2	6 @TPL2			
43	M4 @TPL2	Mi≍er			Water @TPL2	000.022		No	500.0 *
44	Moist Air Conditions @TPL2	Spreadshe	eet		~~~~			No	500.0 *
45	Water Cooling Calcs @TPL2	Spreadshe	et					No	500.0 *
46	Sat Temp for moist air @TPL2	Set						No	500.0 *
47	Dew Point Pressure @TPL2	Set						No	500.0 *
48	Amb Press Set @TPL2	Set						No	500.0 *
49	SET-1@TPL2	Set						No	500.0 *
50 51	Air Fan @TPL2	Compress	or	Moist Air Air Fan F	°@TPL2 Power@TPL2	1 @TPL2		No	500.0 *
52	VLV2 @TPL2	Valve		3@TPL	2	4 @TPL2		No	500.0 *
53									
54									
55									
56			-						
57			-						
58 59									
59 60									
61			I						
62		L				1			1
63	Aspen Technology Inc.		Aspe	n HYSY	S Version 7.3 (2	25.0.0.7336			Page 13 of 14
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1				Case Name:	NA COOLED SUB C	RITICAL RANKINE CY	DLE MODEL V1.HSC					
2			IERGY ALLIANCE	Unit Set:	AFR							
4	0	aspentech ^{Burlington, MA} USA		Date/Time:	Fri Mar 28 10:00:36 3	2014						
5 6				Date/Time.	FILMAL 20 10:00:30 .	2014						
7		Spreadshee	et: Water C	ooling C	alcs @TPL2		Units Set: NGNP1					
8 9		-		•								
9 10				CONNECTIO	DNS							
11			I	mported Vari	ables							
13	Cell	Object		-	Variable Description		Value					
14	B1	Material Stream: Cooling W	ater Out @TPL: Mass	Flow			3318 kg/s					
15	B5	Material Stream: Moist Air @	·	al Volume Flow			3228 m3/s					
16	B3	Material Stream: Saturated		er Comp Mass Flo	w (H2O)		77.2562 kg/s 3250 kg/s					
17	17 B7 Material Stream: Water Return @TPL2 Mass Flow											
18	D1	Energy Stream: Cooling W	ater Pump Powe	r			9.565 kW					
20	ອ ແຮະການເປັນ Exported Variables' Formula Results											
21	Cell	Object			Variable Description		Value					
22	B2	Entrained Water @TPL2	Mass	Flow			3.318 kg/s					
23	B6	Air Fan Power @TPL2	Powe	r			637.6 kW					
24	B4	Blowdown @TPL2		Flow			15.45 kg/s					
25	B8	Make Up Water @TPL2		Flow			68.19 kg/s					
26	D2	Total Cooling Tower Power @TPL	2 Powe	r			647.2 kW					
28				PARAMETE	RS							
29												
30			E	xportable Var	riables							
31	Cell	Visible Name		Variable D	Description	Variable Type	Value					
32	B9	B9:					<empty></empty>					
33	B8	B8: Mass Flow		Flow		Mass Flow	68.19 kg/s					
34	B4 B6	B4: Mass Flow B6: Power	Powe	Flow		Mass Flow Power	15.45 kg/s					
36	B0 B2	B2: Mass Flow		: Flow		Mass Flow	637.6 kW 3.318 kg/s					
37	D7	D7:	111033	11000			<empty></empty>					
38	D2	D2: Power	Powe	r		Power	647.2 kW					
39				User Variab	les							
40 41												
42				FORMULA	IS							
43	Cell			Formula			Result					
44	B2	=.001*B1					3.318 kg/s					
45	B4	=.20*B3					15.45 kg/s					
46	B6	=B5/5.063					637.6 kW					
47	B8 D2	=B1-B7 =(D1+B6)					68.19 kg/s 647.2 kW					
49	02	-(51-56)		On man dalar	4		041.2 ((4)					
50				Spreadshe								
51		A	В		<u> </u>		D					
52 53	1	Cooling Water Mass Flow *		3318 kg/s *	Cooling Water Pur		9.565 KW * 647.2 KW *					
54	2	Entrained Water Mass Flow * Evaporated Water Mass Flow *		3.318 kg/s * 77.2562 kg/s *	Total Cooling Tov	VEL 1- UWEL	047.2 KVV					
55	4	Blowdown Mass Flow *		15.45 kg/s *								
56	5	Moist Air Volume Flow *		3228 m3/s *								
57	6	Fan Power*		637.6 kW *								
58	7	Water Return Flow *		3250 kg/s *			<empty> *</empty>					
59	8	Make Up Water Flow *		68.19 kg/s *								
60	9			<empty> *</empty>								
61	10			<empty> *</empty>								
63	Asne	n Technology Inc.	Asnen HV	SYS Version 7	.3 (25.0.0.7336)		Page 14 of 14					
		to: BATTELLE ENERGY ALLIANCE					* Specified by user.					

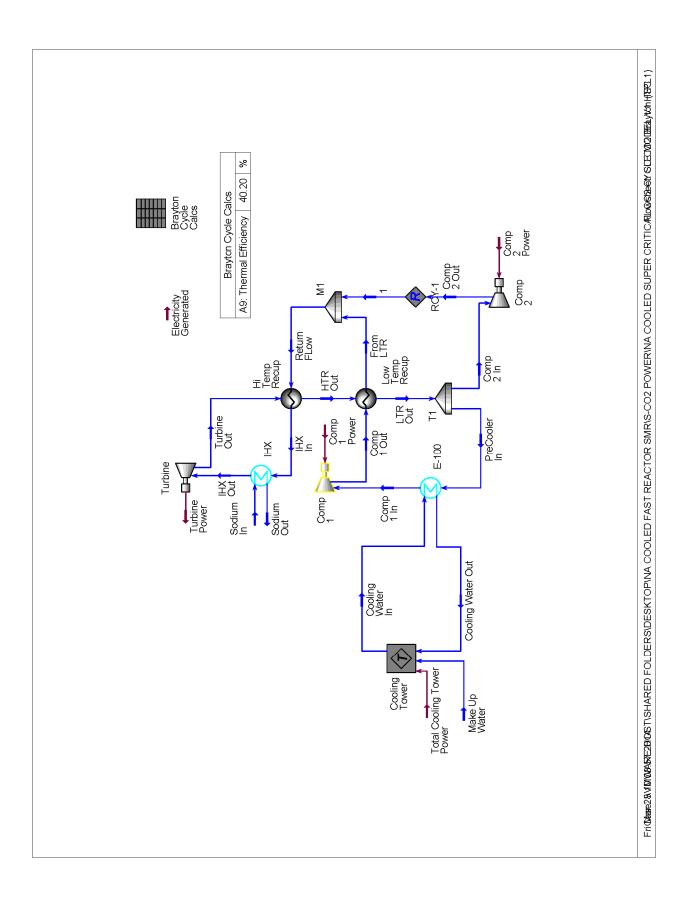


6.3 Supercritical CO₂ Modified Brayton Power Cycle Model

1					Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC						
2 3			ENERGY ALLIANC	e -	Unit Set AFR						
3	aspentech	Burlington, USA	ма	-	Unit Set:	AFR					
5					Date/Time: Fri Mar 28 11:05:37 2014						
6	Mork	(hook)	Case (Ma	ain)							
8	VVOIR	VDOOK.	Case (IVIA	anny							
9				M	aterial Stream	s		Fluid Pkg:	All		
10	Name		Sodium In	4		Reactor Outlet	Reactor Ini		1		
12	Vapour Fraction		0.000		0.0000	0.0000	Reactor III	0.0000	0.0000		
13	Temperature	(C)	530.		374.9	550.0 *		395.0	394.9 *		
14	Pressure	(MPa)	0.701	1	0.7700 *	0.7011		0.7700 *	0.6321		
15		(kgmole/h)	1.857e+00		1.857e+005	1.854e+005	1.8	854e+005	1.854e+005		
16	Mass Flow	(kg/s)	118		1186	1184		1184	1184		
17 18	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	454 818.		4544 568.3	4537 849.9		4537 599.9	4537 599.5		
19	Name	(111 / 11)	Sodium Out		e Up Water	043.3		000.0	000.0		
20	Vapour Fraction		0.000		0.0000						
21	Temperature	(C)	374.	9	20.00						
22	Pressure	(MPa)	0.687	0	0.1013						
23		(kgmole/h)	1.857e+00		1.541e+004						
24	Mass Flow	(kg/s)	118		77.13						
25	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	454 568.		278.2 -1222						
27	Treat 11600	(111.1.1)	555.								
28					Compositions	i		Fluid Pkg:	All		
29	Name		Sodium In	4		Reactor Outlet	Reactor In	let	1		
30	Comp Mole Frac (H2O)		**		***	***		***	***		
31	Comp Mole Frac (Nitrogen)		**		***	***		***	***		
32	Comp Mole Frac (Oxygen)		**		***	***		***	***		
33 34	Comp Mole Frac (Hydrogen)		**		***	***		***	***		
35	Comp Mole Frac (CO2) Comp Mole Frac (CO)		**		***	***		***	***		
36	Comp Mole Frac (Sodium)		1.000		1.0000 *	1.0000		1.0000 *	1.0000		
37	Comp Mole Frac (Air)		*7		***	***		***	***		
38	Name		Sodium Out	Mał	ke Up Water						
39	Comp Mole Frac (H2O)		*7		1.0000						
40	Comp Mole Frac (Nitrogen)		**		***						
41 42	Comp Mole Frac (Oxygen)		**		***						
42	Comp Mole Frac (Hydrogen) Comp Mole Frac (CO2)		**		***						
44	Comp Mole Frac (CO)		**	**	***						
45	Comp Mole Frac (Sodium)		1.000	0	***						
46	Comp Mole Frac (Air)		*7	**	***						
47 48				E	nergy Stream	s		Fluid Pkg:	All		
48	Name		Reactor Heat	Eler	ctricity Generated	Primary Pump Pwr	Secondary	Pump PWF			
50	Heat Flow	(MVV)	250.	1	100.5	0.4345	Secondary	0.2606			
51											
52			<u> </u>		Unit Ops						
53	Operation Name	Ope	ration Type		Feeds	Products		Ignored	Calc Level		
54	Sodium Cooled Reactor	Heater	-	Reactor		Reactor Outlet		No	500.0 *		
55			Reactor Sodium		Sodium Out						
57	SC CO2 Brayton Standard Sub-Flowsheet		Make U		Electricity Generate	d	No	2500 *			
58	Efficiency Calcs	Spreadsh	eet					No	500.0 *		
59	IHX	Heat Exch		Reactor	Outlet	1		No	500.0 *		
60	11.123		iongei	4		Sodium In		140	500.0		
61	Primary Pump	Pump	-	1 Deine en e	Durana Du	Reactor Inlet		No	500.0 *		
62	Aspen Technology Inc.	<u> </u>	Acres		Pump Pwr 'S Version 7.3 ()	25.0.0.7336			Page 1 of 9		
00	Licensed to: BATTELLE ENERGY	ALLIANCE	ASPE	<u> 1113</u>	<u>o version 1.3 (</u> ,	20.0.0.1000			* Specified by user.		

1		BATTELLE ENERGY ALLIAN	Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC					
3	aspentech	Burlington, MA		Unit Set: A	FR			
4 5		USA		Date/Time: Fi				
6 7	Mor	kbook: Case (M	lain)	(continued)			
8	**011		anny	(continued)			
9 10	Unit Ops (continued)							
11 12	Operation Name	Operation Type	Sodiur	Feeds m Out	Products 4	Ignored	Calc Level	
13 14	Secondary Pump	Pump		dary Pump PWR		No	500.0 *	
15								
16 17								
18								
19 20								
21 22								
23								
24 25								
26 27								
28								
29 30								
31								
32 33								
34 35								
36								
37 38								
39 40								
41								
42 43								
44								
45 46								
43 44 45 46 47								
49								
50 51								
52								
53 54								
55								
56 57								
58 59								
60								
61 62								
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	Asp ALLIANCE	en HYS	YS Version 7.3 (25	.0.0.7336)	*	Page 2 of 9 Specified by user.	

1				Case Name	NA COOLED SUPER	R CRITICAL C		MODEL VI HSC	
2			ERGY ALLIANCE				.02 01 0221		
3	Ce	spentech Burlington, MA		Unit Set:	AFR				
4 5		• • • • • •		Date/Time:	Fri Mar 28 11:05:37	28 11:05:37 2014			
6									
7		Spreadshee	t: Efficien	icy Calcs	5		U	Inits Set: NuScale1	
8 9		-		-					
9 10				CONNECT	IONS				
11				Imported Va	riablea				
12									
13	Cell	Object		. 51	Variable Description			Value	
14	A1 A4	Energy Stream: Reactor He Energy Stream: Electricity G		t Flow er				250.0 MVV 100.5 MVV	
16		Energy Stream. Electricity e						100.0 10 10	
17			Exported	I Variables' F	ormula Results				
18	Cell	Object			Variable Description			Value	
19 20				PARAMET	ERS				
20			_						
22			E	Exportable V	ariables				
23	Cell	Visible Name		Variable	Description	Variabl	е Туре	Value	
24	A2	A2:		No Basili - O - I				<empty></empty>	
25 26	A3	A3: Heat to Rankine Cycle		t to Rankine Cycle				<empty></empty>	
26	A5 A6	A5: Power Cycle Efficiency A6: Reactor Heat to HTSE		er Cycle Efficienc ctor Heat to HTSE		Percent		<empty> <empty></empty></empty>	
28	B1	B1:	i tea	ctor near to more	-	Mass Flow		<empty></empty>	
29	B2	B2:				Mass Heat		<empty></empty>	
30	B3	B3: Hydrogen Production Efficiency	· Hydi	rogen Production	Efficiency	Percent		<empty></empty>	
31	C1	C1:				Molar Enth	alpy	<empty></empty>	
32	C2	C2:				Molar Enth	alpy	<empty></empty>	
33	C3	C3:			r	<empty></empty>			
34 35	C4	C4:				<empty></empty>			
36				User Varia	bles				
37				FORMUL	AC				
38		1			AJ				
39 40	Cell			Formula				Result	
40	A3 A5	=A1*A2 =A4/A3*100						<empty> <empty></empty></empty>	
42	A6	=A1-A3						<empty></empty>	
43	B3	=(B1*B2/1000)/A1*100						<empty></empty>	
44	C4	=C3*(C2-C1)/3600000				<empty></empty>			
45 46				Spreadsh	eet				
46		A	В	-	с			D	
48	1	250.0 MW *		<empty> *</empty>		<empty> *</empty>		_	
49	2	<empty> *</empty>		<empty> *</empty>		<empty> *</empty>			
50	3	<empty> *</empty>		<empty> *</empty>		<empty> *</empty>			
51	4	100.5 MVV *				<empty> *</empty>			
52	5	<empty> *</empty>							
53 54	6 7	<empty> *</empty>							
55	8								
56	9								
57	10								
58 59									
59									
60									
61 62									
63	Aspen	Technology Inc.	Aspen H	YSYS Version	7.3 (25.0.0.7336)			Page 3 of 9	
		: BATTELLE ENERGY ALLIANCE						* Specified by user.	

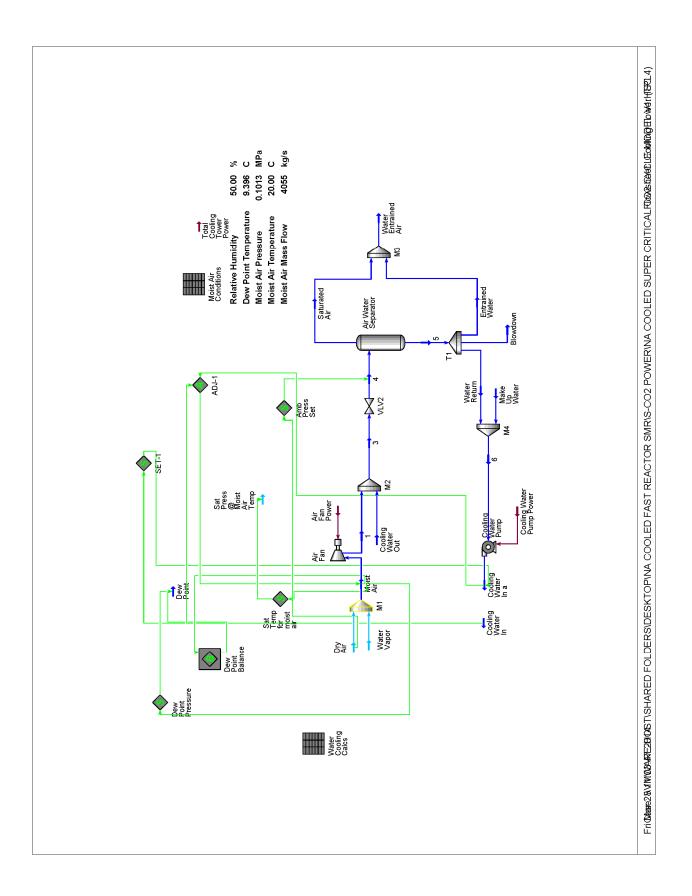


1	_			Case Name:	Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC					
2		BATTELLE Burlington,	ENERGY ALLIANCE	Unit Set:	AFR					
4	aspentech	USA .		Date/Time:	Fri Mar 28 11:05:37 201	4				
5 6				Date/Time. Fit Mar 20 11.00.37 2014						
7	Wor	kbook:	SC CO2 B	rayton (TPL	1)					
8										
9 10				Material Stream	s	Fluid Pk	g: All			
11	Name		Sodium In @TPL1	Sodium Out @TPL1	IHX Out @TPL1	IHX In @TPL1	Turbine Out@TPL1			
12	Vapour Fraction		0.0000	0.0000	1.0000	1.0000	1.0000			
13	Temperature	(C)	530.0	374.9	510.0	354.9	403.8			
14	Pressure	(MPa)	0.7011	0.6870	19.60	20.00	7.866 *			
15	Molar Flow Mass Flow	(kgmole/h)	1.857e+005	1.857e+005	1.075e+005	1.075e+005	1.075e+005			
10	Liquid Volume Flow	(kg/s) (m3/h)	1186 4544	1186 4544	1314 5733	1314 5733	1314 5733			
18	Heat Flow	(MVV)	818.8	568.1	-1.114e+004	-1.139e+004	-1.128e+004			
19	Name	(HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1			
20	Vapour Fraction		1.0000	1.0000	1.0000	0.0000	0.0000			
21	Temperature	(C)	139.3	133.7	74.30	30.56	68.74			
22	Pressure	(MPa)	7.709	20.41	7.555	7.404	20.83			
23	Molar Flow	(kgmole/h)	1.075e+005	1.075e+005	1.075e+005	7.464e+004	7.464e+004			
24	Mass Flow	(kg/s)	1314	1314	1314	912.5	912.5			
25	Liquid Volume Flow	(m3/h)	5733	5733	5733	3980	3980			
26 27	Heat Flow Name	(MVV)	-1.168e+004	-1.178e+004 PreCooler In @TPL1	-1.179e+004 Comp 2 In @TPL1	-8334 Comp 2 Out @TPL1	-8311			
28	Vapour Fraction		From LTR @TPL1 1.0000	1.0000	Comp 2 in @TPL1 1.0000	1.0000	1 @TPL1 1.0000			
29	Temperature	(C)	120.2	74.30	74.30	168.4	168.4 *			
30	Pressure	(MPa)	20.41	7.555	7.555	20.41 *	20.41 *			
31	Molar Flow	(kgmole/h)	7.464e+004	7.464e+004	3.287e+004	3.287e+004	3.287e+004 *			
32	Mass Flow	(kg/s)	912.5	912.5	401.9	401.9	401.9			
33	Liquid Volume Flow	(m3/h)	3980	3980	1753	1753	1753			
34	Heat Flow	(MVV)	-8202	-8185	-3605	-3580	-3580			
35	Name		Cooling Water Out @1	Cooling Water In @TF	Make Up Water @TPL					
36	Vapour Fraction	(0)	0.0000	0.0000	0.0000					
37 38	Temperature	(C) (MPa)	28.70	25.00 *	20.00					
39	Pressure Molar Flow	(MPa) (kgmole/h)	0.1015 1.866e+006	0.1035 1.866e+006	0.1013 1.541e+004					
40	Mass Flow	(kg/s)	9339	9339	77.13					
41	Liquid Volume Flow	(m3/h)	3.369e+004	3.369e+004	278.2					
42	Heat Flow	(MVV)	-1.482e+005	-1.484e+005	-1227					
43				Compositions		Fluid Pk	q: All			
44 45	Name		Sodium In @TPL1	Sodium Out @TPL1	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1			
46	Comp Mole Frac (H2O)		30010111111@TFL1	30010111 Out @1FE1	#**	1HA III @ IFLI				
47	Comp Mole Frac (Nitrogen)		***	***	***	***	***			
48	Comp Mole Frac (Oxygen)		***	***	***	***	***			
49	Comp Mole Frac (Hydrogen))	***	***	***	***	***			
50	Comp Mole Frac (CO2)		***	***	1.0000 *	1.0000	1.0000			
51	Comp Mole Frac (CO)		***	***	***	***	***			
52	Comp Mole Frac (Sodium)		1.0000	1.0000	***	***	***			
53	Comp Mole Frac (Air)			###		Comp 1 In @TDI 1	***			
54 55	Name Comp Mole Frac (H2O)		HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1			
56	Comp Mole Frac (Nitrogen)		***	***	***	***	***			
57	Comp Mole Frac (Oxygen)		***	***	***	***	***			
58	Comp Mole Frac (Hydrogen))	***	***	***	***	***			
59	Comp Mole Frac (CO2)		1.0000	1.0000	1.0000	1.0000	1.0000			
60	Comp Mole Frac (CO)		***	***	***	***	***			
61	Comp Mole Frac (Sodium)		***	***	***	***	***			
62	Comp Mole Frac (Air)		***	***	***	***	***			
63	Aspen Technology Inc. Licensed to: BATTELLE ENERG		Aspen H	HYSYS Version 7.3 (2	25.0.0.7336		* Specified by user.			
	SCORE D. DATIELLE ENERG						арсспса ву цэст.			

1 0	\sim			Case Name:	Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC					
2	aspentech	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR					
4		USA		Date/Time:	Fri Mar 28 11:05:37 201	4				
6										
7 8	Worl	kbook:	SC CO2 I	Brayton (TPL	ton (TPL1) (continued)					
9				Compositions (cont	inued)	Fluid Pk	q: All			
10 11	Name		From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1.@TPL1			
12	Comp Mole Frac (H2O)		***		***	***	***			
13	Comp Mole Frac (Nitrogen)		***	***	***	***	***			
14	Comp Mole Frac (Oxygen)		***	***	***	***	***			
15	Comp Mole Frac (Hydrogen)		**7	***	***	***	***			
16	Comp Mole Frac (CO2)		1.0000		1.0000	1.0000	1.0000 *			
17	Comp Mole Frac (CO)		**7		***	***	***			
18	Comp Mole Frac (Sodium)		***		***	***	***			
19 20	Comp Mole Frac (Air)					008	800			
20	Name Comp Mole Frac (H2O)		Cooling Water Out (1.0000		Make Up Water @TPL 1.0000					
22	Comp Mole Frac (Nitrogen)		0.0000		0.0000					
23	Comp Mole Frac (Oxygen)		0.0000		0.0000					
24	Comp Mole Frac (Hydrogen)		0.0000		0.0000					
25	Comp Mole Frac (CO2)		0.0000		0.0000					
26	Comp Mole Frac (CO)		0.0000		0.0000					
27	Comp Mole Frac (Sodium)		***	***	***					
28	Comp Mole Frac (Air)		***	***	***					
29				Energy Stream	•	Fluid Pk	a: All			
30				Energy Stream	5		y. Ali			
31	Name		Turbine Power @TF		Comp 2 Power @TPL	Electricity Generated (Total Cooling Tower P			
32	Heat Flow	(MVV)	149.8	22.86	25.06	100.5	0.6971			
33 34				Unit Ops						
35	Operation Name	Оре	ration Type	Feeds	Products	Ignored	Calc Level			
36										
37		Lines Duals	L	Sodium In @TPL1	Sodium Out @TPL	1	C00.0.*			
31	IHX @TPL1	Heat Exch	langer	Sodium In @TPL1 IHX In @TPL1	IHX Out @TPL1	1 No	500.0 *			
38			-			No				
_	IHX @TPL1 Hi Temp Recup @TPL1	Heat Exch Heat Exch	-	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1	1No	500.0 *			
38 39 40	Hi Temp Recup @TPL1	Heat Exch	anger –	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1	No				
38 39 40 41			anger –	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1	No No	500.0 *			
38 39 40 41 42	Hi Temp Recup @TPL1	Heat Exch	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No	500.0 *			
38 39 40 41 42 43	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1	Heat Exch Heat Exch Heat Exch	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1	No No QTPL1 No	500.0 * 500.0 * 500.0 *			
38 39 40 41 42	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1	Heat Exch Heat Exch Heat Exch Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No QTPL1 No No	500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	@TPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1	Heat Exch Heat Exch Heat Exch Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No QTPL1 No No	500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	@TPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX tb dP @TPL1 HTR tb dP @TPL1 HTR tb dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No QTPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set Set Set Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No @TPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set Set Set Set Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No Ro @TPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR sh dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1 LTR tb dP @TPL1 Pre Cooler tb dP @TPL1	Heat Exch Heat Exch Heat Exch Set Set Set Set Set Set Set Set	nanger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out	No No QTPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1 Pre Cooler tb dP @TPL1 Pre Cooler sh dP @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out. Comp 1 In @TPL1	No No QTPL1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1 LTR tb dP @TPL1 Pre Cooler tb dP @TPL1 SET-1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1 PreCooler In @TPL1 IHX Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out. Comp 1 In @TPL1	No No QTPL1 No PL1	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR th dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1 LTR tb dP @TPL1 Pre Cooler th dP @TPL1 SET-1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1 PreCooler In @TPL1 INX Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out. Comp 1 In @TPL1	No No QTPL1 No PL1	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX th dP @TPL1 IHX th dP @TPL1 HTR th dP @TPL1 LTR th dP @TPL1 LTR th dP @TPL1 Pre Cooler th dP @TPL1 Pre Cooler th dP @TPL1 SET-1 @TPL1 Turbine @TPL1 M1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1 PreCooler In @TPL1 IHX Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out Comp 1 in @TPL1 Cooling Water Out Comp 1 in @TPL1 Turbine Out @TPL Turbine Out @TPL Turbine Power @TPL Return FLow @TPL	No No QTPL1 No PL1 1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR sh dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1 Pre Cooler tb dP @TPL1 Pre Cooler sh dP @TPL1 SET-1 @TPL1 Turbine @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1 PreCooler In @TPL1 INX Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out: Comp 1 In @TPL1 Cooling Water Out: Comp 1 In @TPL1 Turbine Out @TPL Turbine Out @TPL Turbine Power @TPL Turbine Power @TPL Return FLow @TPL Pre Cooler In @TPL	No No QTPL1 No PL1 1 No	500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 HTR th dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1 Pre Cooler tb dP @TPL1 Pre Cooler sh dP @TPL1 SET-1 @TPL1 Turbine @TPL1 M1 @TPL1 T1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	ianger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 PreCooler In @TPL1 PreCooler In @TPL1 IHX Out @TPL1 From LTR @TPL1 LTR Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 LTR Out @TPL1 Cooling Water Out Comp 1 in @TPL1 Cooling Water Out Comp 1 in @TPL1 Turbine Out @TPL Turbine Out @TPL Turbine Power @TPL Return FLow @TPL	No No QTPL1 No 1 No 1 No 1 No 1 No	500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX th dP @TPL1 IHX th dP @TPL1 HTR th dP @TPL1 LTR th dP @TPL1 LTR th dP @TPL1 Pre Cooler th dP @TPL1 Pre Cooler th dP @TPL1 SET-1 @TPL1 Turbine @TPL1 M1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	ianger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 Cooling Water In @TPL1 PreCooler In @TPL1 IHX Out @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out Comp 1 In @TPL1 Cooling Water Out Comp 1 In @TPL1 Turbine Out @TPL Turbine Power @TPL Turbine Power @TPL PreCooler In @TPL1 Comp 2 In @TPL1	No No QTPL1 No 1 1 No .1 No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 HTR th dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1 Pre Cooler tb dP @TPL1 Pre Cooler sh dP @TPL1 SET-1 @TPL1 Turbine @TPL1 M1 @TPL1 T1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	ianger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 PreCooler In @TPL1 PreCooler In @TPL1 IHX Out @TPL1 From LTR @TPL1 1 @TPL1 LTR Out @TPL1 Comp 1 In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out Comp 1 In @TPL1 Cooling Water Out Comp 1 In @TPL1 Untrine Power @T Turbine Out @TPL Turbine Power @T Return FLow @TPL PreCooler In @TPL1 Comp 2 In @TPL1	No No QTPL1 No 1 No 1 No 1 No 1 No	500.0 * 500.0 *			
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Hi Temp Recup @TPL1 Low Temp Recup @TPL1 E-100 @TPL1 IHX tb dP @TPL1 IHX sh dP @TPL1 HTR tb dP @TPL1 HTR th dP @TPL1 LTR sh dP @TPL1 LTR sh dP @TPL1 Pre Cooler tb dP @TPL1 Pre Cooler sh dP @TPL1 SET-1 @TPL1 Turbine @TPL1 M1 @TPL1 T1 @TPL1	Heat Exch Heat Exch Set Set Set Set Set Set Set Set Set Set	anger	IHX In @TPL1 Return FLow @TPL1 Turbine Out @TPL1 Comp 1 Out @TPL1 HTR Out @TPL1 PreCooler In @TPL1 PreCooler In @TPL1 IHX Out @TPL1 From LTR @TPL1 1 @TPL1 LTR Out @TPL1 Comp 1 In @TPL1	IHX Out @TPL1 IHX In @TPL1 HTR Out @TPL1 From LTR @TPL1 Cooling Water Out. Comp 1 in @TPL1 Cooling Water Out. Comp 1 in @TPL1 Comp 1 out @TPL Turbine Out @TPL Turbine Power @T Return FLow @TPL Comp 2 in @TPL1 Comp 1 Out @TPL	No No QTPL1 No 1 No 1 No 1 No 1 No	500.0 * 500.0 *			

1		BATTELLE ENERGY ALLIANCE		Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC					
2 3 4	entech	Burlington, N		-	Unit Set:	AF	R		
4 5	- acpointed	USA			Date/Time:	Fr	i Mar 28 11:05:37 2014		
6				D .) (()		
7 8	Work	(DOOK:	SC CO2	Bra	yton (TPI	L1)) (continued)		
9 10				Un	it Ops (contin	ued	i)		
11	Operation Name	Opera	ation Type		Feeds		Products	Ignored	Calc Level
12 13									
14									
15 16									
17									
18 19									
20									
21									
23									
24 25									
26									
27 28									
29									
22 23 24 25 26 27 28 29 30 31 32									
32									
33 34									
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51									
36 37									
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56 57 58 59									
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60 61									
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63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	ALLIANCE	Aspe	en HYS	YS Version 7.3	(25.	0.0.7336)		Page 6 of 9 Specified by user.

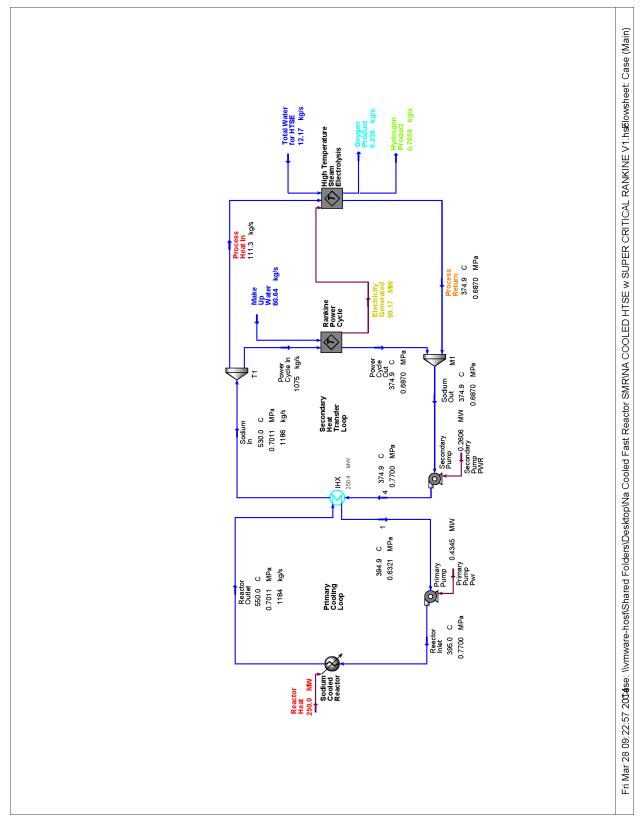
1	(Case Name: NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC					
3		aspentech Burlington, M	NERGY ALLIANCE A	•	Unit Set:	AFR				
4 5		USA USA		_ [Date/Time: Fri Mar 28 11:05:37 2014					
6		• • • •								
7 8		Spreadshe	et: Brayt	ion C	Sycle Ca			Units Set: NuScale2		
9 10				c	ONNECTION	IS				
11				Im	ported Varial	oles				
12 13	Cell	Object			•	Variable Description		Value		
14	A1		ower@TPL1	Power		ľ		149.8 MVV		
15	A2			Power				22.86 MVV		
16	A3			Power				25.06 MVV		
17	A4			Power				0.6971 MVV		
18 19	A5 A6	Energy Stream: Primary F	1	Power				0.4345 MW		
20	A6 A8	Energy Stream: Secondar Energy Stream: Reactor H	· · · · · · · · · · · · · · · · · · ·	Power Heat Flo	1147			0.2606 MVV 250.0 MVV		
21	70	Energy Stream. Reactorn						230.0 11177		
22			Expo	rted Va	ariables' Forr	nula Results				
23	Cell	Object				Variable Description		Value		
24	A7	Electricity Generated @TPL1		Power				100.5 MVV		
25 26				F	PARAMETER	s				
27 28				Exp	ortable Varia	bles				
29	Cell	Visible Name			Variable Des	Variable Type	Value			
30	A7	A7: Power		Power Power				100.5 MVV		
31	A9	A9: Thermal Efficiency			Efficiency	Percent	40.20			
32 33				User Variables						
34 35					FORMULAS					
36	Cell			Fo	ormula			Result		
37	A7	=A1-A2-A3-A4-A5-A6						100.5 MVV		
38	A9	=A7/A8*100					40.20			
39 40					Spreadshee	t				
41		A		В		С		D		
42	1	149.8 MVV *								
43 44	2	22.86 MVV *								
44	4	25.06 MVV * 0.6971 MVV *								
46	5	0.4345 MVV *								
47	6	0.2606 MVV *								
48	7	100.5 MVV *								
49	8	250.0 MVV *								
50	9	40.20 *								
51	10									
52										
53 54										
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56										
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58										
55 56 57 58 59 60										
60										
62 63	Acna	n Tachnology Inc	A		VS Varaian 7.3	(25.0.0.7236)		Bana 7 cf 0		
03		n Technology Inc. d to: BATTELLE ENERGY ALLIANCE	Aspe	II II I S'	YS Version 7.3	(20.0.0.7336)		Page 7 of 9 * Specified by user.		



1				Case Name:		RITICAL CO2 CYCLE M	ODEL VI HSC	
2			E ENERGY ALLIANCE				ODEE (TINGE	
3	aspentech	Burlington, USA	, МА	Unit Set:	AFR			
5				Date/Time:	Fri Mar 28 11:05:37 201	4		
6				()				
7	Wo	rkbook	: Cooling To	ower (TPL4)				
9				Material Ctream	-	Fluid Pkg: All		
10				Material Stream				
11	Name Manager Frenklan		Cooling Water Out @1	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air	
12	Vapour Fraction Temperature	(C)	0.0000 28.70	0.0000			1.0000 * 20.00	
14	Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	2.339e-003	
15	Molar Flow	(kgmole/h)	1.866e+006	1.866e+006	5.023e+005	5845		
16	Mass Flow	(kg/s)	9339	9339	4026	29.25		
17	Liquid Volume Flow	(m3/h)	3.369e+004	3.369e+004	1.675e+004	105.5		
18	Heat Flow	(MVV)	-1.482e+005	-1.484e+005				
19	Name		1 @TPL4	3 @TPL4	Dew Point @TPL4	4@TPL4	Saturated Air @TPL4	
20	Vapour Fraction		1.0000	0.2184	1.0000 *	0.2184	1.0000	
21	Temperature	(C)	20.16	25.05	9.396	25.04	25.04	
22	Pressure	(MPa)	0.1015	0.1015	0.1013	0.1013	0.1013	
23	Molar Flow	(kgmole/h)	5.082e+005	2.374e+006	5.082e+005	2.374e+006	5.185e+005	
24	Mass Flow	(kg/s)	4055	1.339e+004	4055	1.339e+004	4107	
25 26	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	1.686e+004 -413.9	5.055e+004 -1.486e+005	1.686e+004 -458.2	5.055e+004 -1.486e+005	1.705e+004 -1087	
20		(111 V V)		Entrained Water @TP	-458.2 Blowdown @TPL4		- 1087 Water Entrained Air @	
27	Name Vapour Fraction		5 @TPL4 0.0000	Entrained voater @ IP 0.0000	Biowdown @TPL4	Water Return @TPL4 0.0000	Vvater Entrained Air (2) 0.9964	
29	Temperature	(C)	25.04	25.04	25.04	25.04	25.04	
30	Pressure	(C) (MPa)	0.1013	0.1013	0.1013	0.1013	0.1013	
31	Molar Flow	(kgmole/h)	1.856e+006	1866	3233	1.851e+006	5.204e+005	
32	Mass Flow	(kg/s)	9287	9.339	16.18	9262	4116	
33	Liquid Volume Flow	(m3/h)	3.350e+004	33.69	58.36	3.341e+004	1.708e+004	
34	Heat Flow	(MVV)	-1.475e+005	-148.4	-257.0	-1.471e+005	-1235	
35	Name		Make Up Water @TPL	Cooling Water In a @1	6 @TPL4	Moist Air @TPL4		
36	Vapour Fraction		0.0000	0.0000	0.0000	1.0000		
37	Temperature	(C)	20.00 *	25.00	25.00	20.00 *		
38	Pressure	(MPa)	0.1013	0.1035	0.1013	0.1013 *		
39	Molar Flow	(kgmole/h)	1.541e+004	1.866e+006	1.866e+006	5.082e+005		
40	Mass Flow	(kg/s)	77.13	9339	9339	4055 *		
41	Liquid Volume Flow	(m3/h)	278.2	3.369e+004	3.369e+004	1.686e+004		
42	Heat Flow	(MVV)	-1227	-1.484e+005	-1.484e+005	-414.5		
43 44				Compositions		Fluid Pkg	j: All	
45	Name		Cooling Water Out @	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air	
46	Comp Mole Frac (H2O)		1.0000	1.0000 *	0.0000 *	1.0000 *	1.0000 *	
47	Comp Mole Frac (Nitroger	1)	0.0000	0.0000 *	0.7900 *	0.0000 *	***	
48	Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	* 0.000.0	***	
49	Comp Mole Frac (Hydroge	en)	0.0000	0.0000 *	0.0000 *	* 0.000.0	***	
50	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000 *	* 0.000 *	***	
51	Comp Mole Frac (CO)		0.0000	0.0000 *	0.0000 *	0.0000 *	***	
52	Comp Mole Frac (Sodium))	***	***	***	***	***	
53	Comp Mole Frac (Air)		***	***	***	***	***	
54	Name Comp Molo Erec (U2O)		1 @TPL4 0.0115	3@TPL4 0.7884	Dew Point @TPL4	4@TPL4 0.7884	Saturated Air @TPL4	
55 56	Comp Mole Frac (H2O) Comp Mole Frac (Nitroger	2	0.0115	0.7884	0.0115 0.7809	0.7884	0.0312	
57	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen		0.7809	0.0444	0.7809	0.0444	0.2035	
58	Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge		0.0000	0.0000	0.0000	0.0000	0.0000	
59	Comp Mole Frac (CO2)	any .	0.0000	0.0000	0.0000	0.0000	0.0000	
60	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000	
61	Comp Mole Frac (Sodium))	***	***	***	***	***	
62	Comp Mole Frac (Air)		***	***	***	***	***	
62 63		6.		*** IYSYS Version 7.3 (2		***	*** Page 8 of 9	

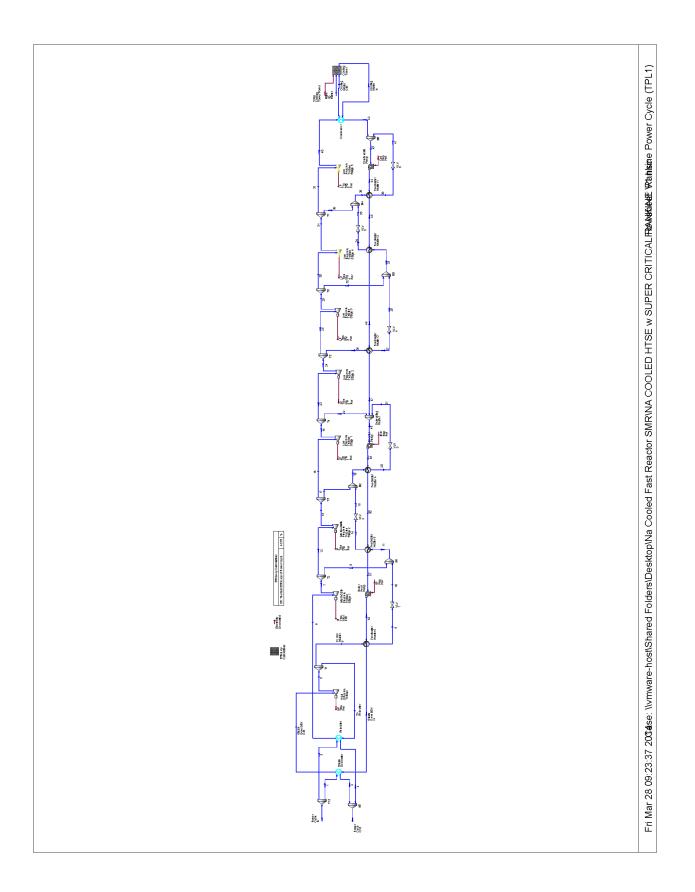
1			ENERGY ALLIANCI	_	Case Name:	NA COOLED	SUPER C	RITICAL C	O2 CYCLE M	ODEL V1.HSC
3	aspentech	Burlington,			Unit Set:	AFR				
4 5		USA			Date/Time:	Fri Mar 28 11	:05:37 201	4		
6			0 I'	 _				、		
8	VVORK	DOOK:	Cooling	IOW	/er (1PL4)	(conti	nuea)		
9 10				Comp	ositions (conti	inued)			Fluid Pkg: All	
11	Name		5 @TPL4	En	trained Water @TP	Blowdown @	DTPL4	Water Re	eturn @TPL4	Water Entrained Air @
12	Comp Mole Frac (H2O)		1.000	0	1.0000		1.0000		1.0000	0.0346
13	Comp Mole Frac (Nitrogen)		0.000		0.0000		0.0000		0.0000	0.7626
14	Comp Mole Frac (Oxygen)		0.000		0.0000		0.0000		0.0000	0.2027
15	Comp Mole Frac (Hydrogen)		0.000		0.0000		0.0000		0.0000	0.0000
16 17	Comp Mole Frac (CO2)		0.0000		0.0000		0.0000		0.0000	0.0000
18	Comp Mole Frac (CO) Comp Mole Frac (Sodium)		U.UUU		0.0000		0.0000		0.0000	0.0000
19	Comp Mole Frac (Sodium) Comp Mole Frac (Air)		**	*	***		***		***	***
20	Name		Make Up Water @	TPI Co	oling Water In a @1	6 @TPL4		Moist Air	@TPL4	
21	Name Comp Mole Frac (H2O)		1.000		1.0000	0.001121	1.0000		0.0115	
22	Comp Mole Frac (Nitrogen)		0.000		0.0000		0.0000		0.7809	
23	Comp Mole Frac (Oxygen)		0.000		0.0000		0.0000		0.2076	
24	Comp Mole Frac (Hydrogen)		0.000	0 *	0.0000		0.0000		0.0000	
25	Comp Mole Frac (CO2)		0.000	0 *	0.0000		0.0000		0.0000	
26	Comp Mole Frac (CO)		0.000	0 *	0.0000		0.0000		0.0000	
27	Comp Mole Frac (Sodium)		**	*	***		***		***	
28	Comp Mole Frac (Air)		**	**	***		***		***	
29 30 Ene				Energy Stream	5			Fluid Pkg	j: All	
31					oling Water Pump F	Total Coolin	a Tower P			
32			0.670		2.692e-002	Total Coolin	0.6971			
33					Unit Ops					
34 35	Operation Name	Ope	ration Type		Feeds		Products		Ignored	Calc Level
36	M1 @TPL4	Mixer		Dry Air	@TPL4	Moist Air @TPL4		No	500.0 *	
37	MI QII L4	INTIACI		Water Vapor @TPL4				INU	500.0	
38	M2 @TPL4	Mixer	-	1@TP		3 @TPL4		No	500.0 *	
39	0				g Water Out @TPL4					
40 41	M3 @TPL4	Mixer	-		ted Air @TPL4	Water Er	ntrained Air	°@TPL4	No	500.0 *
41					ed Water @TPL4 Return @TPL4	RATEL	4			
42	M4 @TPL4	Mixer			Jp Water @TPL4	6 @TPL4	4		No	500.0 *
43	Moist Air Conditions @TPL4	Spreadsh	eet	widke (2p Vilater (@TEL4	-			No	500.0 *
45	Water Cooling Calcs @TPL4	Spreadsh							No	500.0 *
46	Sat Temp for moist air @TPL4	Set							No	500.0 *
47	Dew Point Pressure @TPL4	Set						1	No	500.0 *
48	Amb Press Set @TPL4	Set							No	500.0 *
49	SET-1@TPL4	Set							No	500.0 *
50 51	Air Fan @TPL4	Compress	or		Air@TPL4	1 @TPL4	4		No	500.0 *
52		Value			Power@TPL4	4.@TDL	4		No	500.0 *
53	VLV2 @TPL4	Valve		3@TP	L4	4 @TPL4	4		NO	500.0 *
54										
55										
56										
57										
58										
59										
60						_				
61										
62	Asses Task 1		•		VO.V					D- 0.75
63	Aspen Technology Inc.		Aspe	en HYS	YS Version 7.3 ()	25.0.0.7336)				Page 9 of 9

* Specified by user.



1				Case Name:	NA COOLED HTSE w 5	SUPER CRITICAL RANK	INE V1.hsc
2 3	aspentech		E ENERGY ALLIANCE , MA	Unit Set:	AFR		
4	aspented	USA		Date/Time:	Fri Mar 28 11:16:39 201	4	
6							
7 8	Wo	rkbook	: Case (Mai	n)			
9 10				Material Stream	s	Fluid Pk	g: All
11	Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
12	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
13	Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
14	Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
15	Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
15	Mass Flow	(kg/s)	1186	1186	1184	1184	1184
18	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	4544 818.8	4544 568.3	4537 849.9	4537 599.9	4537 599.5
19	Name	(141 V V)	Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE
20	Vapour Fraction		0.0000	0.0000	1.0000	1.0000	0.0000
21	Temperature	(C)	374.9	20.00	54.44	54.44	21.11
22	Pressure	(MPa)	0.6870	0.1013	6.901	6.901	0.1013
23	Molar Flow	(kgmole/h)	1.857e+005	1.212e+004	1403	701.6	2431
24	Mass Flow	(kg/s)	1186	60.64	0.7858	6.236	12.17
25	Liquid Volume Flow	(m3/h)	4544	218.8	40.49	19.73	43.89
26	Heat Flow	(MVV)	568.1	-960.6	0.3318	6.804e-002	-193.5
27	Name		Process Heat In	Process Return	Power Cycle In	Power Cycle Out	
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000	
29	Temperature	(C)	530.0	374.9	530.0	374.9	
30	Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	
31	Molar Flow	(kgmole/h)	1.743e+004	1.743e+004	1.683e+005	1.683e+005	
32	Mass Flow	(kg/s)	111.3	111.3	1075	1075	
33 34	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	426.5 76.85	426.5	4117 741.9	41 17 514.8	
94	HEAL FIUW	(141 A A)	70.60	00.02	741.9	014.0	
35				Compositions		Eluid Dia	~: All
36	Name		Sodium In	Compositions		Fluid Pk	g: All
36 37	Name Comp Mole Frac (H2O)		Sodium In	Compositions	Reactor Outlet	Fluid Pk	g: All 1
36	Comp Mole Frac (H2O))		4	Reactor Outlet	Reactor Inlet	1
36 37 38	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen		***	4	Reactor Outlet	Reactor Inlet	- 1 ***
36 37 38 39	Comp Mole Frac (H2O))	***	4	Reactor Outlet ***	Reactor Inlet	- 1 ***
36 37 38 39 40	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen))	***	4 *** ***	Reactor Outlet	Reactor Inlet	- 1
36 37 38 39 40 41	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge)	*** ***	4 *** *** ***	Reactor Outlet *** *** ***	Reactor Inlet ****	- 1 *** *** ***
36 37 38 40 41 42 43 44	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)	n)	*** *** *** *** *** 1.0000	4 *** *** *** *** *** *** *** 1.0000 *	Reactor Outlet	Reactor Inlet **** **** **** **** **** **** **** *	1 *** *** *** *** *** ***
36 37 38 39 40 41 42 43	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air)	n)	**** *** *** *** 1.0000	4 *** *** *** 1.0000 *	Reactor Outlet	Reactor Inlet **** **** **** **** **** **** 1.0000 * ****	1 **** **** **** **** 1.0000 ****
36 37 38 39 40 41 42 43 44 45 46	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name	n)	**** **** **** **** **** 1.0000 *** Sodium Out	4 **** *** *** *** *** *** 1.0000* *** Make Up Water	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product	Reactor Inlet	1 *** *** *** *** *** *** *** *** *** *
36 37 38 39 40 41 42 43 44 45 46 47	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O)) in) i	**** **** **** **** 1.0000 *** Sodium Out ***	4 *** *** *** 1.0000 *	Reactor Outlet	Reactor Inlet	1 **** **** **** **** **** 1.0000 *** Total Water for HTSE 1.0000
36 37 38 39 40 41 42 43 44 45 46	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) in) i	**** **** **** **** **** 1.0000 *** Sodium Out	4 *** *** *** *** *** *** *** 1.000 *** Make Up Water 1.0000	Reactor Outlet	Reactor Inlet **** **** **** **** **** **** **** **** **** **** **** **** Oxygen Product 0.0000 0.0000	1 *** *** *** *** *** *** *** 1.000 *** Total Water for HTSE 1.0000 0.0000
36 37 38 39 40 41 42 43 44 45 46 47	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen)) in) i i i i i) i)	**** **** **** **** 1.0000 *** Sodium Out ***	4 *** *** *** *** *** *** *** *** *** *	Reactor Outlet **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.0000 0.0000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Sodium) Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Hydroge) in) i i i i i) i)	**** **** **** **** **** **** **** **** ****	4 *** *** *** *** 1.0000 *** Make Up Water 1.0000 *** ***	Heactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 1.0000	Reactor Inlet	1 *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Coxygen) Comp Mole Frac (Hydroge Comp Mole Frac (Hydroge Comp Mole Frac (CO2)) in) i i i i i) i)	**** **** **** **** 1.0000 **** Sodium Out *** *** **** **** ****	4 *** *** *** *** 1.0000 *** Make Up Water 1.0000 *** *** *** ***	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** 1.000 *** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000 0.0000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (H2dydoge Comp Mole Frac (Coygen) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** Sodium Out **** **** **** **** **** **** **** *	4 *** *** *** *** *** *** *** *** *** *	Heactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 1.0000	Reactor Inlet	1 *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Coxygen) Comp Mole Frac (Hydroge Comp Mole Frac (Hydroge Comp Mole Frac (CO2)) n) i i i)))	****	4 **** *** *** *** *** *** *** *** ***	Heactor Outlet **** **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** *
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** *
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO)) n) i i i)))	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet **** **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (Air) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air)) n) 	**** **** **** **** **** **** **** **** ****	4 *** *** *** *** *** *** *** *** *** *	Reactor Outlet	Reactor Inlet	1 **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 **** ***
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO)) n) 	**** **** **** **** **** **** **** **** ****	4 **** *** *** *** *** *** *** *** ***	Reactor Outlet	Reactor Inlet	1 **** **** **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000

1					Case Name:	NA	COOLED HTSE w 5	OUPER CR	RITICAL RANKINE	V1.hsc
2		BATTELLE	E ENERGY ALLIANC	CE	Unit Set:	AF	R			
4	aspentech	USA						4		
5					Date/Time:	Date/Time: Fri Mar 28 11:16:39 2014				
8	Work	book	: Case (M	ain	ı) (continue	ed))			
9				Compositions (continued)				Fluid Pkg:	All	
11	Name		Process Heat In		. , ,			Power C	Cycle Out	
12	Comp Mole Frac (H2O)			***	***		***		***	
13	Comp Mole Frac (Nitrogen)			***	***		***		***	
14 15	Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen)			***	***	-	***		***	
16	Comp Mole Frac (CO2)			***	***		***		***	
17	Comp Mole Frac (CO)		-	***	***		***		***	
18	Comp Mole Frac (Sodium)		1.00	00	1.0000		1.0000		1.0000	
19	Comp Mole Frac (Air)			***	***		***		***	
20 21					Energy Stream	s			Fluid Pkg:	All
22	Name		Reactor Heat		Electricity Generated	P	rimary Pump Pwr	Second:	ary Pump PWF	
23	Heat Flow	(MVV)	250).0 *	99.17		0.4345		0.2606	
24 25					Unit Ops					
26	Operation Name	Ope	eration Type		Feeds		Products		Ignored	Calc Level
27	Sodium Cooled Reactor	Heater		Rea	actor Inlet		Reactor Outlet		No	500.0 *
28	Source Cooled Neactor	Tieatei			actor Heat	$ \rightarrow$	<u> </u>		INU	500.0
29	Rankine Power Cycle	Standard Sub-Flowsheet			ower Cycle In		Power Cycle Out		No	2500 *
30 31				Make Up Water Process Heat In		+	Electricity Generate Hydrogen Product	a		
32	High Temperature Steam Elec	nperature Steam Elec Standard S			al Water for HTSE	\rightarrow	Oxygen Product		No	2500 *
33					ctricity Generated		Process Return			
34	IHX	Heat Excl	anger	Rea	actor Outlet		1		No	500.0 *
35	11.123	TICAL EXC	ranger	4					140	500.0
36	Primary Pump	Pump		1 Primony Pump Pwy		+	Reactor Inlet		No	500.0 *
38				Primary Pump Pwr Sodium Out		-	4			
39	Secondary Pump	Pump			ondary Pump PWR				No	500.0 *
40	T1	Тее		Sod	lium In	Power Cycle In			No	500.0 *
41				_		\rightarrow	Process Heat In			000.0
42	M1	Mixer			cess Return ver Cycle Out	+	Sodium Out		No	500.0 *
43				FUM						
45										
46										
47										
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49 50										
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63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY		Asp	en H\	YSYS Version 7.3 (2	25.0	0.0.7336		*	Page 2 of 34 Specified by user.
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1				Case Name:	NA COOLED HTSE w S	UPER CRITICAL RANK	INE V1.hsc	
2 3	aspentec	Burlington,	ENERGY ALLIANCE	Unit Set:	AFR			
4 5		USA		Date/Time:	Fri Mar 28 11:16:39 201	4		
6								
7	Wo	orkbook:	Rankine P	ower Cycle	(TPL1)			
9				Streams		Fluid Pkg: All		
10	N				T 0000 - 0.070		-	
11 12	Name Vapour Fraction		Steam Generator Out 1.0000	To Reheater @TPL1 1.0000	To FW Heater 6 @TPL 1.0000	6@TPL1 1.0000	9 @TPL1 0.0000	
13	Temperature	(C)	510.0	354.9	354.9	510.0	276.0	
14	Pressure	(C) (MPa)	24.00	8.510	8.510	8.340	8.340	
15	Molar Flow	(kgmole/h)	1.965e+004	1.828e+004	1363	1.828e+004	1363	
16	Mass Flow	(kg/s)	98.32	91.49	6.823	91.49	6.823	
17	Std I deal Liq Vol Flow	(m3/h)	354.7	330.0	24.61	330.0	24.61	
18	Heat Flow	(MVV)	-1249	-1184	-88.27	-1144	-100.4	
19	Molar Enthalpy	(kJ/kgmole)	-2.289e+005	-2.330e+005	-2.330e+005	-2.253e+005	-2.650e+005	
20	Name		52 @TPL1	Steam Generator In @	51@TPL1	8@TPL1	12@TPL1	
21	Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000	
22	Temperature	(C)	270.5	295.3	263.1	442.4	442.4	
23	Pressure	(MPa)	24.99 *	24.49	4.936	5.390	5.390	
24	Molar Flow	(kgmole/h)	1.965e+004	1.965e+004	1.965e+004	1269	1.701e+004	
25	Mass Flow Std I deal Liq Vol Flow	(kg/s)	98.32 354.7	98.32 354.7	98.32 354.7	6.350 22.90	85.14 307.1	
20	Heat Flow	(m3/h) (MVV)	-1449	-1437	-1453	-80.20	-1075	
28	Molar Enthalpy	(MVV) (kJ/kgmole)	-1449 -2.655e+005	-1437 -2.633e+005	-1453 -2.662e+005	-2.276e+005	-2.276e+005	
29	Name	(Karkginore)	11 @TPL1	16 @TPL1	18@TPL1	23 @TPL1	22@TPL1	
30	Vapour Fraction		0.6439	1.0000	0.3688	1.0000	1.0000	
31	Temperature	(C)	268.7	363.6	235.4	272.6	272.6	
32	Pressure	(MPa)	5.390	3.080	3.080	1.365	1.365	
33	Molar Flow	(kgmole/h)	2632	1.583e+004	3813	1.473e+004	1099	
34	Mass Flow	(kg/s)	13.17	79.23	19.08	73.74	5.499	
35	Std I deal Liq Vol Flow	(m3/h)	47.52	285.8	68.83	266.0	19.84	
36	Heat Flow	(MVV)	-180.6	-1013	-271.9	-954.5	-71.18	
37	Molar Enthalpy	(kJ/kgmole)	-2.469e+005	-2.302e+005	-2.567e+005	-2.332e+005	-2.332e+005	
38	Name		49 @TPL1	14@TPL1	20 @TPL1	47 @TPL1	48@TPL1	
39	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000	
40	Temperature	(C)	194.5	235.2	200.1	155.2	193.6	
41	Pressure	(MPa)	5.140 *	5.390	3.018	1.365	1.365	
42 43	Molar Flow Mass Flow	(kgmole/h)	1.965e+004 98.32	2632	3813 19.08	1.473e+004 73.74	1.965e+004 98.32	
43	Mass Flow Std I deal Liq Vol Flow	(kg/s) (m3/h)	354.7	13.17 47.52	68.83	266.0	354.7	
45	Heat Flow	(MVV)	-1484	-196.4	-287.6	-1126	-1485	
46	Molar Enthalpy	(kJ/kgmole)	-2.719e+005	-2.686e+005	-2.715e+005	-2.751e+005	-2.720e+005	
47	Name		21 @TPL1	25@TPL1	26 @TPL1	27 @TPL1	30@TPL1	
48	Vapour Fraction		0.0145	1.0000	1.0000	0.0000	0.9923	
49	Temperature	(C)	193.9	196.4	196.4	123.1	123.1	
50	Pressure	(MPa)	1.365	0.6210	0.6210	0.6086	0.2190	
51	Molar Flow	(kgmole/h)	3813	1.371e+004	1023	1023	1.276e+004	
52	Mass Flow	(kg/s)	19.08	68.62	5.117	5.117	63.86	
53	Std I deal Liq Vol Flow	(m3/h)	68.83	247.5	18.46	18.46	230.3	
54	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-287.6 -2.715e+005	-897.8 -2.357e+005	-66.95 -2.357e+005	-78.84 -2.776e+005	-844.8 -2.383e+005	
56 57 58 60 61								
62 63	Aspen Technology In		Aspen H	YSYS Version 7.3 (2	25.0.0.7336)		Page 3 of 34 * Specified by user.	

1				Case Name:		SUPER CRITICAL RANK	
2			E ENERGY ALLIANCE	Unit Set:	AFR	JOF ER CRITICAL RANK	INE VILISE
4	aspentec	USA	, MA			4	
5 6				Date/Time:	Fri Mar 28 11:16:39 201	14	
7	Wa	orkbook	: Rankine P	ower Cvcle	(TPL1) (con	tinued)	
8					(),(,	
9 10				Streams (continu	ed)	Fluid Pk	g: All
11	Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44@TPL1
12	Vapour Fraction		0.9923	0.9421	0.0000	0.0000	0.0000
13 14	Temperature	(C)	123.1 0.2190	84.55	84.50 0.2146	45.88 5.566e-002	40.33
14	Pressure Molar Flow	(MPa) (kgmole/h)	951.6	5.680e-002 1.187e+004	1974	2860	1.450 * 1.473e+004
16	Mass Flow	(kg/s)	4.762	59.42	9.879	14.31	73.74
17	Std I deal Liq Vol Flow	(m3/h)	17.18	214.4	35.64	51.62	266.0
18	Heat Flow	(MVV)	-63.00	-796.7	-153.8	-225.1	-1162
19	Molar Enthalpy	(kJ/kgmole)	-2.383e+005	-2.415e+005	-2.805e+005	-2.834e+005	-2.838e+005
20	Name		40 @TPL1	38@TPL1	42@TPL1	33 @TPL1	41@TPL1
21 22	Vapour Fraction	(0)	0.8839	0.2917 84.55	0.0000	0.4783	0.0100
22	Temperature Pressure	(C) (MPa)	40.51 7.584e-003 *	5.680e-002	38.79 7.433e-003	123.1 0.2190	40.13 7.433e-003
24	Molar Flow	(kgmole/h)	1.187e+003	2860	1.187e+004	1974	2860
25	Mass Flow	(kg/s)	59.42	14.31	59.42	9.879	14.31
26	Std I deal Liq Vol Flow	(m3/h)	214.4	51.62	214.4	35.64	51.62
27	Heat Flow	(MVV)	-809.9	-213.2	-936.6	-141.8	-225.1
28	Molar Enthalpy	(kJ/kgmole)	-2.455e+005	-2.684e+005	-2.839e+005	-2.587e+005	-2.834e+005
29	Name		1 @TPL1	3@TPL1	2 @TPL1	4@TPL1	Power Cycle In @TPL
30	Vapour Fraction	(0)	0.0000	0.0000	0.0000	0.0000	0.0000
31 32	Temperature Pressure	(C) (MPa)	530.0 0.7011	530.0 0.7011	374.9 0.6870	374.9 * 0.6870	530.0 0.7011
33	Molar Flow	(kgmole/h)	1.390e+005	2.926e+004	1.390e+005	2.926e+004	1.683e+005
34	Mass Flow	(kg/s)	887.8	186.9	887.8	186.9	1075
35	Std I deal Liq Vol Flow	(m3/h)	3401	715.9	3401	715.9	4117
36	Heat Flow	(MVV)	612.9	129.0	425.3	89.51	741.9
37	Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004
38	Name		Power Cycle Out @TF	5@TPL1	10@TPL1	7@TPL1	13@TPL1
39 40	Vapour Fraction	(0)	0.0000	1.0000	0.0226	1.0000	1.0000
40	Temperature Pressure	(C) (MPa)	374.9 0.6870	354.9 8.510 *	268.7 5.390	442.4 5.390 *	363.6 3.080 *
42	Molar Flow	(kgmole/h)	1.683e+005	1.965e+004	1363	1.828e+004	1.701e+004
43	Mass Flow	(kg/s)	1075	98.32	6.823	91.49	85.14
44	Std I deal Liq Vol Flow	(m3/h)	4117	354.7	24.61	330.0	307.1
45	Heat Flow	(MVV)	514.8	-1272	-100.4	-1156	-1088
46	Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.330e+005	-2.650e+005	-2.276e+005	-2.302e+005
47 48	Name Veneur Freetien		19 @TPL1	24 @TPL1	29@TPL1	31 @TPL1	45@TPL1
40 ⊿9	Vapour Fraction Temperature	(C)	1.0000 272.6	1.0000 196.4	0.9923	0.9421 84.55	0.0000 78.94
50	Pressure	(C) (MPa)	1.365	0.6210 *	0.2190 *	5.680e-002 *	1.421
51	Molar Flow	(kgmole/h)	1.583e+004	1.473e+004	1.371e+004	1.276e+004	1.473e+004
52	Mass Flow	(kg/s)	79.23	73.74	68.62	63.86	73.74
53	Std I deal Liq Vol Flow	(m3/h)	285.8	266.0	247.5	230.3	266.0
54	Heat Flow	(MVV)	-1026	-964.7	-907.8	-856.1	-1150
55 56	Molar Enthalpy	(kJ/kgmole)	-2.332e+005	-2.357e+005	-2.383e+005	-2.415e+005	-2.809e+005
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63	Aspen Technology In Licensed to: BATTELLE ENE		Aspen H	HYSYS Version 7.3 (25.0.0.7336		Page 4 of 34 * Specified by user.
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1				Case Name:	NA COOLED HTSE w S	OUPER CRITICAL RANK	INE V1.hsc
2 3			ENERGY ALLIANCE	Unit Set:	AFR		
4	aspented	USA		Date/Time:	Fri Mar 28 11:16:39 201	4	
5 6				Date/Time.	111110120 11110.00 201	7	
7	W	orkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)	
9				Streams (continu	ed)	Fluid Pkg	g: All
11	Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28@TPL1
12	Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
13	Temperature	(C)	117.5	229.7	363.6	235.3	123.1
14	Pressure	(MPa)	1.393	5.037	3.080	3.080	0.2190
15	Molar Flow	(kgmole/h)	1.473e+004	1.965e+004	1181	2632	1023
16	Mass Flow	(kg/s)	73.74	98.32	5.909	13.17	5.117
17	Std I deal Liq Vol Flow	(m3/h)	266.0	354.7	21.32	47.52 - 196.4	18.46 -78.84
19	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-1138 -2.780e+005	-1468 -2.691e+005	-75.51 -2.302e+005	-190.4 -2.686e+005	-78.84 -2.776e+005
20	Name	(Rorrightore)	36 @TPL1	35 @TPL1	43@TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
21	Vapour Fraction		0.9421	0.0000	0.0001		
22	Temperature	(C)	84.55	84.53	40.13		
23	Pressure	(MPa)	5.680e-002	5.680e-002	7.433e-003		
24	Molar Flow	(kgmole/h)	885.6	1974	1.473e+004		
25	Mass Flow	(kg/s)	4.432	9.879	73.74		
26	Std I deal Liq Vol Flow	(m3/h)	15.99	35.64	266.0		
27 28	Heat Flow	(MVV)	-59.41	-153.8	-1162	22.40	11.61
20	Molar Enthalpy Name	(kJ/kgmole)	-2.415e+005 IP Trbn Stg 2 Pwr @T	-2.805e+005 LP Trb Stg 1 Pwr @TF	-2.838e+005 Bstr Pmp Pwr @TPL1	LP Trbn Stg 2 Pwr @T	LP Trbn Stg 3 Pwr @1
30	Vapour Fraction		ir indiisig zirwi (@i		osu rinp rwi @irci	LF ITBITISTY 2 FWT (@)	LE HUN SUJJEWIQU
31	Temperature	(C)					
32	Pressure	(MPa)					
33	Molar Flow	(kgmole/h)					
34	Mass Flow	(kg/s)					
35	Std I deal Liq Vol Flow	(m3/h)					
36	Heat Flow	(MVV)	12.54	13.13	0.5664	10.24	10.06
37	Molar Enthalpy	(kJ/kgmole)					
38 39	Name Manue Frantian		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated (
39 40	Vapour Fraction Temperature	(C)					
41	Pressure	(MPa)					
42	Molar Flow	(kgmole/h)					
43	Mass Flow	(kg/s)					
44	Std I deal Liq Vol Flow	(m3/h)					
45	Heat Flow	(M <i>\</i> √V)	11.26	13.23	3.319	0.1429	99.17
46	Molar Enthalpy	(kJ/kgmole)					
47	Name		Cooling Water Out @1	Cooling Water In @TF		Total Cooling Tower P	
48	Vapour Fraction	(0)	0.0000	0.0000	0.0000		
49 50	Temperature Pressure	(C) (MPa)	34.95 0.1015	25.00 0.1035	20.00 0.1013		
50	Molar Flow	(MPa) (kgmole/h)	5.899e+005	5.899e+005	1.212e+004		
52	Mass Flow	(kg/s)	2952	2952	60.64		
53	Std I deal Liq Vol Flow	(m3/h)	1.065e+004	1.065e+004	218.8		
54	Heat Flow	(MVV)	-4.678e+004	-4.690e+004	-960.6	0.5756	
55	Molar Enthalpy	(kJ/kgmole)	-2.854e+005	-2.862e+005	-2.854e+005		
56							
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вU 61							
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63	Aspen Technology I	nc.	Aspen F	HYSYS Version 7.3 (25.0.0.7336		Page 5 of 34
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1				_	Case Name:	NA COOLED HTSE w 5	SUPER CR	RITICAL RANK	NE V1.hsc
3	aspentech	Burlington,	ENERGY ALLIANC		Unit Set:	AFR			
4 5		USA			Date/Time:	Fri Mar 28 11:16:39 201	4		
6			Denkine	Davis			41	(ا م	
8	VVOIK	DOOK:	Rankine	Pow	er Cycle	(TPL1) (con	unue	ea)	
9 10					Expanders			Fluid Pkg	;: All
11	Name		High Pressure Turl	bine Inter	rmdiate Pressure 1	Intermediatte Pressure	Low Pre	essure Turbine	Low Pressure Turbine
12	Power	(M <i>\</i> V)	22.4	.0	11.61	12.54		13.13	10.24
13	Capacity (act feed vol flow) (A	CT_m3/h)	427	4	1.337e+004	1.768e+004		2.579e+004	4.692e+004
14	Feed Pressure	(MPa)	24.0	10	8.340	5.390		3.080	1.365
15	Product Pressure	(MPa)	8.51	0 *	5.390 *	3.080 *		1.365	0.6210 *
16	Product Temperature	(C)	354.	.9	442.4	363.6		272.6	196.4
17	Adiabatic Efficiency		8	5 *	90 *	90 *		80 *	80 *
18	Name		Low Pressure Turk	oine Low	Pressure Turbine	Low Pressure Turbine			
19	Power	(MW)	10.0	16	11.26	13.23			
20	Capacity (act feed vol flow) (A	CT_m3/h)	8.315e+00	4	1.856e+005	5.797e+005			
21	Feed Pressure	(MPa)	0.621	0	0.2190	5.680e-002			
22	Product Pressure	(MPa)	0.219	0 *	5.680e-002 *	7.584e-003 *			
23	Product Temperature	(C)	123.	.1	84.55	40.51			
24	Adiabatic Efficiency		7	5 *	80 *	80 *			
25					D				
26					Pumps			Fluid Pkg	j: All
27	Name		Boiler Feed Pump	@T Boo:	ster Pump @TPL1	Condensate Pump @1			
28	Power	(MW)	3.31	9	0.5664	0.1429			
29	Capacity(Actual Vol. Flow)	(m3/h)	454.	.4	405.8	618.0			
30	Feed Pressure	(MPa)	4.93	6	1.365	7.433e-003			
31	Product Pressure	(MPa)	24.9	9 *	5.140 *	1.450 *			
32	Product Temperature	(C)	270.	.5	194.5	40.33			
33	Adiabatic Efficiency	(%)	75.0	10 *	75.00 *	75.00 *			
34 35				He	at Exchanger	s		Fluid Pkg	: All
36	Name		Feedwater Heater	6 @ Feer	dwater Heater 5 @	Feedwater Heater 4 @	Feedwa	ter Heater 3 @	Feedwater Heater 2 @
37	Duty	(MVV)	12.1		15.82	15.67		11.89	11.98
38	Tube Side Feed Mass Flow	(kg/s)	98.3		98.32	98.32		73.74	73.74
39	Shell Side Feed Mass Flow	(kg/s)	6.82		13.17	19.08		5.117	9.879
40	Tube Inlet Temperature	(C)	270.		229.7	194.5		117.5	78.94
41	Tube Outlet Temperature	(C)	295.		263.1	229.7		155.2	117.5
42	Shell Inlet Temperature	(C)	354.		268.7	235.4		196.4	123.1
43	Shell Outlet Temperature	(C)	276.		235.2	200.1		123.1	84.50
44	LMTD	(C)	15.0		15.75	15.48		18.00	17.06
45	Minimum Approach	(C)	5.55		5.556	5.556		5.556	5.556
46	UA	(kJ/C-h)	2.888e+00		3.617e+006	3.643e+006		2.378e+006	2.527e+006
47	Name	(Feedwater Heater		am Generator @TF	Reheater @TPL1		ser @TPL1	
48	Duty	(MVV)	11.9		187.7	39.50		126.7	
49	Tube Side Feed Mass Flow	(kg/s)	73.7		887.8	186.9		2952	
50	Shell Side Feed Mass Flow	(kg/s)	14.3		98.32	91.49		59.42	
51	Tube Inlet Temperature	(C)	40.3	13	530.0	530.0		25.00	
52	Tube Outlet Temperature	(C)	78.9		374.9	374.9 *		34.95	
53	Shell Inlet Temperature	(C)	84.5		295.3	354.9		40.51	
54	Shell Outlet Temperature	(C)	45.8		510.0	510.0		38.79	
55	LMTD	(C)	16.4		57.33	23.77		9.558	
56	Minimum Approach	(C)	5.55		20.00	20.00		5.556	
57	UA	(kJ/C-h)	2.607e+00		1.178e+007	5.983e+006		4.773e+007	
58					Unit Ops				
59 60	Operation Name	0	veties Trues		•	Deschuste		lan and d	Cala Lauri
БU 61	Operation Name	Upe	ration Type	Steam G	Feeds enerator Out @TP	Products L1 5@TPL1		Ignored	Calc Level
62	High Pressure Turbine @TPL	Expander		Jieanno		HP Trbn Pwr @TPL	1	No	500.0 *
63	Aspen Technology Inc.		Asne	en HYSY	S Version 7.3 (2				Page 6 of 34
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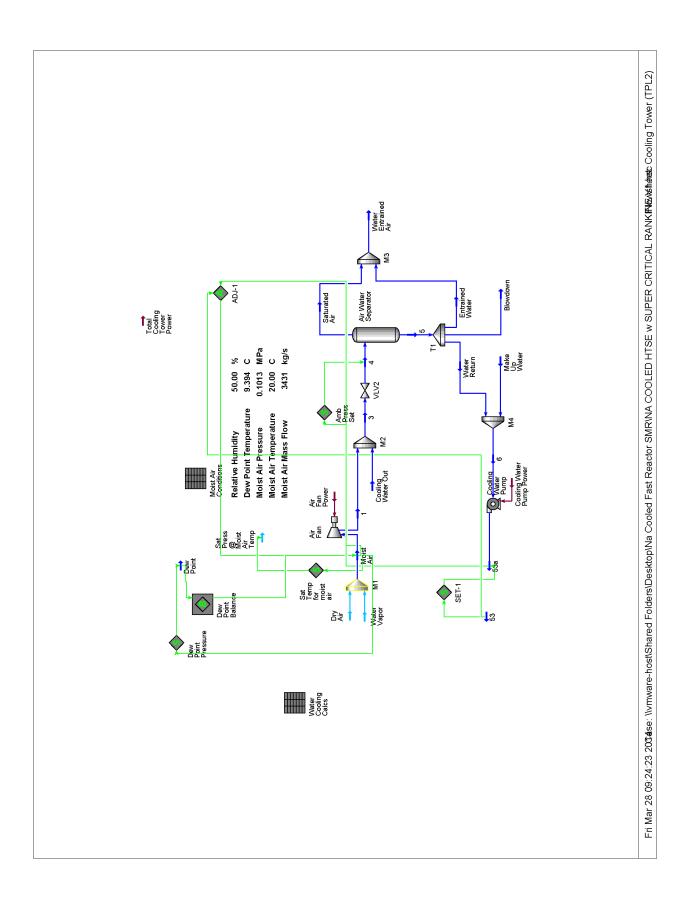
1			05	Case Name: N	NA COOLED HTSE W SUPER CR		V1.hsc		
3	aspentech	BATTELLE ENERGY ALLIAN Burlington, MA	UE	Unit Set: A	AFR				
4	aspenteen	USA		Date/Time: F	Fri Mar 28 11:16:39 2014				
5 6									
7 8	Work	book: Rankine	e Pov	wer Cycle (TPL1) (continue	d)			
9 10			Un	it Ops (continue	d)				
11	Operation Name	Operation Type		Feeds	Products	Ignored	Calc Level		
12 13	Intermdiate Pressure Turbine	Expander	6 @TF	PL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *		
14	Intermediatte Pressure Turbin	Expander	12 @	FPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *		
16	Low Pressure Turbine Stage 1	Expander	16 @	FPL1	19@TPL1	No	500.0 *		
18	Low Pressure Turbine Stage 2	Expander	23@	TPL1	LP Trb Stg 1 Pwr @TPL1 24 @TPL1	No	500.0 *		
19 20	Low Pressure Turbine Stage 3	Expander	25 @	ſPL1	LP Trbn Stg 2 Pwr @TPL1 29 @TPL1	No	500.0 *		
21	Low ressure furbine stages	Expander			LP Trbn Stg 3 Pwr @TPL1	NU	566.6		
22	Low Pressure Turbine Stage 4	E×pander	30 @	IPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *		
24 25	Low Pressure Turbine Stage 5	Expander	37 @	FPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *		
26 27	Feedwater Heater 6 @TPL1	Heat Exchanger	52 @	FPL1 V Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *		
28	Feedwater Heater 5 @TPL1	Heat Exchanger	50@	TPL1	51@TPL1	No	500.0 *		
29 30	Feedwater Heater 4 @TPL1	Heat Exchanger	11 @ 49 @	TPL1	14 @TPL1 50 @TPL1	No	500.0 *		
31 32	- counter rioutor right Er	Theat Excitating of	18 @ 46 @		20@TPL1 47@TPL1				
33	Feedwater Heater 3 @TPL1	Heat Exchanger	26 @	FPL1	27@TPL1	No	500.0 *		
34 35	Feedwater Heater 2 @TPL1	Heat Exchanger	45 @ 33 @		46@TPL1 34@TPL1	No	500.0 *		
36 37	Feedwater Heater 1 @TPL1	Heat Exchanger	44 @ 38 @		45@TPL1 39@TPL1	No	500.0 *		
38	Steam Generator @TPL1	Heat Exchanger	1@TI	PL1	2 @TPL1	No	500.0 *		
39 40			3 @TH	n Generator In @TPL1_ PL1	Steam Generator Out@TPL1 4 @TPL1				
41	Reheater @TPL1	Heat Exchanger		heater @TPL1	6 @TPL1	No	500.0 *		
42 43	Condenser @TPL1	Heat Exchanger	Coolin 40 @	ig Water In @TPL1 IPL1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *		
44 45	Boiler Feed Pump @TPL1	Pump	51 @		52@TPL1	No	500.0 *		
46	Booster Pump @TPL1	Pump	48 @	TPL1	49@TPL1	No	500.0 *		
48	Condensate Pump @TPL1	Pump	43 @		44@TPL1	No	500.0 *		
49 50	M1 @TPL1	Mixer	Cnd P 10 @	mp Pwr @TPL1 IPL1	11@TPL1	No	500.0 *		
51 52	-		8 @TH		18@TPL1				
53	M2 @TPL1	Mixer	15 @	FPL1		No	500.0 *		
54 55	Deaerating Heater @TPL1	Deaerating Heater @TPL1 Mixer		rpl1 rpl1	48@TPL1	No	500.0 *		
56 57			22 @ 36 @		38 @TPL1				
58	M4 @TPL1	Mixer	35 @	FPL1		No	500.0 *		
59 60	M3 @TPL1	Mixer	32 @ ⁻ 28 @ ⁻		33@TPL1	No	500.0 *		
61 62	M5@TPL1	Mixer	41 @	TPL1	43@TPL1	No	500.0 *		
63	Aspen Technology Inc. Aspe			42 @TPL1 en HYSYS Version 7.3 (25.0.0.7336)			Page 7 of 34		
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1				NA COOLED HTSE W SUPER CR	RITICAL RANKINE	V1.hsc
3	aspentech	BATTELLE ENERGY ALLIAN Burlington , MA		AFR		
4 5		USA	Date/Time:	Fri Mar 28 11:16:39 2014		
5						
7	Work	book: Ranking	e Power Cycle ((TPL1) (continue	ed)	
8 9				. ,.	•	
9 10			Unit Ops (continue	ed)		
11	Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
12	M7 @TPL1	Mixer	2@TPL1	Power Cycle Out @TPL1	No	500.0 *
13 14	VLV 3 @TPL1	Valve	4@TPL1 20@TPL1	21 @TPL1	No	500.0 *
15	VLV 4 @TPL1	Valve	27 @TPL1	28@TPL1	No	500.0 *
16	VLV 5 @TPL1	Valve	34 @TPL1	35@TPL1	No	500.0 *
17	VLV 1 @TPL1	Valve	9@TPL1	10@TPL1	No	500.0 *
18	VLV 2 @TPL1	Valve	14 @TPL1	15@TPL1	No	500.0 *
19 20	VLV 6 @TPL1 SG tb dP @TPL1	Valve Set	39 @TPL1	41@TPL1	No No	500.0 * 500.0 *
20	SG to dP @TPL1 SG sh dP @TPL1	Set			NO	500.0 *
22	FW6 tb dP @TPL1	Set			No	500.0 *
23	FW6 sh dP @TPL1	Set			No	500.0 *
24	FW4 tb dP @TPL1	Set	<u> </u>		No	500.0 *
25	FW5 tb dP @TPL1	Set			No	500.0 *
26 27	FW5 sh dP @TPL1 FW4 sh dP @TPL1	Set Set			No No	500.0 * 500.0 *
28	Cnd sh dP @TPL1	Set	1		No	500.0 *
29	FW1 tb dP @TPL1	Set			No	500.0 *
30	FW1 sh dP @TPL1	Set		Ì	No	500.0 *
31	FW2 tb dP @TPL1	Set			No	500.0 *
32	FW2 sh dP @TPL1	Set			No	500.0 *
33 34	FW3 tb dP @TPL1	Set			No No	500.0 *
35	FW3 sh dP @TPL1 Rht tb dP @TPL1	Set Set			No	500.0 * 500.0 *
36	SET-1@TPL1	Set			No	500.0 *
37	Cnd Tb dP @TPL1	Set			No	500.0 *
38	SET-3@TPL1	Set]		No	500.0 *
39	SET-4@TPL1	Set			No	500.0 *
40 41	SET-5@TPL1	Set			No	500.0 *
41 42	SET-6@TPL1 SET-7@TPL1	Set Set			No No	500.0 * 500.0 *
43	SET-8@TPL1	Set			No	500.0 *
44			5@TPL1	To FW Heater 6 @TPL1	No	500.0 *
45	T1@TPL1	Tee		To Reheater @TPL1	INU	300.0
46	T2@TPL1	Tee	7@TPL1	8 @TPL1	No	500.0 *
47 48			13 @TPI 1	12@TPL1 17@TPL1		
48 49	T3 @TPL1	Tee	13 @TPL1	16@TPL1	No	500.0 *
50		T	19 @TPL1	22@TPL1	ы	500 5 5
51	T4@TPL1	Tee		23@TPL1	No	500.0 *
52	T5@TPL1	Tee	24 @TPL1	26 @TPL1	No	500.0 *
53 54	9=.	-		25@TPL1		5.55.0
54 55	T6@TPL1	Tee	29 @TPL1	32@TPL1 30@TPL1	No	500.0 *
56			31 @TPL1	36@TPL1		
57	T7 @TPL1	Tee		37 @TPL1	No	500.0 *
58	T13 @TPL1	Тее	Power Cycle In @TPL1	3 @TPL1	No	500.0 *
59			<u> </u>	1 @TPL1		
60 61	Efficiency Calculations@TPL	Spreadsheet	Cooling Water Out @TPL1	Cooling Water In @TPL1	No	500.0 *
62	Cooling Tower @TPL1	Standard Sub-Flowsheet	Make Up Water @TPL1		No	2500 *
63	Aspen Technology Inc.	۵e	pen HYSYS Version 7.3 (2	5 0 0 7336)	• 1	Page 8 of 34

1		PATTELLE		_	Case Name:	NA CO	OLED HTSE w SUPER C	RITICAL RANKINE	E V1.hsc
3	espentech Work	Burlington, M	ENERGY ALLIANC 1A	=	Unit Set:	AFR			
4 5		USA			Date/Time:	Fri Mar	28 11:16:39 2014		
6		hooly	Donkine	Dar			1) (continu	od)	
8	VVOR	(DOOK:	Rankine	P0\	wer Cyci	e(IPI	L1) (continu	ea)	
9 10				Un	it Ops (conti	nued)			
11	Operation Name		ition Type		Feeds		Products	Ignored	Calc Level
12 13	Cooling Tower @TPL1	Standard Su	ub-Flowsheet	Total (Cooling Tower Po	wer @		No	2500 *
14 15									
10									
17 18									
19									
20 21									
22									
23 24									
24 25									
26 27									
28									
29 30									
31 32									
33									
34 35									
36									
37 38									
39									
40 41									
42 43									
43 44									
44 45 46									
46									
48 49 50									
51 52									
53									
54 55									
56									
57 58									
59									
60 61									
62 63	Aspon Tochnology In-		Acres		VC Vorsion 7	3 (25 0 0 7	7336)		Dago 0 of 34
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	ALLIANCE	ASPE	1112	SYS Version 7.3	5 (25.0.0.1	330.		Page 9 of 34 * Specified by user.

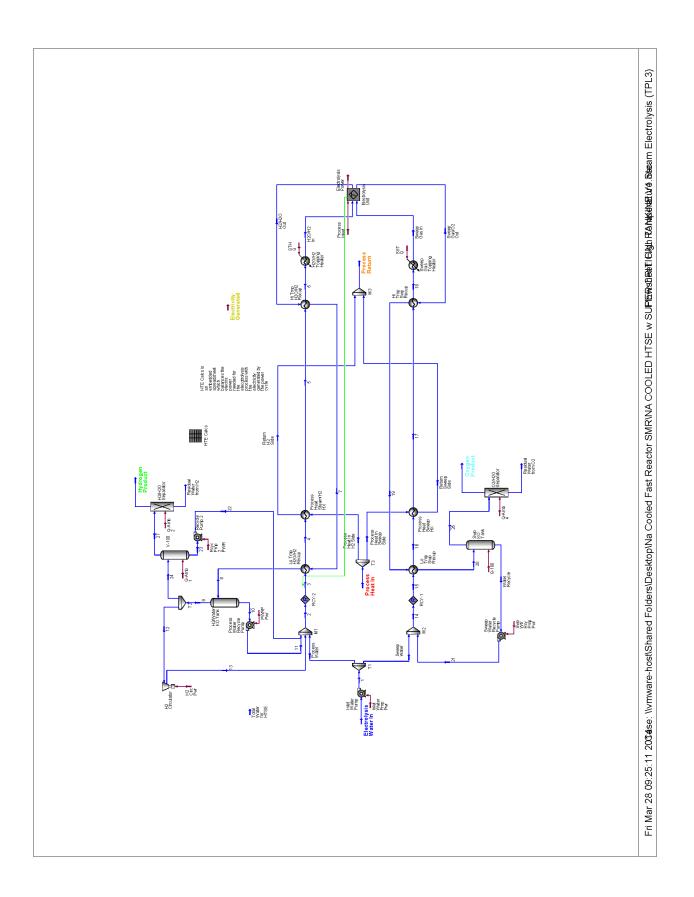
1				Case Name	NA COOLED HTSE	w SUPER CR	ITICAL RANKINE V1.hsc				
2		BATTELLE EN Burlington, MA	ERGY ALLIANCE	Unit Set:	AFR						
4 5	\sim	USA USA		Date/Time:	Fri Mar 28 11:16:39	2014					
6											
7 8		Spreadshee	t: Efficiend	cy Calcı	ulations @TF	PL1	Units Set: NuScale2				
9				CONNECT	IONS						
10 11				mported Va							
12	Cell	Object		inported va	Variable Description		Value				
14	B1	Energy Stream: HP Trbn Pv	vr@TPL1 Powe	r	Valiable Description		22.40 MW				
15	B2		1 Pwr@TPL1 Powe				11.61 MW				
16	B3	Energy Stream: IP Trbn Stg	2 Pwr@TPL1 Powe	r			12.54 MW				
17	B4		1 Pwr@TPL1 Powe	r			13.13 MVV				
18	B5		3 Pwr@TPL1 Powe 3 Pwr@TPL1 Powe				10.24 MVV				
19 20	B6 B7	10.06 MVV 11.26 MVV									
20	 B8		3 4 Pwr@TPL1 Powe 5 Pwr@TPL1 Powe				13.23 MW				
22	B9	Energy Stream: Cnd Pmp F					0.1429 MW				
23	B10	Energy Stream: Bstr Pmp P		r			0.5664 MVV				
24	D1	Energy Stream: BF Pmp Pv	r@TPL1 Powe	r			3.319 MVV				
25	D2	Energy Stream: Primary Pu	mp Pwr Powe	r			0.4345 MVV				
26	D3		Pump PWR Powe				0.2606 MVV				
27	D4		ng Tower Powe Powe				0.5756 MVV				
28 29	D5 C9	Energy Stream: Reactor He Tee: T1		riow Ratio (Flow Rati	- 1)		250.0 MVV 0.9061				
30	63	Tee. 11	FIUW	rtaliu (FIUW rtali	J_1)		0.9001				
31	Exported Variables' Formula Results										
32	Cell	Object			Variable Description		Value				
33	D7	Electricity Generated @TPL1	Powe	r			99.17 MVV				
34	F1	Steam Generator In @TPL1	Mass	Flow			98.32 kg/s				
35 36				PARAMET	ERS						
37 38			E	xportable V	ariables						
39	Cell	Visible Name		Variable	Description	Variable	e Type Value				
40	F1	F1: Mass Flow	Mass	Flow		Mass Flow	98.32 kg/s				
41	D7	D7: Power	Powe	r		Power	99.17 MVV				
42	D10	D10: Power	Powe			Mass Flow	108.5 kg/s				
43	D8	D8: Thermal Efficiency of Power Cy		nal Efficiency of	Power Cycle	Percent	43.78				
44 45	D6	D6: Total Turbine Power	iotal	Turbine Power		Power	104.5 MVV				
46				User Varia	bles						
47 48				FORMUL	AS						
49	Cell			Formula			Result				
50	D6	=B1+B2+B3+B4+B5+B6+B7+B8					104.5 MVV				
51	D7	=D6-B9-B10-D1-D2-D3-D4					99.17 MVV				
52	D8	=D7/(D5*C9)*100					43.78				
53 54	F1	=C9*D10					98.32 kg/s				
55				Spreadsh	leet						
56		А	В		С		D				
57	1	HP Trb Pwr *		22.40 MW *	В	FPmpPvvr*	3.319 MVV *				
58	2	IP Trb Stg 1 Pwr *		11.61 MW*		ump Power *	0.4345 MVV *				
59	3	IP Trb Stg 2 Pwr *		12.54 MW *	Secondary P		0.2606 MVV *				
60 61	4 5	LP Trb Stg 1 Pwr * LP Trb Stg 2 Pwr *		13.13 MW* 10.24 MW*		wer Power *	0.5756 MVV * 250.0 MVV *				
62	5 6	LP Trb Stg 2 Pwr *		10.24 MVV *		bine Power *	104.5 MVV *				
63		Technology Inc.	Aspen HY		7.3 (25.0.0.7336)		Page 10 of 34				
		D: BATTELLE ENERGY ALLIANCE					* Specified by user.				

1			Case Name:	NA COOLED HTSE w SUPER C	CRITICAL RANKINE V1.hsc
2		ENERGY ALLIANCE //A	Unit Set:	AFR	
4			Date/Time:	Fri Mar 28 11:16:39 2014	
6					
7	Spreadshe	et: Efficienc	cy Calcu	ulations @TPL1 (co	Ontinu Units Set: NuScale2
9			Spreadsh	eet	
10 11 7	LP Trb Stg 4 Pwr	•	11.26 MW *	Electricity Generated *	99.17 MVV *
12 8	LP Trb Stg 5 Pwr		13.23 MW *	Thermal Efficiency of Power Cycle *	43.78 *
13 9 14 10	Cnd Pmp Pwr 1		0.1429 MW*	0.9061 * 1000/ Decking Flow *	Power flow split * 108.5 kg/s *
14 10 15	Bstr Pmp Pwr ⁻ E	F	0.5664 MVV *	100% Rankine Flow *	108.5 KU/S
16 1	Mass Flow @ Steam Generator In *	•	98.32 kg/s *		
17 2 18 3					
19 4					
20 5 21 6					
22 7					
23 8					
24 9 25 10					
26	7				
27 28 29 30 31 32					
29					
30					
31					
32					
34					
35					
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38					
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49					
40 41					
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52 53 54 55 56 57 58 59 60					
60					
62					
	pen Technology Inc. Ised to: BATTELLE ENERGY ALLIANCE	Aspen HYS	SYS Version	7.3 (25.0.0.7336)	Page 11 of 34 * Specified by user.
2001					opcomeanly abor.



1				Case Name:	NA COOLED HTSE w.S	UPER CRITICAL RANKI	NE V1 hsc
2			ENERGY ALLIANCE				142 91,130
3 4	aspentech	Burlington, USA	MA	Unit Set:	AFR		
5		0011		Date/Time:	Fri Mar 28 11:16:39 201	4	
6							
7	Woi	rkbook:	Cooling To	ower (TPL2)			
9							
10				Material Stream	15	Fluid Pkg	j: All
11	Name		Cooling Water Out @1	53@TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
12 13	Vapour Fraction Temperature	(C)	0.0000	0.0000 25.00 *			1.0000 20.00 *
14	Pressure	(C) (MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
15	Molar Flow	(kgmole/h)	5.899e+005	5.899e+005	4.250e+005	4946	4.300e+005
16	Mass Flow	(kg/s)	2952	2952	3406	24.75	3431 *
17	Liquid Volume Flow	(m3/h)	1.065e+004	1.065e+004	1.418e+004	89.28	1.426e+004
18	Heat Flow	(MVV)	-4.678e+004	-4.690e+004			-350.7
19	Name		Sat Press@ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
20	Vapour Fraction		1.0000 *	1.0000	0.4302	1.0000 *	0.4302
21	Temperature	(C)	20.00	20.16	25.11	9.394	25.10
22 23	Pressure Malas Elaur	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013
23 24	Molar Flow Mass Flow	(kgmole/h)		4.300e+005 3431	1.020e+006 6383	4.300e+005 3431	1.020e+006 6383
24	Liquid Volume Flow	(kg/s) (m3/h)		1.426e+004	2.491e+004	1.426e+004	2.491e+004
26	Heat Flow	(MVV)		-350.2	-4.713e+004	-387.7	-4.713e+004
27	Name	(1111)	Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
28	Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
29	Temperature	(C)	25.10	25.10	25.10	25.10	25.10
30	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
31	Molar Flow	(kgmole/h)	4.388e+005	5.812e+005	589.9	2746	5.778e+005
32	Mass Flow	(kg/s)	3475	2908	2.952	13.74	2892
33	Liquid Volume Flow	(m3/h)	1.442e+004	1.049e+004	10.65	49.57	1.043e+004
34	Heat Flow	(MVV)	-923.1	-4.620e+004	-46.90	-218.3	-4.594e+004
35	Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
36 37	Vapour Fraction Temperature	(C)	0.9987 25.10	0.0000 * 20.00 *	0.0000 25.00	0.0000 25.00	
38	Pressure	(C) (MPa)	0.1013	0.1013	0.1013	0.1035	
39	Molar Flow	(kgmole/h)	4.394e+005	1.212e+004	5.899e+005	5.899e+005	
40	Mass Flow	(kg/s)	3478	60.64	2952	2952	
41	Liquid Volume Flow	(m3/h)	1.443e+004	218.8	1.065e+004	1.065e+004	
42	Heat Flow	(MVV)	-970.0	-964.8	-4.690e+004	-4.690e+004	
43				Compositions		Fluid Pkg	c All
44	Neme		Casting Mater Out @	•		Mater Vener @TDL2	Maiat Air @TDL 3
45 46	Name Comp Mole Frac (H2O)		Cooling Water Out @1 1.0000	53@TPL2 1.0000 *	Dry Air @TPL2 0.0000 *	Water Vapor @TPL2 1.0000 *	Moist Air @TPL2 0.0115
40	Comp Mole Frac (Nitrogen)		0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
48	Comp Mole Frac (Oxygen)		0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
49	Comp Mole Frac (Hydrogen	1)	0.0000	0.0000 *	0.0000 *	* 0.000.0	0.0000
50	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000 *	* 0.000.0	0.0000
51	Comp Mole Frac (CO)		0.0000	0.0000 *	0.0000 *	* 0.0000 *	0.0000
52	Comp Mole Frac (Sodium)		***	***	***	***	***
53	Comp Mole Frac (Air)		0.0000	0.0000 *	0.0000 *	* 0.0000 *	0.0000
54	Name		Sat Press@ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
55	Comp Mole Frac (H2O)		1.0000 *	0.0115	0.5833	0.0115	0.5833
56 57	Comp Mole Frac (Nitrogen)		***	0.7809	0.3292	0.7809	0.3292
57	Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen		***	0.2076	0.0875	0.2076	0.0000
59	Comp Mole Frac (Hydrogen Comp Mole Frac (CO2)	9	***	0.0000	0.0000	0.0000	0.0000
60	Comp Mole Frac (CO2)		***	0.0000	0.0000	0.0000	0.0000
61	Comp Mole Frac (Sodium)		***	***	***	***	***
62	Comp Mole Frac (Air)		***	0.0000	0.0000	0.0000	0.0000
60							
63	Aspen Technology Inc. Licensed to: BATTELLE ENERG		Aspen H	YSYS Version 7.3 (25.0.0.7336		Page 12 of 34 * Specified by user.

1	\sim			Case Name:	NA COOLED HTSE w S	UPER CRITICAL RANK	INE V1.hsc
3	aspentech	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 11:16:39 201	4	
6							
7 8	Work	book:	Cooling 1	ower (TPL2)	(continued))	
9				Compositions (conti	nued)	Fluid Pk	g: All
1U 11	Name		Saturated Air @TPL		, Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
12	Comp Mole Frac (H2O)		0.0313	1.0000	1.0000	1.0000	1.0000
13	Comp Mole Frac (Nitrogen)		0.7653	0.0000	0.0000	0.000	0.0000
14	Comp Mole Frac (Oxygen)		0.2034	0.0000	0.0000	0.0000	0.0000
15	Comp Mole Frac (Hydrogen)		0.0000	0.0000	0.0000	0.0000	0.0000
16	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.000.0	0.0000
17	Comp Mole Frac (CO)		0.0000	0.0000	0.0000	0.000.0	0.0000
18	Comp Mole Frac (Sodium)		***	***	***	***	***
19	Comp Mole Frac (Air)		0.0000	0.0000	0.0000	0.0000	0.0000
20	Name		Water Entrained Air		6 @TPL2	53a@TPL2	
21	Comp Mole Frac (H2O)		0.0326	1.0000 *	1.0000	1.0000	
22	Comp Mole Frac (Nitrogen)		0.7643	0.0000 *	0.0000	0.0000	
23	Comp Mole Frac (Oxygen)		0.2032	0.0000 *	0.0000	0.0000	
24	Comp Mole Frac (Hydrogen)		0.0000	0.0000 *	0.0000	0.0000	
25 26	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000	0.0000	
26	Comp Mole Frac (CO)		0.0000	0.0000 ~	U.UUUU	0.0000	
28	Comp Mole Frac (Sodium)			0.0000 *	0.0000	0.0000	
20	Comp Mole Frac (Air)		0.000	0.0000	0.0000	U.UUU	
30				Energy Streams	;	Fluid Pk	g: All
31	Name		Air Fan Power @TP	L2 Cooling Water Pump F	Total Cooling Tower P		
32	Heat Flow	(MW)	0.5670	8.509e-003	0.5756		
33 34				Unit Ops			
35	Operation Name	One	ration Type	Feeds	Products	Ignored	Calc Level
36	·			Dry Air @TPL2	Moist Air @TPL2		
37	M1 @TPL2	Mixer		Water Vapor @TPL2		No	500.0 *
38				1@TPL2	3 @TPL2		
39	M2 @TPL2	Mixer		Cooling Water Out @TPL2		No	500.0 *
40		Miran		Saturated Air @TPL2	Water Entrained Air	@TPL2	500.0 *
41	M3 @TPL2	Mixer		Entrained Water @TPL2		No	500.0 *
42	M4 OTD 0	Miran		Water Return @TPL2	6 @TPL2	N.	500.0 *
43	M4 @TPL2	Mixer		Make Up Water @TPL2			5000
44	Moist Air Conditions @TPL2					No	000.0
45	0	Spreadshe				No	500.0 *
	Water Cooling Calcs @TPL2	Spreadshe Spreadshe	et			No No	500.0 * 500.0 *
46	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2	Spreadshe Set	et			No No No	500.0 * 500.0 * 500.0 *
46 47	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2	Spreadshe Set Set	et			No No No No	500.0 * 500.0 * 500.0 * 500.0 *
46 47 48	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2	Spreadshe Set Set	et			No No No No	500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 50 51 52	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 50 51 52 53 54 55	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 55 56 57	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 55	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 56 57 58 59	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 56 57 58	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set	et			No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Water Cooling Calcs @TPL2 Sat Temp for moist air @TPL2 Dew Point Pressure @TPL2 Amb Press Set @TPL2	Spreadshe Set Set Set Set	et	HYSYS Version 7.3 (2	5.0.0.7336)	No No No No No No	500.0 * 500.0 * 500.0 * 500.0 * 500.0 *



1				Case Name:	NA COOLED HTSE w S	UPER CRITICAL RANK	INE V1.hsc
2 3	aspentech	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 11:16:39 201	4	
5							
7	Wo	rkbook	High Temp	perature Ste	am Electrol	ysis (TPL3)	
9 10				Material Stream	s	Fluid Pk	g: All
11	Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
12	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
13	Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6
14	Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042
15	Molar Flow	(kgmole/h)	3509	3509	1406	704.2	3509
16	Mass Flow	(kg/s)	12.88	6.643	9.762	3.526	6.643
17	Liquid Volume Flow	(m3/h)	74.71	89.88	32.45	12.72	89.88
18 19	Heat Flow	(MVV)	-138.8	-46.60	-36.73	-41.72	-55.95
20	Name Vapour Fraction		6 @TPL3 1.0000	5@TPL3 1.0000	18 @TPL3 1.0000	19 @TPL3 1.0000	17@TPL3 1.0000
20	Temperature	(C)	757.2	510.0 *	794.4	641.2	510.0 *
22	Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482
23	Molar Flow	(kgmole/h)	3509	3509	704.2	1406	704.2
24	Mass Flow	(kg/s)	12.88	12.88	3.526	9.762	3.526
25	Liquid Volume Flow	(m3/h)	74.71	74.71	12.72	32.45	12.72
26	Heat Flow	(MVV)	-140.4	-149.8	-41.77	-39.15	-44.18
27	Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000	0.6276
29	Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5
30	Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634
31	Molar Flow	(kgmole/h)	1.559e+004	1.559e+004	1838	1838	3509
32	Mass Flow	(kg/s)	99.58	99.58	11.74	11.74	12.88
33	Liquid Volume Flow	(m3/h)	381.5	381.5	44.96	44.96	74.71
34 35	Heat Flow Name	(MVV)	68.75 20 @TPL3	47.70 26 @TPL3	8.102 Water Recycle @TPL3	5.622 Sweep Water @TPL3	-170.8 21@TPL3
35	Vapour Fraction		20 @TPL3 0.8415	26 @ TPL3 1.0000	0.0000	Sweep vvater @TPL3	21(@1PL3 0.0000
37	Temperature	(C)	222.8	100.0 *	100.0	21.77	100.1
38	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
39	Molar Flow	(kgmole/h)	1406	716.3	689.4	14.75	689.4
40	Mass Flow	(kg/s)	9.762	6.310	3.452	7.380e-002	3.452
41	Liquid Volume Flow	(m3/h)	32.45	20.00	12.45	0.2662	12.45
42	Heat Flow	(M <i>\</i> √)	-47.28	-0.6359	-53.62	-1.173	-53.62
43	Name		14 @TPL3	15 @TPL3	16@TPL3	8 @TPL3	9 @TPL3
44	Vapour Fraction		0.0000	0.0000	0.9063	0.7769	1.0000
45	Temperature	(C)	98.49	98.48 *	290.8	158.5	158.5
46	Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901
47	Molar Flow	(kgmole/h)	704.2	704.2	704.2	3509	2726
48	Mass Flow	(kg/s)	3.526	3.526 *	3.526	6.643	2.729
49 50	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	12.72 _54.79	-54.79	12.72 -46.66	-75.15	-15.30
51	Name	(m vv)	-54.79 10 @TPL3	-54.79 12@TPL3	-40.00 24 @TPL3	13 @TPL3	-15.30 11@TPL3
52	Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000
53	Temperature	(C)	158.5	158.5	158.5	178.6	158.6
54	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
55	Molar Flow	(kgmole/h)	782.8	1168	1558	1168	782.8
56	Mass Flow	(kg/s)	3.914	1.169	1.560	1.169	3.914
57	Liquid Volume Flow	(m3/h)	14.14	32.45	43.29	32.45	14.14
58	Heat Flow	(MVV)	-59.85	-6.556	-8.745	-6.362	-59.84
59							
60							
61							
62	Aspen Technology Inc		Annen I	YSYS Version 7.3 (2	25.0.0.7336		Dage 14 of 24
00	Licensed to: BATTELLE ENER		Aspenie	11313 Vel3I0I17.3 (.	20.0.0.7000		* Specified by user.
	Source DATIELE ENER						opeoned by door.

1			Case Name:	NA COOLED HTSE w 5	UPER CRITICAL RANK	INE V1 hsc
2 3	aspentech Barringt	LE ENERGY ALLIANCE	Unit Set:	AFR		
4			Date/Time:	Fri Mar 28 11:16:39 201	4	
5 6			Date/Time.	111 Mar 20 11.10.00 201	7	
7	Workboo	k: High Tem	perature Ste	eam Electrol	vsis (TPL3)	(continued)
8		J			, (,	·,
9 10		Mat	erial Streams (co	ntinued)	Fluid Pkç	g: All
11	Name	Electrolysis Water In @	3 @TPL3	2 @TPL3	1@TPL3	Process Water @TPL
12	Vapour Fraction	0.0000	0.3055	0.3055	0.0000	0.0000
13	Temperature (C		104.8 *	104.8	21.77	21.77
14	Pressure (MPa		7.790 *	7.790	7.790 *	7.790
15	Molar Flow (kgmole/h		3509	3509	1422	1407
16 17	Mass Flow (kg/s		12.88 *	12.88	7.116	7.042
18	Liquid Volume Flow (m3/h) Heat Flow (MW		74.71	74.71	25.67	25.40 -111.9
19	Name	Hydrogen Product @1	23 @TPL3	Oxygen Product @TPI	Residual Water from C	Process Heat In @TP
20	Vapour Fraction	1.0000	0.0000	1.0000	0.0000	0.0000
21	Temperature (C		54.44 *	54.44 *	54.44 *	530.0
22	Pressure (MPa		6.901	6.901	0.1013 *	0.7011
23	Molar Flow (kgmole/h	1403	150.7	701.6	14.75	1.743e+004
24	Mass Flow (kg/s	0.7858	0.7540	6.236	7.380e-002	111.3
25	Liquid Volume Flow (m3/h		2.720	19.73	0.2662	426.5
26	Heat Flow (MW)		-11.88	6.804e-002	-1.163	76.85
27	Name	Process Return @TPL	22@TPL3	27 @TPL3	Residual Water from H	Total Water for HTSE
28	Vapour Fraction	0.0000	0.0000	1.0000	0.0000	0.0000
29	Temperature (C		54.53	54.44	54.44 *	21.11 *
30	Pressure (MPa)		7.790	6.901	0.1013 *	0.1013 *
31	Molar Flow (kgmole/h) Mass Flow (kg/s		150.7 0.7540	1407 0.8057	3.981 1.992e-002	2431
33	Liquid Volume Flow (rg/s)		2.720	40.57	7.186e-002	43.89
34	Heat Flow (MVV		-11.88	6.378e-002	-0.3140	-193.5
35		00108				
36			Compositions		Fluid Pk	
37 38	Name	H2O/H2 In @TPL3 0.6999	H2/H2O Out @TPL3 0.3000	Sweep Gas/O2 Out @ 0.5005	Sweep Gas In @TPL3 0.9992	7 @TPL3
39	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.3000
40	Comp Mole Frac (Oxygen)	0.0000	0.0000	0.4995	0.0008	0.0000
41	Comp Mole Frac (Hydrogen)	0.3001	0.7000	0.0000	0.0000	0.7000
42	Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
43	Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.000	0.0000
44	Comp Mole Frac (Sodium)	***	***	***	***	***
45	Comp Mole Frac (Air)	***	***	***	***	***
46	Name	6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17@TPL3
47	Comp Mole Frac (H2O)	0.6999	0.6999	0.9992	0.5005	0.9992
48	Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
49	Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0008	0.4995	0.0008
50 51	Comp Mole Frac (Hydrogen)	0.3001	0.3001	0.0000	0.0000	0.0000
52	Comp Mole Frac (CO2) Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
53	Comp Mole Frac (CO) Comp Mole Frac (Sodium)	0.0000	0.0000	0.0000	0.0000	0.0000
54	Comp Mole Frac (Air)	***	***	***	***	***
55						
56						
57						
58						
59						
60						
61						
62			N/01/0 1/			
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY ALLIANCE		HYSYS Version 7.3 (25.0.0.7336)		* Specified by user
	LICENSED ID: BATTELLE ENERGY ALLIANCE					* Specified by user.

1	<u>_</u>		Case Name:	NA COOLED HTSE w S	UPER CRITICAL RANK	INE V1.hsc
3	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4			Date/Time:	Fri Mar 28 11:16:39 201	4	
5 6			Bato, Finito.	1111111120 11110.00 201		
7	Workbook:	High Temp	perature Ste	am Electrol	ysis (TPL3)	(continued)
9 10		Co	mpositions (conti	nued)	Fluid Pkç	j: All
11	Name	Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
12	Comp Mole Frac (H2O)	***	***	***	***	0.6999
13	Comp Mole Frac (Nitrogen)	***	***	***	***	0.0000
14	Comp Mole Frac (Oxygen)	***	***	***	***	0.0000
15	Comp Mole Frac (Hydrogen)	***	***	***	***	0.3001
16	Comp Mole Frac (CO2)	***	***	***	***	0.0000
17	Comp Mole Frac (CO)	***	***	***	***	0.0000
18	Comp Mole Frac (Sodium)	1.0000	1.0000	1.0000	1.0000	***
19	Comp Mole Frac (Air)	***	***	***	***	***
20	Name	20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21@TPL3
21	Comp Mole Frac (H2O)	0.5005	0.0206	0.9992	1.0000 *	0.9992
22	Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
23	Comp Mole Frac (Oxygen)	0.4995	0.9794	0.0008	* 0.0000 *	0.0008
24	Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	* 0.000 *	0.0000
25 26	Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	* 0.000 *	0.0000
	Comp Mole Frac (CO)		0.0000	0.0000	0.0000 *	0.0000
27 28	Comp Mole Frac (Sodium)	***	***	***	***	***
29	Comp Mole Frac (Air) Name	14 @TPL3				
30	Comp Mole Frac (H2O)	0.9992	15@TPL3 0.9992 *	16 @TPL3 0.9992	8@TPL3 0.3000	9 @TPL3 0.0993
31	Comp Mole Frac (Nitrogen)	0.9992	0.0000 *	0.0000	0.0000	0.0000
32	Comp Mole Frac (Oxygen)	0.0008	0.0008 *	0.0008	0.0000	0.0000
33	Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.0000	0.7000	0.9007
34	Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.000	0.0000
35	Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	0.0000
36	Comp Mole Frac (CC)	***	***	***	***	***
37	Comp Mole Frac (Air)	***	***	***	***	***
38	Name	10 @TPL3	12@TPL3	24 @TPL3	13 @TPL3	11@TPL3
39	Comp Mole Frac (H2O)	0.9989	0.0993	0.0993	0.0993	0.9989
40	Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
41	Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
42	Comp Mole Frac (Hydrogen)	0.0011	0.9007	0.9007	0.9007	0.0011
43	Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
44	Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
45	Comp Mole Frac (Sodium)	***	***	***	***	***
46	Comp Mole Frac (Air)	***	***	***	***	***
47	Name	Electrolysis Water In @	3 @TPL3	2 @TPL3	1@TPL3	Process Water @TPL
48	Comp Mole Frac (H2O)	1.0000 *	0.6999 *	0.6999	1.0000	1.0000 *
49	Comp Mole Frac (Nitrogen)	* 0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
50	Comp Mole Frac (Oxygen)	* 0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
51	Comp Mole Frac (Hydrogen)	* 0.0000 *	0.3001 *	0.3001	0.0000	0.0000 *
52	Comp Mole Frac (CO2)	* 0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
53	Comp Mole Frac (CO)	* 0.0000	0.0000 *	0.0000	0.0000	0.0000 *
54	Comp Mole Frac (Sodium)	***	***	***	***	***
55	Comp Mole Frac (Air)	***	***	***	***	***
56 57						
57						
50						
60						
61						
62						
63	Aspen Technology Inc.	Asnen H	YSYS Version 7.3 (2	25.0.0.7336		Page 16 of 34
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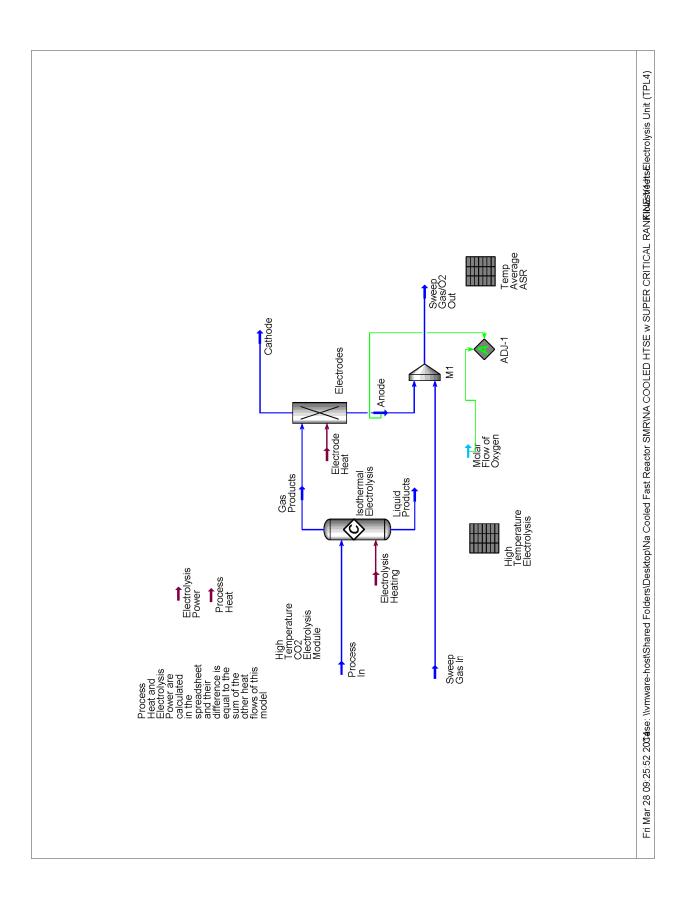
1					Case Name:	NA	A COOLED HTSE w S	UPER CR	ITICAL RANKI	NE V1.hsc
3		BATTELLE Burlington,	ENERGY ALLIAN	CE	Unit Set:	AF				
4	C aspentech	USA	MA		Offic Sec.	AF	-1			
5					Date/Time:	Fri	i Mar 28 11:16:39 201	4		
6										
7	Work	book:	High Te	mpe	erature Ste	a	m Electroly	ysis (TPL3)	(continued)
8 9										
9				Com	positions (conti	nu	led)		Fluid Pkg	: All
11	Name		Hydrogen Produ	t@T 2	3@TPL3	С	Οxygen Product @TPI	Residua	l Water from C	Process Heat In @TPI
12	Comp Mole Frac (H2O)		0.00	100	0.9998		0.0000		1.0000	***
13	Comp Mole Frac (Nitrogen)		0.00	100	0.0000		0.0000		0.0000	***
14	Comp Mole Frac (Oxygen)		0.00	100	0.0000		1.0000		0.0000	***
15	Comp Mole Frac (Hydrogen)		1.00		0.0002		0.0000		0.0000	***
16	Comp Mole Frac (CO2)		0.00		0.0000		0.0000		0.0000	***
17	Comp Mole Frac (CO)		0.00	***	0.0000		0.0000		0.0000	***
18	Comp Mole Frac (Sodium)			***	***		***		***	1.0000
19	Comp Mole Frac (Air) Name		Process Return (2@TPL3	2	 7 @TPL3	Residuo	I Water from H	Total Water for HTSE
20	Comp Mole Frac (H2O)		FIDLESS Return (***	0.9998	2	0.0028	rtesiuua	1.0000	1.0000 *
22	Comp Mole Frac (Nitrogen)			***	0.0000		0.0000		0.0000	0.0000 *
23	Comp Mole Frac (Oxygen)			***	0.0000		0.0000		0.0000	0.0000 *
24	Comp Mole Frac (Hydrogen)			***	0.0002		0.9972		0.0000	0.0000 *
25	Comp Mole Frac (CO2)			***	0.0000		0.0000		0.0000	0.0000 *
26	Comp Mole Frac (CO)			***	0.0000		0.0000		0.0000	0.0000 *
27	Comp Mole Frac (Sodium)		1.00		***		***		***	***
28	Comp Mole Frac (Air)			***	***		***		***	***
29					Energy Streams	s			Fluid Pkg	: All
30	NI		D					0 144		
31 32	Name Heat Flow	(MVV)	Process Heat @ 2.762e-0		ectrolysis Power @1 -97.14-	5	GT Q @TPL3 5.078e-002		Rcy Pmp Pw 4.305e-003	H2 Circ Pwr @TPL3 0.1935
33	Name	(141 V V)	PWRP Pwr @TF		-97.14 STH Q @TPL3	lr.	nlet Water Pmp Pwr @		4.305e-003 V Generated (Q-Amb 2 @TPL3
34	Heat Flow	(MVV)	5.168e-0		1.656		7.221e-002	Electricit	99.17	-4.594e-002
35	Name	(1177)	Q-Amb 4 @TPL3		Royc Pmp 2 PWR @T	C	Q-Amb 1 @TPL3	Q-100 @		1.0010 002
36	Heat Flow	(MVV)	-0.45	-	9.060e-004		-3.070		-6.982	
37					l Init On a		•			
38					Unit Ops	_				
39	Operation Name	Oper	ration Type	<u> </u>	Feeds	4	Products		Ignored	Calc Level
40					H2 In @TPL3		H2/H2O Out @TPL			
41 42	Electrolysis Unit @TPL3	Standard 5	Sub-Flowsheet		p Gas In @TPL3	+	Sweep Gas/O2 Out		No	2500 *
42				6 @ T	ess Heat @TPL3	+	Electrolysis Power (201PL3		
43	H2O/H2 Topping Heater @TP	Heater			Q@TPL3		H2O/H2 In @TPL3		No	500.0 *
45				18 @		+	Sweep Gas In @TP	L3		
46	Sweep Gas Topping Heater @	Heater		\vdash	Q @TPL3	1			No	500.0 *
47				5@T		Í	6 @TPL3			500.0 t
48	Hi Tmp H2O/H2 Recup @TPL	Heat Exch	anger	H2/H	20 Out @TPL3		7 @TPL3		No	500.0 *
49	Hi Tmp Swp Recup @TPL3	Heat Exch	anger	17 @	TPL3		18 @TPL3		No	500.0 *
50	n nip onp receip @ n zo	Troat Exon	anger		p Gas/O2 Out @TPL3	3	19 @TPL3		140	000.0
51	Process Heat Steam/H2 HX @	Heat Exch	anger	4@T		\downarrow	5 @TPL3		No	500.0 *
52			-		ess Heat In H2 Side @	277	Return H2 Side @T	PL3		
53 54	Process Heat Sweep HX @TF	Heat Exch	anger	16 @			17 @TPL3		No	500.0 *
55					ess Heat In Sweep Sid TPL3	ie e	Return Sweep Side 16 @TPL3	@IPL3		
56	Lo Tmp Swp Recup @TPL3	Heat Exch	anger		TPL3	+	20 @TPL3		No	500.0 *
57				3@1		+	4 @TPL3			
58	Lo Tmp H2O/H2 Recup @TPL	Heat Exch	anger	7@1			8 @TPL3		No	500.0 *
59				20 @			Water Recycle @TF	PL3		
60	Swp KO Tank @TPL3	Separator		Q-10) @TPL3		26 @TPL3		No	500.0 *
						_	Q-100 @TPL3			
61									No	E 00 0 *
61 62	H2/Water KO Tank @TPL3 Aspen Technology Inc.	Separator		8@T	PL3 SYS Version 7.3 (2		10@TPL3		No	500.0 * Page 17 of 34

1				A COOLED HTSE W SUPER CRI		V1.hsc
3	aspentech	BATTELLE ENERGY ALLIANC Burlington, MA	Unit Set: AF	FR		
4 5	- aspontoon	USA	Date/Time: Fr	i Mar 28 11:16:39 2014		
6						
7	Work	book: High Ter	mperature Stea	m Electrolysis (TPL3) (c	ontinued)
8 9			Unit Ops (continued			
10	Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
12	H2/Water KO Tank @TPL3	Separator	reeus	9 @TPL3	No	500.0 *
13			24 @TPL3	23@TPL3		
14	V-100 @TPL3	Separator	Q-Amb 1@TPL3	27 @TPL3	No	500.0 *
15				Q-Amb 1 @TPL3		
16	Sweep Water Recycle Pump (Pump	Water Recycle @TPL3	21 @TPL3	No	500.0 *
17			Swp Wtr Rcy Pmp Pwr @TPL 10 @TPL3	11 @TPL 2		
19	Process Water Recycle Pump	Pump	PWRP Pwr @TPL3	11@TPL3	No	500.0 *
20		_	Electrolysis Water In @TPL3	1 @TPL3		
21	Inlet Water Pump @TPL3	Pump	Inlet Water Pmp Pwr @TPL3		No	500.0 *
22	Recycle Pump 2 @ TDL 2	Pump	23 @TPL3	22@TPL3	No	500.0 *
23	Recycle Pump 2 @TPL3	r unip	Rcyc Pmp 2 PWR @TPL3		UVI	ວບບ.ບ
24	M2 @TPL3	Mixer	Sweep Water @TPL3	14 @TPL3	No	500.0 *
25	-		21 @TPL3			
26 27			13 @TPL3	2 @TPL3		
28	M1 @TPL3	Mixer	11 @TPL3 Process Water @TPL3		No	500.0 *
29			22 @TPL3			
30			Return Sweep Side @TPL3	Process Return @TPL3		
31	M3 @TPL3	Mixer	Return H2 Side @TPL3		No	500.0 *
32	RCY-1 @TPL3	Recycle	14 @TPL3	15@TPL3	No	3500 *
33	RCY-2 @TPL3	Recycle	2@TPL3	3 @TPL3	No	3500 *
34	H2 Circulator @TPL3	Compressor	12 @TPL3	13@TPL3	No	500.0 *
35		·	H2 Circ Pwr @TPL3			
36 37	T2@TPL3	Tee	9@TPL3	24 @TPL3 12 @TPL3	No	500.0 *
38			1@TPL3	Sweep Water @TPL3		
39	T1@TPL3	Tee	riginizo	Process Water @TPL3	No	500.0 *
40		T	Process Heat In @TPL3	Process Heat In H2 Side @TF	N	500.0 *
41	T3 @TPL3	Tee		Process Heat In Sweep Side (No	500.0 *
42	HTE Calcs @TPL3	Spreadsheet			No	500.0 *
43	LTHR Tb dP @TPL3	Set			No	500.0 *
44 45	PHSH Tb dP @TPL3 HTHR Tb dP @TPL3	Set Set			No	500.0 * 500.0 *
45 46	HTH dP @TPL3	Set			No No	500.0 *
40	HTHR Sh dP @TPL3	Set			No	500.0 *
48	LTSR Sh dP @TPL3	Set			No	500.0 *
49	LTSR Tb dP @TPL3	Set			No	500.0 *
50	PHSH Sh dP @TPL3	Set			No	500.0 *
51	SET-1@TPL3	Set			No	500.0 *
52	SET-2@TPL3	Set			No	500.0 *
53 54	HTSR ShidP @TPL3	Set			No	500.0 *
54 55	SET-3@TPL3	Set			No	500.0 *
56						
57						
58						
59						
60						
61						
62						
63	Aspen Technology Inc.	Aspe	en HYSYS Version 7.3 (25.	0.0./336		Page 18 of 34

1				Case Name: N/	A COOLED HTSE W			E V1.hsc
2 3 4	espentech	BATTELLE ENERGY ALLIANC Burlington, MA		Unit Set: AF	R			
4 5		USA		Date/Time: Fr	i Mar 28 11:16:39 2	014		
6		de e el contrato 🔽		- 1		l		-
7 8	vvork	kbook: High Te	mpera	ature Stea	m Electro	iysis (TPL3) (continued)
9 10			Unit	Ops (continued	l)			
11	Operation Name	Operation Type		Feeds	Products	s	Ignored	Calc Level
12 13								
14								
15 16								
17 18								
19								
20 21								
22								
23 24								
25								
26 27								
28 29								
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31 32								
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42 43								
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44 45 46								
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48 49								
50 51								
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56 57								
58 59								
59 60								
61 62								
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY		en HYSY:	S Version 7.3 (25.	0.0.7336)			Page 19 of 34 * Specified by user.

1			Case Name: NA COOLED I	HTSE W SUPER CRITICAL RAN	NKINE V1.hsc								
2		BATTELLE ENERGY ALLIAN Burlington, MA	CE Unit Set: AFR										
4	d	spentech ^{Burlington, MA} USA	Date/Time: Fri Mar 28 11:	16:39 2014									
5 6			Datornine. Thimai 20 ff.	10.00 2014									
7		Spreadsheet: HTE	Calcs @TPL3	l.	Jnits Set: NuScale								
8 9		-											
10	CONNECTIONS												
11	1 2 Imported Variables												
12	Cell	Object	· Variable Descrip	tion	Value								
14	B1	Material Stream: Residual Water from H2 @	Mass Flow		1.992e-002 kg/s								
15	B2	Material Stream: Residual Water from O2 @	Mass Flow		7.380e-002 kg/s								
16	B3	Material Stream: H2O/H2 In @TPL3	Master Comp Mass Flow (H2O)		44240.7588 kg/h								
17	B4		18961.5892 kg/h										
18	D1	Energy Stream: Rcyc Pmp 2 PWR @TPL3	Power		9.060e-004 MW								
19	D2	Energy Stream: H2 Circ Pwr @TPL3	Power		0.1935 MVV								
20	D3	Energy Stream: PWRP Pwr @TPL3	Power		5.168e-003 MW								
21	D4	Energy Stream: Inlet Water Pmp Pwr @TF	Power		7.221e-002 MW								
22	D5 D7	Energy Stream: Swp Wtr Rcy Pmp Pwr @ Energy Stream: STH Q @TPL3	Power Heat Flow		4.305e-003 MW 1.656 MVV								
23	D7	Energy Stream: STH Q @TPL3 Energy Stream: SGT Q @TPL3	Heat Flow Heat Flow		5.078e-002 MW								
25	D10	Energy Stream: Electrolysis Power @TPL3	Power		-97.14 MVV								
26	B6	Heat Exchanger: Process Heat Steam/H2 H	Exchanger Cold Duty		21.05 MVV								
27	B7	Heat Exchanger: Process Heat Sweep HX (Exchanger Cold Duty		2.480 MVV								
28	B10	Energy Stream: Electricity Generated @TF	Power		99.17 MVV								
29	E1	Energy Stream: Q-100 @TPL3	Heat Flow		-6.982 MW								
30	E2	Energy Stream: Q-Amb 1 @TPL3	Heat Flow		-3.070 MVV								
31	E3	Energy Stream: Q-Amb 2 @TPL3	Heat Flow		-4.594e-002 MVV								
32	E4	Energy Stream: Q-Amb 4 @TPL3	Heat Flow		-0.4592 MW								
33	F6	Heat Exchanger: Condenser @TPL1	Exchanger Cold Duty		126.7 MVV								
34	F7	Energy Stream: Total Cooling Tower Powe	Power		0.5756 MVV								
35	F8	Material Stream: Make Up Water @TPL2	Mass Flow		60.64 kg/s								
36	F1	Material Stream: Hydrogen Product @TPL3	Mass Higher Heating Value		1.404e+005 kJ/kg								
37 38	F2	Material Stream: Hydrogen Product @TPL3	Mass Flow		0.7858 kg/s								
38	F3	Energy Stream: Reactor Heat	Heat Flow		250.0 MVV								
40		Exp	orted Variables' Formula Results										
41	Cell	Object	Variable Descrip	tion	Value								
42	F11	Total Water for HTSE @TPL3	Mass Flow		12.17 kg/s								
43 44			PARAMETERS										
44 45													
46		1	Exportable Variables	1	1								
47	Cell	Visible Name	Variable Description	Variable Type	Value								
48	B5	B5: Water Loss	Water Loss	Mass Flow	7.116 kg/s								
49	D6	D6: Total Power for flow	Total Power for flow	Power	0.2761 MVV								
50	D9	D9: Total Topping Heat	Total Topping Heat	Energy	1.707 MVV								
51	B8	B8:		Energy	23.53 MVV								
52 53	B9 B11	B9: B11:		Power Power	99.17 MW 1.912e-004 MW								
54	C11	C11:		Power	0.1912 MVV								
55	F5	F5:		Energy	10.56 MVV								
56	F9	F9:		Power	4.795e-002 MW								
57	F10	F10:		Mass Flow	5.052 kg/s								
58	F11	F11: Mass Flow	Mass Flow	Mass Flow	12.17 kg/s								
59	59 D11 D11: Power 8.259e-002 MW												
60	F4	F4: Hydrogen Production Efficiency	Hydrogen Production Efficiency	Percent	44.12								
61			User Variables										
62	0	Facharala mula a			Dan- 00 -601								
63		Fechnology Inc. Asp BATTELLE ENERGY ALLIANCE	en HYSYS Version 7.3 (25.0.0.7336)		* Specified by user.								
					оростой бу цэст.								

BATTELLE DENDOY ALLANCE Usa Lat Set ATE Batter in the set of	1				Case Name:	NA COOLED HTSE w SUPER CF	RITICAL RAN	KINE V1.hsc
Cosperition Usa Determin Fit Mar 28 11 18 38 2014 Cosperation Spreadsheet: HTE Calcs @TPL3 (continued) Units Set Nussele Cosperation Formula Formula Interval Nussele Cosperation Formula Formula Tessule Nussele Cosperation Formula Formula Formula Pressile B -state of the Set 2035 W/L Besole -state B -state of the Set 2035 W/L Besole -state B -state of the Set 2035 W/L Besole -state D -state D -state D D D -state D -state D D D D -state State State D D D D D D -state State State State D D D D D D D D D <thd< th=""> D D</thd<>	2				Unit Set:	AFR		
Spreadsheet: HTE Calcs @TPL3 (continued) Units Gitt: Muddate 1 FORMULAS FORMULAS T110 kg6 1 Cell -01-927-493-649/3800 7110 kg6 23.53 kW7 2 B8 -19-927-493-649/3800 7110 kg6 00.17 kW7 2 B9 -19-927-493-649/3800 00.17 kW7 00.17 kW7 2 B9 -19-927-493-649/3800 0.13 kW7 00.17 kW7 2 B9 -19-927-493-649/3800 0.13 kW7 0.13 kW7 2 B9 -19-927-1970-1970 0.02 kW7 0.02 kW7 2 B1 -19-1970-1970-100 0.03 kW7 10.32 kW7 2 F5 -19-1970-100 0.02 kW7 0.02 kW7 2 F5 <td< th=""><th>4</th><th>C</th><th></th><th></th><th></th><th></th><th></th><th></th></td<>	4	C						
Spreadsheet: HTE Calcs @TPL3 (continued) Units Bit Nuclear 0 FORMULAS Formuls Reads 7.1184ps 1 66 7.1184ps 2.333MV 10 B5 -81+62+135.81/(3500) 7.1184ps 3.337MV 10 B8 -80-67 .9317MV 9.337MV 10 B9 -00-67010+59 .9317MV .9317MV 10 D9 -10-62-00-40-55 .02761 MW .01912 AV 10 D9 -27-68 .1327MV .41192 AV 11 -261-62-00-40-55 .1277 MW .41192 AV 12 F4 -16782*101000 .4219 AV 13 F4 -16782*101000 .4219 AV 14 1358-000 kg/s C D 14 T456*170 .559 kg/s .599 kg/s 14 1496-00 kg/s C D 15 F4 -16977 MW .699 kg/s 16 Paisted/D hen H2 7388-0001 kg/s C	5				Date/Time:	Fri Mar 28 11:16:39 2014		
State FORMULAS 11 Cell Formula Feault 12 B6 =81+82+(83.89/3600 7.118 sg/s 13 B8 =86+82 23.53 M/Y 14 B8 =86+82 23.53 M/Y 15 B8 =86+82 23.53 M/Y 16 B11 =10-80 1.812-60.01 M/Y 15 D1 =10-22 0.172 M/Y 0.1912 AW/Y 15 D4 =10-22 0.272 H/W 0.272 H/W 15 D4 =10-22 0.272 H/W 0.272 H/W 16 D11 =10-22 0.272 H/W 1.92 M/Y 17 D11 =10-22 0.276 H/W 1.92 M/Y 18 D11 =10-22 1.92 M/Y 1.93 M/Y 19 =55 H-12 1.92 M/Y 1.93 M/Y 21 F6 =61 H/2 Tram 4.12 K/HY 22 1 Read H/D Tram H/2 1.92 M/Y 1.92 M/Y 23 Marat trans trans 7.118 kg/Y			Spreadshe	et: HTE Cald	s @TPL3	(continued)	ι	Inits Set: NuScale
FORMULAS Cell Famula Result 12 B5 -201+02/025-04/050 7.118 kgs 13 B9 -208-05-010+79 23.31 M/M 14 B91 -208-05-010+79 99.17 M/M 15 B11 -011-000 0.112-00-14 M/M 16 C11 -611-0100 0.912 M/M 17 D9 -507-063 1.073 M/M 18 D1 -011-02-04-04/05 0.2751 M/M 19 F4 -417-262 *10000 -414 19 -564-07 -458-072 4195-002 M/M 21 F9 -564-07 -458-072 4195-002 M/M 22 P9 -564-07 -000 121 kgs 23 - Spreadsheet 0.602 kgs 121 kgs 24 Result H20 from H2* 1.892-002 M/M 141 Bes-002 M/M 25 Water rute Calls* 1.4930-002 M/M 3.080-000 M/M 24 Result H20 from H2* 1.902-002 kgs Roye Pmp Z+M* 6.0000-000 M			opreadone			(continuou)		
Coll Formula Result 11 Coll 7.18 Gys 7.18 Gys 12 B9 -28 H07 23 51 MW 13 B9 -28 H07 23 51 MW 14 B9 -28 H07 28 51 MW 15 B11 -810 Gys 18 12 - 400 MW 16 C11 -51 H00 0.912 MW 17 D6 -01 - 40 - 40 - 40 - 5 0.721 MW 17 D11 -01 - 40 - 40 - 40 - 5 0.721 MW 17 D11 -01 - 40 - 40 - 40 - 5 0.721 MW 18 D11 -01 - 40 - 40 - 40 - 5 0.721 MW 19 -91 - 45 - 69 T7 -41 - 55 - 69 T7 41 - 55 - 69 T7 14 D11 - 56 + 10 12.17 Lg/s 12.17 Lg/s 15 -21 - 57 - 56 T7 T -56 - 51 T 5.02 Lg/s 16 Process Hot Coron +2 7.88 - 60 - 02 Lg/s Rgyp Pmp 2 PWR 9.08 Bender MV' 16 Process Hot Coron +2 1.822 - 60 2 Lg/s H0 Cor PW - 5.18 Bende MV' 17 H0 - 50					FORMULAS			
In BB = 36 + 67. 225 MW BB = 56 + 67. 99 + 17 MW 111 + 121 + 014 MW 112 + 014 MW CH1 = 51 + 02 + 02 + 02 + 02 + 02 + 02 0.91 + 21 WW 0.91 + 21 WW CH1 = 51 + 02 + 02 + 02 + 02 + 02 0.91 + 21 WW 0.91 + 21 WW D D = 51 + 02 + 02 + 02 + 02 + 02 0.92 + 21 WW 0.91 + 21 WW D D = 51 + 02 + 02 + 02 + 02 0.92 + 21 WW 0.91 + 21 WW 0.95 + 22 + 22 + 24 + 24 + 24 + 24 + 24 + 2	11	Ce	əll 🛛		Formula			Result
Is B9 Col::Doc::Doc::P2 B811 B911 B912::B914	12	Bŝ	5 =B1+B2+(B3-B4)/3600					7.116 kg/s
13 B11 611.68 1.127-004 MV 13 D6 401402+03-04+05 0.1912 MV 14 D6 401402+03-04+05 0.2761 MV 15 D11 c)1-02+04+05 0.2761 MV 14 D11 c)1-02+04+05 0.2761 MV 15 6:[1:62+25+64] 0.1058 MV 412 16 F5 6:[1:62+25+64] 0.1058 MV 42758 17 F5 757676 0.5052 ky5 5052 ky5 16 T Resid H20 from H2* 1.892-602 ky5 Rey C mp 2 PVR* 9.888-004 MV* 18 4 Water out of Cells 4420 2 (see Ne* 0.1383 MV* 10.138 MV* 12 Resid H20 from H2* 1.892-602 ky5 Rey C mp 2 PVR* 9.888-004 MV* 0.1383 MV* 14 Vater out of Cells 4420 7 058 ky5 Rey C mp PV** 4.3056.000 MV* 15 Water out of Cells 1.8926-802 ky5 Rey C mp PV** 4.3056.000 MV* 15 FV moder for from 0 0.2781 MV* 10.138 MV* 0.1383 MV* 16 Process Heat Sweet MVL tove 1 2.105 MV* 7.100 MV	13							
In Citil 48111000 0.9121 XW 10 06 401-020-03-04-05 0.2781 MW 11 01 201-03-04-05 0.2781 MW 11 01 201-03-04-05 0.288-002 MW 12 076 6.258-002 MW 44:12 12 075 -(E1+62+28-14) 100.80 MW 12 0.91 -6576*7 4.7856-002 AW 21 0.91 -6576*7 5.828 Mg 22 0.92 -100.50 1.178 g8 23 1 Read H20 from H2 1.939-002 Mg* H2 Circ Pwr 9.006-004 MW* 21 Read H20 from H2 1.939-002 Mg* H2 Circ Pwr 9.006-004 MW* 23 Water tools 1.1892-002 Mg* H2 Circ Pwr 9.006-004 MW* 23 Water tools 1.1892-002 Mg* H2 Circ Pwr 9.006-004 MW* 24 Water tools 1.1892-002 MW 7.1806-005 MW* 7.210.000 MW* 23 Potel H20 from 02 7.309-002 Mg* H2 Circ Pwr 7.0128 MW	14							
10 06 01-02-03-04-05 0.2781 MW 10 D9 -07-08 1707 MW 11 -01-09-04-05 0.258e-002 MW 21 F5 -(E1+22+13-4) 44.12 21 F5 -(E1+22+13-4) 1058 MW 22 F9 -#5/6*7 4.785e-002 AW 23 F10 -#5/6*7 4.785e-002 AW 24 F1 -#5/6*7 4.785e-002 AW 25 Spreadshet 5.82 kys 12.17 kys 26 T Read H20 from H2 * 1.982-002 kys * Roy Emg 2 MM * 9.080e/08 MW * 26 T Read H20 from H2 * 1.982-002 kys * Roy Emg 2 MM * 5.082 kys * 27 Z Read H20 from H2 * 1.982-002 kys * Roy Emg 2 MM * 5.080e/08 MW * 28 G Nater rota Cels * 1.442 0.768 kys * P.042 Pm * 5.080e/08 MW * 29 Rower rota Cels * 1.982 MW * 1.016 MW * 1.980 MW * 2.216 0.00 MW * 210 Water rota Cels * <t< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>								
10 D11 D10-03-04-06 # 299-002 MW 21 F4 -F154F3*100/100 44.12 21 F5	17							
20 F4 =F1*P2#2*100/000 44.12 21 F5 =(E1+E2+E3+E4) 10.58 MV 22 F9 =F5/E7*F8 5.052 kg/s 23 F10 =F5/E7*F8 5.052 kg/s 24 F10 =SF10 12.17 kg/s 25 Spreadsheet 26 P3 27 A B C D 28 P10 =S6710 12.17 kg/s 29 P10 =S6710 12.17 kg/s 20 P17 9.0600-004 MV* 20 P18 9.0600-004 MV* 21 P18:e34120 from 02 7.380e-002 MV* 21 P18:e34120 from 02 7.380e-002 MV* 31 A Water inces* 7.181e/gs* Swp Mtr Prop Par* 4.305e003 MV* 22 P10 P10 P10 35 F10 F10 36	18	DS	9 =D7+D8					1.707 MVV
1 FS =fE:FE?HS+G) 10.50 kW/ 22 F3 =F5/FE?HS 50/52 kg/s 24 F10 =5/FE?HS 50/52 kg/s 25 F11 =8/FE?HS 50/52 kg/s 26 Spreadsheet 12.17 kg/s 26 Spreadsheet 0.185 kW/ 27 Resid H20 from H2 * 1.9826-002 kg/s * Royc Prop. 2 PWR * 9.0808-004 MW * 28 Resid H20 from H2 * 1.9826-002 kg/s * Royc Prop. 2 PWR * 0.1858 MW * 28 Resid H20 from H2 * 1.9826-002 kg/s * Royc Prop. 2 PWR * 0.1858 MW * 29 Resid H20 from H2 * 1.9826-002 kg/s * Royc Prop. PWR * 7.216-002 MW * 30 Water out of Cells * 1.9816-030 MW * FMR PwR * 7.216-002 MW * 31 4 Water out of Cells * 1.9816-1981 WW * Total Power Prop Pwr * 7.216-002 MW * 35 G Water out of Cells * 1.9816-1981 WW * 1.926-002 MW * 36 Process Heat SteamH2 HX Cuty * 2.168 MW * 1.926-002 MW * 1.926	19							
22 F9 =F5/6777 4 738-002 MW 23 F10 =F5/67678 5.052 kgs F11 =E5/67678 5.052 kgs 23 F10 =E5/67678 5.052 kgs 24 F11 =E5/67678 12.17 kgs 25 Spreadsheet 12.17 kgs 9.080-004 kW 24 Resid H20 from H2* 1.982-002 kgs* Rcyc Pmp. 2PWR* 9.080-004 WK 25 Resid H20 from H2* 1.982-002 kgs* Rcyc Pmp. 2PWR** 5.1880-003 MW* 30 Water into Cells* 4.4240.788 kgh* PWR*** 5.1880-003 MW* 36 Process Heat Steam/H2 KDuy* 2.16.052 MW* Total Power For for* 0.1935 MW* 37 Process Heat Steam/H2 KDuy* 2.16.052 MW* Total Power for for* 0.2716 MW* 38 Total Heat from Reactor 2.33 MW* Soft O * 6.072e-002 MW* 39 Power Keed de for Electrolysis * 9.91.71 MW* Total Power for flow * 0.9714 MW* 31 Excess Electroly* 1.912-004 MW* 0.1912 MW* 8.259e-002 MW* <th>20</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>	20							
21 F10 #=56F87F8 5 052 kg/s 21 F11 =85+F10 12.17 kg/s 22 A B C D 23 1 Read H20 fram H2* 1.832+002 kg/s* Reyc Pmp 2 PWN* 9.068e-004 MW* 23 1 Read H20 fram H2* 1.832+002 kg/s* Reyc Pmp 2 PWN* 9.068e-004 MW* 23 2 Read H20 fram H2* 1.832+002 kg/s* Reyc Pmp 2 PWN* 9.068e-004 MW* 24 1 Read H20 fram H2* 1.832+002 kg/s* Reyc Pmp 2 PWN* 9.068e-004 MW* 23 3 Water iots * 7.116 kg/s* Swy We Pmp Pw* 7.221+602 MW* 25 6 Process Heat SteamA12 HX Cky* 2.105 MW* Total Power for flow* 0.2781 MW* 26 8 Total Heat fram React/* 2.838 MW* S02 O O * 5.078-002 MW* 27 Process Heat SteamA12 HX Cky* 1.912 kg/s04 AW* Total Topping Heat * 7.777 MW* 28 Total H2* 1.438 MW* 1.912 kg/s 1.977 kg/s 1.971 kg/s	22							
F11 -B5 +F10 12.17 kg/s Spreadsheet Spreadsheet 27 A B C D 28 C D 0.09.0-0.04 MW* 0.09.0-0.04 MW* 29 1 Read H20 from H2 1.992e-002 kg/s* Reyc Pmp 2 PWR* 0.09.00-0.04 MW* 20 3 Water uito Cells* 1.992e-002 kg/s* H2 Crc Pwr* 0.09.00-0.04 MW* 20 3 Water uito Cells* 1.992e-002 kg/s* H2 Crc Pwr* 0.09.00-0.04 MW* 20 3 Water uito Cells* 1.992e-002 kg/s* H2 Crc Pwr* 0.19.05 MW 20 4 Water uit of Cells* 1.992e-002 kg/s* PWR Pwr* 4.305e-0.03 MW* 21 5 Water toto of Cells* 1.9916-082 kg/s* Set WF Pmp Pwr* 4.305e-0.03 MW* 30 6 Process Heat Seneep H2 LNDy 2.216 MW* Total Power for filework 0.2751 MW* 31 10 Electricity's Benzon 2.33 MW* Set O 6.078e-0.02 MW* 32 10 Electricity'Seneerad	23							
Spreadsheet 21 A B C D 21 A B Co D 22 Read H20 from 02 7.388-002 kg/s H2 Crc Pwr 0.908-004 MWr 23 3 Water into Cells 44240.7588 kg/h PWR Pwr 5.188-003 MWr 33 Water into Cells 19916 692 kg/h Innet Water Pmp Pwr 7.221-002 MWr 34 Water into Cells 19916 692 kg/h Swy MF Pmp Pwr 4.305-003 MWr 35 Water into Cells 19916 692 kg/h Innet Water Pmp Pwr 4.2120 ZMVr 35 Water into Cells 19916 692 kg/h Innet Water Pmp Pwr 4.205-003 MWr 36 Process Heat Sweep HX Duty 2.480 MWr Striba /								
A B C D 23 1 Resid H20 from H2* 1.992e-002 kg/s* Rcyc Pmp 2 PWR* 9.080e-004 MW* 23 2 Resid H20 from Q2* 7.389e-002 kg/s* H2 Circ Pwr* D.1385 MW* 23 Water into Cells* 44240.7588 kg/s* PWR Pwr* 5.188e-003 MW* 34 Water out of Cells* 1.9816 kg/s* Swp Wt Pmp Pwr* 7.221e-002 MW* 35 Forcess Heat SteamH2 HK Duty* 2.1165 MW* Total Power for flow* 0.2781 MW* 36 Process Heat SteamH2 HK Duty* 2.480 MW* Total Power for flow* 0.2781 MW* 37 Process Heat SteamH2 HK Duty* 2.480 MW* Total Power for flow* 0.2781 MW* 38 Total Heat from Reactor 2.363 MW* Total Topping Heat* 1.707 MW* 39 Power Needed for Electrolysis* 9.917 MW* Total Topping Heat* 1.714 MW* 311 Excess Electroly* 1.912e-004 MW* 0.1912 MW* 8.259e-002 MW* 312 -6.982 MW* 1.0404e+005 kJ/kg* - - -	_				Spreadsheet			
28 1 Resid H20 from H2 * 1.982e-002 kg/s * Rey Pmp 2 PWR * 9.086e-004 MW* 20 2 Resid H20 from 02 * 7.360e-002 kg/s * H.2 Circ Pwr * 0.1835 MW* 31 Water into Cells * 19891 5892 kg/h * PWR Pwr * 5.186e-003 MW* 32 5 Water into Cells * 19891 5892 kg/h * Intet Water Pmp Pwr * 7.221e-002 MW* 32 5 Water loss * 7.118 kg/s * Swy Mtr Pmp Pwr * 4.305e-003 MW* 33 7 Process Heat Steam/H2 HX Cuty * 2.165 MW* Total Power for forw * 0.2761 MW* 34 9 Forder shart from Reactor * 23.83 MW * Soft O * 5.078e-002 MW* 35 8 Total Hart from Reactor * 9.917 MW * Total Topping Heat * 1.707 MW* 36 9 Power Needed for Electrolysis * 9.917 MW * Electrolysis Power * -9.714 MW* 37 10 Electrolysis Power * 0.1912 MW * 8.258e-002 MW * 38 1 Electrolysis Power * 0.714 MW * 8.258e-002 MW *			Δ	В				
22 Read H2O from O2 * 7.380e-002 kg/s * H2 Circ Pwr * 0.1385 MWr * 33 Water into Cells * 44240-7588 kg/n * PVAR Pwr * 5.168e-003 MWr * 32 5 Water into Cells * 1881.6882 kg/n * Inter Water Pmp Pwr * 7.168 kg/s * 32 6 Process Heat StarmH2 HX Duty * 2.165 MWr * Total Power for flow * 0.2761 MWr * 33 8 Total Heat from Reactor * 2.353 MWr * SGT 0 * 5.078e-002 MWr * 36 9 Power Needed for Electrolysis * 981.7 MWr * Total Topping Heat * 1.707 MWr * 37 10 Electrolysis * 981.7 MWr * Total Topping Heat * 1.707 MWr * 38 Total Heat from Reactor * 9.917 MWr * Total Topping Heat * 1.707 MWr * 39 Power Needed for Electrolysis * 981.7 MWr * 0.1812 MWr * 8.259e-002 MWr * 31 L Excess Electricity * 1.912e-004 MWr * 0.1812 MWr * 9.714 MWr * 30 E F 0.1812 MWr * 0.1812 MWr * 0.1812 MWr * <th></th> <th>1</th> <th></th> <th></th> <th>12e-002 ka/s *</th> <th></th> <th></th> <th></th>		1			12e-002 ka/s *			
31 4 Water out of Cells* 19961.5892.kg/n* Initet Water Pmp Pwr* 7.221e-002 MW* 32 5 Water loss* 7.116 kg/s* Swy WH* Pmp Pwr* 4.305e-003 MW* 33 6 Process Heat Sweep HX Duty* 2.105 MW* Total Power for flow* 0.2761 MW* 34 7 Process Heat Sweep HX Duty* 2.400 MW* STH Q.* 1.858 MW* 35 8 Total Heat from Reactor 2.353 MW* SGT Q.* 6.5078e-002 MW* 37 Power Needed for Electrolysis* 9.917 MW* Total Topping Heat* 1.707 MW* 37 10 Electricity Generated * 99.17 MW* Electrolysis Power* -97.14 MW* 38 11 Excess Electricity* 1.812e-004 MW** 0.1812 MW* 8.258e-002 MW* 40 1 -6.982 MW* 1.404e+006 kJ/kg * 41 2 -3.070 MW* 0.7658 kg/s* 42 3 -4.594e-002 MW* 2.500 MW* 43 4 -0.4592 MW* 0.7658 kg/s* 44 5 C	29		Resid H2O from O2 *					
32 5 Water loss* 7.118 kg/s* Swp Wtr Pmp Pwr* 4.305e-003 MW* 33 6 Process Heat Steam/L HX LDu* 2.105 MW* Total Power for flow* 0.2761 MW* 34 7 Process Heat Sweep HX Duy* 2.480 MW* SGT O* 5.078e-002 MW* 34 7 Process Heat Sweep HX Duy* 2.480 MW* SGT O* 5.078e-002 MW* 35 9 Power Needed for Electrolysis* 99.17 MW* Total Topping Heat* 1.707 MW* 37 10 Electrolysis Power* .99.17 MW* Electrolysis Power* .97.14 MW* 37 10 Electrolysis 99.17 MW* 1.912e-004 MW* 0.1912 MW* 8.259e-002 MW* 38 1 Excess Electroly* 1.912e-004 MW* 0.1912 MW* 8.259e-002 MW* 39 1 Excess Electroly* 0.7868 kg/s*		3	Water into Cells *	4424	0.7588 kg/h *			5.168e-003 MVV *
6 Process Heat Steem/H2 HX Duty 21.05 MVV Total Power for flow 0.2781 MVV 31 7 Process Heat Steem HX Duty 2.400 MVV STH 0 1.666 MVV 32 9 Total Heat from Reactor 2.33 MVV SGT 0 5.07 0e- 5.0	31			1896				
34 7 Process Heat Sweep HX Duty * 2 480 MVV* STH Q.* 1 656 MVV* 35 8 Total Heat from Reactor * 23 53 MVV* SGT Q.* 5.070e-002 MVV* 36 9 Power Needed for Electrolysis * 99.17 MVV * Total Topping Heat * 1.707 MVV* 37 10 Electroly Generated * 99.17 MVV * Electrolysis Power * 97.14 MVV * 38 11 Excess Electricity * 1.912e-004 MVV * 0.1912 MVV * 8.259e-002 MVV* 39 E F - 97.14 MVV * 0.1912 MVV * 8.259e-002 MVV* 30 I 6.882 MVV * 1.912e-004 MVV * 0.1912 MVV * 8.259e-002 MVV * 40 1 6.882 MVV * 1.912e-004 MVV * 0.1912 MVV * 8.259e-002 MVV * 41 2 3.070 MVV * 0.7858 Kg/s * - - - 42 3 4.594e-002 MVV * 0.7858 Kg/s * - - - 43 4 -0.4592 MVV * 4.12 * - - - - 44 5 Total HTSE Ambient Heat * 10.57	32							
35 8 Total Heat from Reactor * 23.53 MW* SGT O* 5.078e-002 MW* 36 9 Power Needed for Electrolysis * 9817 MW* Total Topping Heat * 1.707 MW* 37 10 Electrolysis Generated * 9817 MW* Electrolysis Power * .97.14 MW* 38 11 Excess Electricity * 1.912e-004 MW* 0.1912 MW* 8.258e-002 MW* 39 E F	33							
36 9 Power Needed for Electrolysis * 99.17 MVV * Total Topping Heat * 1.707 MVV * 37 10 Electroly Generated * 99.17 MVV * Electrolysis Power *	35							
38 11 Excess Electricity* 1.912e-004 MW* 0.1912 MW* 8.259e-002 MW* 39 E F 40 1 -6.892 MW* 1.404e+005 kJ/kg* 41 2 -3.070 MW* 0.7658 kg/s* 42 3 -4.594e-002 MW* 250.0 MW* 43 4 -0.4592 MW* 44.12 * 44 5 Total HTSE Ambient Heat* 10.56 MW* 45 6 Condenser Heat* 10.25 MW* 46 7 Cooling Tower Power * 0.5756 MW* 47 8 Cooling Tower Make Up Water * 60.64 kg/s * 47 8 Cooling Tower Make Up Water * 5.052 kg/s * 49 0 Water needed to cool for HTSE * 5.052 kg/s * 50 50 50 5.052 kg/s * 51 50 5.052 kg/s *	36							
B E F 40 1 -6.982 MW* 1.404e+005 kJ/kg* 41 2 -3.070 MW* 0.7858 kg/s* 42 3 -4.594e-002 MW* 2500 MW* 43 4 -0.4592 MW* 44.12 * 44 5 Total HTSE Ambient Heat * 10.56 MW* 45 6 Condenser Heat * 128.7 MW* 46 7 Cooling Tower Power * 0.5766 MW* 47 8 Cooling Tower Power * 60.64 kg/s * 48 9 HTSE Cooling Power * 4.795e-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 56 56 56 56 56 56 56 57 58 59 50 58 59 50 50 59 50 50 56 58 59 50 50	37							
40 1 -6.882 MW* 1.404e+005 kJ/kg* 41 2 -3.070 MW* 0.7858 kg/s* 42 3 -4.594e-002 MW* 250.0 MW* 43 4 -0.4592 MW* 260.0 MW* 43 4 -0.4592 MW* 260.0 MW* 44 5 Total HTSE Ambient Heat* 10.56 MW* 45 6 Condenser Heat* 128.7 MW* 46 7 Cooling Tower Power* 0.5756 MW* 47 8 Cooling Tower Power* 0.5756 MW* 48 9 HTSE Cooling Power* 4.795e-002 MW* 48 9 HTSE Cooling Power* 4.795e-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 53 53 53 56 56 57 53 57 53 54 55 56 56 56 56 57 58 59 50 58 59 50 50 <	38	11			2e-004 MVV *	0.1912 MW*		8.259e-002 MW*
41 2 -3.070 MW* 0.7858 kg/s* 42 3 -4.594e-002 MW* 250 0 MW* 43 4 -0.4592 MW* 44.12* 43 4 -0.4592 MW* 44.12* 44 5 Total HTSE Ambient Heat * 10.56 MW*	39 40	1			e+0.05 kJ/ka *			
43 4 .0.4592 MW* 44.12* 44 5 Total HTSE Ambient Heat * 10.56 MW* 45 6 Condenser Heat * 128.7 MW* 46 7 Cooling Tower Power * 0.5756 MW* 47 8 Cooling Tower Make Up Water * 60.64 kg/s * 48 9 HTSE Cooling Power * 4.7356-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 52 53 54 55 56 56 56 56 56 56 56 57 58 56 58 56 56 59 56 56 56 56 56 57 58 56 58 56 56 59 56 56 50 57 58 58 58 58 59 59 59 50 50 50 5								
44 5 Total HTSE Ambient Heat * 10.56 MW* 45 6 Condenser Heat * 128.7 MW* 46 7 Cooling Tower Power * 0.5756 MW* 47 8 Cooling Tower Make Up Water * 60.64 kg/s * 48 9 HTSE Cooling Power * 4.7956-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 55 56 56 56 56 56 56 57 58 59 50 58 59 50 50 59 50 50 50 50 56 57 58 56 56 56 57 57 58 59 50 58 59 50 50 59 50 50 50 50 50 50 50 50 50 50 50 50 50 50 50 <			-4.594e-002 MW*		250.0 MVV *			
45 6 Condenser Heat * 128.7 MW* 46 7 Cooling Tower Power * 0.5756 MW* 47 8 Cooling Tower Make Up Water * 60.64 kg/s * 48 9 HTSE Cooling Power * 4.795e-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 56 57 50 50 56 56 56 56 56 57 58 59 56 56 58 59 56 56 56 59 56 56 56 56 59 56 56 56 56 59 56 57 58 59 50 56 56 56 56 57 58 59 59 59 50 56 56 56 56 57 57 58 59 59 58 59 59 59 50								
46 7 Cooling Tower Power* 0.5756 MVV* 47 8 Cooling Tower Make Up Water* 60.84 kg/s* 48 9 HTSE Cooling Power* 4.795e-002 MW* 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 52 53 54 52 53 54 55 56 56 57 56 57 58 56 57 58 56 57 56 59 56 57 56 58 56 57 56 59 56 57 56 59 56 57 56 58 59 56 57 59 56 57 56 50 57 57 57 58 58 59 56 57 59 56 57 57 57 51 57 57 57 57								
47 8 Cooling Tower Make Up Water * 60.64 kg/s * 48 9 HTSE Cooling Power * 4.795e-002 MW * 49 10 Water needed to cool for HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 52 53 54 54 54 55 56 55 56 56 57 56 56 57 58 57 58 59 56 58 59 56 56 59 56 56 56 56 56 57 58 58 59 59 56 59 56 56 56 51 56 56 56 56 57 58 56 58 59 59 59 59 50 50 50 51 56 57 56 52 56 57 57 58 58 58 59 <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>								
Intermediation Intermediation 10 Water needed to cooling HTSE * 5.052 kg/s * 50 11 Total Water for HTSE * 12.17 kg/s * 51 52 53 54 55 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 58 58 56 58 59 56 56 59 56 56 56 50 56 56 56 59 56 56 56 50 56 56 56 51 56 56 56 52 57 58 58 53 58 59 50 50	47							
50 11 Total Water for HTSE* 12.17 kg/s* 51 52 53 53 54 55 56 56 56 57 58 59 58 59 56 59 56 56 50 56 56 59 56 56 50 56 56 59 56 56 50 56 56 59 56 56 50 56 56 50 56 56 51 56 56 52 56 56 53 56 56 54 56 56 56 56 56 57 50 56 58 50 50 50 50 50 51 50 50 52 50 50 53 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336)	48			4.79	35e-002 MVV *			
51 52 53 54 55 56 57 58 59 60 61 62 62 63 64 65 56 57 58 59 60 61 62 63 64 65 56 56 57 58 59 59 50 50 50 50 50 50 50 50 50 50	49							
52 53 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34		11	Total Water for HISE "		12.17 Kg/S *			
63 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34								
56 57 58 59 60 61 62 63 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	53							
56 57 58 59 60 61 62 63 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	54							
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	55							
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	Эb 57							
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	58							
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 21 of 34	59							
	60							
	61							
	63	Asn	en Technology Inc	Aspen HYS	SYS Version 7.3.0	25.0.0.7336		Page 21 of 34



1				Case Name:	NA COOLED HTSE w SU	JPER CRITICAL RANK	(INE V1.hsc
3	aspentech	Burlington, I	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5	- aspenteen	USA		Date/Time:	Fri Mar 28 11:16:39 2014	ŀ	
6							
7 8	Work	(book:	Electrolys	sis Unit (TPL	4)		
9 10				Streams		Fluid Pk	g: All
11	Name		Process In @TPL4	Sweep Gas In @TPL4	Cathode @TPL4	Sweep Gas/O2 Out @	Gas Products @TPL4
12	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
13	Temperature	(C)	800.0	800.0	800.0 *	800.0	800.0
14	Pressure	(MPa)	7.185	7.185	7.185	7.185	7.185
15		kgmole/h)	3509	704.2	3509	1406	4210
16	Mass Flow	(kg/s)	12.88	3.526	6.643	9.762	12.88
17	Liquid Volume Flow	(m3/h)	74.71	12.72	89.88	32.45	109.6
18	Heat Flow	(MVV)	-138.8	-41.72	-46.60	-36.73	-41.66
19	Molar Enthalpy (k	J/kgmole)	-1.424e+005	-2.133e+005	-4.781e+004	-9.407e+004	-3.563e+004
20	Name		Liquid Products @TF	PL Anode @TPL4	Molar Flow of Oxygen	Electrolysis Heating @	Electrode Heat @TPL
21	Vapour Fraction		0.0000	1.0000			
22	Temperature	(C)	800.0	807.2			
23	Pressure	(MPa)	7.185	7.185			
24	Molar Flow (kgmole/h)	0.0000	701.6	701.6		
25	Mass Flow	(kg/s)	0.0000	6.236	6.236		
26	Liquid Volume Flow	(m3/h)	0.0000	19.73	19.73		
27	Heat Flow	(MVV)	0.0000	4.984		97.09	4.650e-002
28	Molar Enthalpy (k	J/kgmole)	-3.412e+004	2.558e+004			
29	Name		Process Heat @TPL	4 Electrolysis Power @1			
30	Vapour Fraction						
31	Temperature	(C)					
32	Pressure	(MPa)					
33	Molar Flow (kgmole/h)					
34	Mass Flow	(kg/s)					
35	Liquid Volume Flow	(m3/h)					
36	Heat Flow	(MVV)	2.762e-003	-97.14			
37	Molar Enthalpy (k	J/kgmole)					
38 39				Conversion React	ors	Fluid Pk	g: All
40	Name		Isothermal Electrolys	is			
41	Separator Type						
42	Vessel Temperature	(C)	800.0				
43	Vessel Pressure	(MPa)	7.185				
44	Vapour Molar Flow (kgmole/h)	4210				
45	Liquid Molar Flow (kgmole/h)	0.0000				
46	Heat Flow	(MVV)	97.09				
47 48				Unit Ops			
49	Operation Name	Oper	ation Type	Feeds	Products	Ignored	Calc Level
50				Process In @TPL4	Liquid Products @TF	PL4	
51	Isothermal Electrolysis @TPL	Conversion	n Reactor 🛛 🛛 🛛		4 Gas Products@TPL	.4 No	500.0 *
52					Electrolysis Heating	@TPL4	
53		_		Gas Products @TPL4	Cathode @TPL4		
54	Electrodes @TPL4	Componen	t Soliffer	Electrode Heat @TPL4	Anode @TPL4	No	500.0 *
55	Gas Product Temperature @T	Set				No	500.0 *
56	Outlet Temperature @TPL4	Set				No	500.0 *
57	Inlet Temperature @TPL4	Set				No	500.0 *
58	SET-1@TPL4	Set				No	500.0 *
59	High Temperature Electrolysis	Spreadshe	et			No	500.0 *
60	Temp Average ASR @TPL4	Spreadshe	et			No	500.0 *
61	M1 @TPL4	Mixer		Anode @TPL4	Sweep Gas/O2 Out (@TPL4 No	500.0 *
62	_	MIAG		Sweep Gas In @TPL4		0/1	
63	Aspen Technology Inc.		Aspen	HYSYS Version 7.3 (2	25.0.0.7336		Page 22 of 34
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1				Case Name: NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc				
З		BATTELLE ENERGY ALLIANCE Burlington, MA		bet: AFR				
4 5		USA	Date	/Time: F	ri Mar 28 11:16:	39 2014		
6	۱۸/ا	(haal), Elaster-l) (acati			
7 8	VVOF	kbook: Electroly	/sis Uni	It (TPL4) (contil	nued)		
9 10			Unit Op	s (continue	d)			
11	Operation Name	Operation Type	Fee	eds	Pro	ducts	Ignored	Calc Level
12 13	ADJ-1 @TPL4	Adjust					No	3500 *
14								
15 16								
17								
18 19								
20 21								
22								
23 24								
25 26								
27								
28 29								
30								
31 32								
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59 60								
61 62								
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	Aspe	en HYSYS Ve	ersion 7.3 (25	.0.0.7336)		1	Page 23 of 34 * Specified by user.

1	\sim) HTSE W SUPER CRITICAL R	ANKINE V1.hsc					
3	(🌵 🛓	BATTELLE ENERGY ALLIANG Spentech Burlington, MA	Unit Set: AFR							
4 5			Date/Time: Fri Mar 28 1	1:16:39 2014						
6										
7 8		Spreadsheet: High	Temperature Electro	olysis @TPL4	Units Set: Electrolysis_					
9			CONNECTIONS							
10 11										
12	0-"		Imported Variables							
13 14	Cell D2	Object Material Stream: Process In @TPL4	Variable Descr	iption	Value 1073 K					
14	D2 D3	Material Stream: Process In @TPL4 Material Stream: Cathode @TPL4	Temperature Temperature		1073 K					
16	A8	Material Stream: Cathole @1FL4 Material Stream: Sweep Gas/O2 Out @TPL	Pressure		7.185e+006 N/m2					
17	E2	Material Stream: Process In @TPL4	Master Comp Mole Frac (H2O)		0.6999					
18	F2	Material Stream: Process In @TPL4	Master Comp Mole Frac (Hydrogen)		0.3001					
19	G2	Material Stream: Sweep Gas In @TPL4	Master Comp Mole Frac (Oxygen)		0.0008					
20	E3	Material Stream: Cathode @TPL4	Master Comp Mole Frac (OXygen)		0.3000					
20	F3	Material Stream: Cathode @TPL4	Master Comp Mole Frac (Hydrogen)		0.7000					
22	G3	Material Stream: Sweep Gas/O2 Out @TPL	Master Comp Mole Frac (Oxygen)		0.4995					
23	B16	SpreadSheetCell: Temp Average ASR@B2	B2: Temp Aver ASR		0.4000					
24	D10	Energy Stream: Electrolysis Heating @TPI	Heat Flow		9.709e+004 kW					
25	D12	Energy Stream: Electrode Heat @TPL4	Heat Flow		46.50 kW					
26		• • • •			,					
27		Exp	orted Variables' Formula Result	S						
28	Cell	Object	Variable Descr	iption	Value					
29	B15	Molar Flow of Oxygen @TPL4	Molar Flow		194.9 gmole/s					
30	B19	Electrolysis Power @TPL4	Power		-9.714e+004 kW					
31	B20	Process Heat @TPL4	Heat Flow		2.762 kW					
32			BABAMETERO							
33 34			PARAMETERS							
35			Exportable Variables							
36	Cell	Visible Name	Variable Description	Variable Type	Value					
37	E9	E9:			<empty></empty>					
38	C20	C20:		Energy	<empty></empty>					
39	E8	E8:		Temperature	<empty></empty>					
40	F10	F10:		Vapour Fraction	<empty></empty>					
41	C18	C18:			<empty></empty>					
42	F20	F20:			<empty></empty>					
43	H5	H5:			91.15					
44	J2	J2:		Entropy	2.321e+008 J/gmole-K					
45	J3	J3:		Entropy	2.321e+008 J/gmole-K					
46	K2	K2:			0.8721					
47	K3	K3:			1.099					
48	B17	B17:		Vapour Fraction	1.0373					
49	H2	H2:			5.663e-002					
50	111	111:			<empty></empty>					
51	12	12:		Molar Enthalpy	1.887e+005 J/gmole					
52	13	13:		Molar Enthalpy	1.887e+005 J/gmole					
53	16	16:		Molar Enthalpy	1.887e+005 J/gmole					
54 66	E4	E4:		Vapour Fraction	-0.3999					
55 56	F4	F4:		Vapour Fraction	0.3999					
56 57	D4	D4:		Temperature	-2.319e-011 K					
58	D6	D6:		Temperature	1073 K					
58 59	K6	K6:		Vapour Fraction	1.0373					
59 60	K7 B18	K7: B18:			1.032					
61	B18 D8	D8:		Vapour Fraction	3.664e-007					
62	D8 D9	D9:			1.580e+004					
63			en HYSYS Version 7.3 (25.0.0.7336		Page 24 of 34					
20		: BATTELLE ENERGY ALLIANCE	on 11 of the version 7.5 (25.0.0.7330		* Specified by user.					
	acenseu ID	. DATITULE ENERGI ALLIANCE			apecilieu by user.					

1	Case Name: NA COOLED HTSE w SUPER CRITICAL RANKIN								
3	BATTELLE ENERGY ALLIANCE Burlington, MA Usa Unit Set: AFR								
4 5	<u> </u>	USA	Date/Time: Fri Mar 28 11:16:3	9 2014					
6									
7 8		Spreadsheet: High Temperature Electrolysis @TPL4 Units Set: Electrolysis_							
9			PARAMETERS						
10 11			FARAIMETERS						
12			Exportable Variables						
13	Cell	Visible Name	Variable Description	Variable Type	Value				
14	A9	A9: Standard Pressure	Standard Pressure	Pressure	1.013e+005 N/m2				
15	A6	A6: Fa Faraday Number (J/Volt-gmole)	Fa Faraday Number (J/Volt-gmole)		9.649e+004				
16 17	A5 A4	A5: A5 for Gibbs Formation Energy	A5 for Gibbs Formation Energy	Gibbs. Coeff. CB	-12.85 J/gmole-K -3.532e-008				
18	A4 A3	A4: A4 for Gibbs Formation Energy (kJ/gmol-K ^A 3) A3: A3 for Gibbs Formation Energy	A4 for Gibbs Formation Energy (kJ/gmol-K ^A 3) A3 for Gibbs Formation Energy	Gibbs. Coeff. CC	3.319e-003 kJ/gmol-K*:				
19	A0 A2	A2: A2 for Gibbs Formation Energy	A2 for Gibbs Formation Energy	Gibbs: Coeff. CB	39.95 J/gmole-K				
20	A7	A7: R Universal Gas Constant	R Universal Gas Constant	Entropy	8.314 J/gmole-K				
21	G4	G4:		Vapour Fraction	0.4987				
22	H3	H3:			35.42				
23	H4	H4:			35.36				
24	E5	E5:		Vapour Fraction	0.2885				
25	F5	F5:		Vapour Fraction	-0.2884				
26	G5	G5:		Vapour Fraction	-0.8397				
27	B11	B11: B2: Number of Cells	B2: Number of Cells		5.260e+005				
28	B12	B12: B3: Cell Area	B3: Cell Area	Small Area	225.0 cm2				
29	B13	B13: B4: Current Density (Amperes/cm ⁶ 2)	B4: Current Density (Amperes/cm [*] 2)		0.6355				
30	B14	B14:			143.0				
31	B15	B15: Molar Flow	Molar Flow	Molar Flow	194.9 gmole/s				
32	A1	A1: A1 for Gibbs Formation Energy	A1 for Gibbs Formation Energy	Gibbs. Coeff. CA	2.382e+005 J/gmole				
33 34	B19 B20	B19: Power B20: Heat Flow	Power Heat Flow	Power Energy	-9.714e+004 kW 2.762 kW				
35	D20	D20. Heat how	User Variables	Lifeigy	2.702.899				
36 37									
38			FORMULAS						
39	Cell		Formula		Result				
40 41	B14	=B12*B13			143.0				
41	B15 B17	=B11*B14/(4*A6)			194.9 gmole/s 1.0373				
42	B17 B18	@IF(@ABS(D4)<1e-3,K6,K7) =B17+B13*B16			1.2915				
44	B19	=B11*B18*B14/1000			-9.714e+004 kW				
45	B10 B20	=B19+D11+D12			2.762 kW				
46	D4	=D2-D3			-2.319e-011 K				
47	D6	=(D2+D3)/2			1073 K				
48	D8	=1/(2*A6*H4*F4)			3.664e-007				
49	D9	=1/(2*A6*H4*F4*D4)			1.580e+004				
50	E4	=E3-E2			-0.3999				
51	E5	=(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2)			0.2885				
52	F4	=F3-F2			0.3999				
53	F5	=(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2)			-0.2884				
54	G4	=G3-G2 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2)			0.4987				
55 56	G5 ມາ	-0.8397							
57	H2 H3	5.663e-002 35.42							
58	— пз Н4	35.36							
59									
60									
61	13	=A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN			1.887e+005 J/gmole 1.887e+005 J/gmole				
62	16 =A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6) 1.887e+005 J/gmole								
63	Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 34								
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1	Contech Burlington, MA		NERGY ALLIANCE		NA COOLED HTSE w SUPER C	IA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc			
3					it Set. AFR				
4 5		USA	Date/Time: Fri Mar 28 11:16:39 2014						
6									
8	Spreadsheet: High Temperature Electrolysis @TPL4 Units Set: Electrolysis_								
9	FORMULAS								
11	1 Cell Formula Resi								
12	12 J2 = A1*D2 + A2/2*D2*2 + A3/3*D2*3 + A4/4*D2*4 + A5/2*D2*2*(@LN(D2)=0.5)				2.321e+008 J/gmole-K				
13	J3 = A1*D3 + A2/2*D3*2 + A3/3*D3*3 + A4/4*D3*4 + A5/2*D3*2*(@LN(D3)-0.5) 4 K2 =1/(2*A6)*(12-A7*D2*@LN(E2/(F2*H2*0.5)))				2.321e+008 J/gmole-K 0.8721				
15	K					1.099			
16	K	6 =D8*(16*F4*H4 + A7*D6*((E5+F	5)*H4 + H5/2*F4))			1.0373			
17	K	7 =D9*(A7/2*(D3^2-D2^2)*((E5+F	5)*H4 + H5/2*F4) + F4*H4*I	(J3-J2))		1.032			
18				Spreadsh	ieet				
20		А	В		C	D			
21	1	2.382e+005 J/gmole *	A1 for Gibbs Forma			Temperature *			
22	2	39.95 J/gmole-K *	A2 for Gibbs Forma		in *	1073 K*			
23	3 4	3.319e-003 kJ/gmol-K^2 * -3.532e-008 *	A3 for Gibbs Forma bibbs Formation Energy (k		out * Delta *	1073 K * -2.319e-011 K *			
24	4 5	-3.5320-008 -12.85 J/gmole-K *	A5 for Gibbs Forma		Integration Coeff *	-2.3188-011 K			
26	6	9.649e+004 *	Fa Faraday Number (J		Average *	1073 K *			
27	7	8.314 J/gmole-K *	R Universal G	as Constant *					
28	8	7.185e+006 N/m2 *		Pressure *	C isothermal *	3.664e-007 *			
29	9	1.013e+005 N/m2 * Standa		rd Pressure *	C average *	1.580e+004 *			
30			5.260e+005 *	Electrolysis Heating *	9.709e+004 kW *				
32	11 Number of Cells * 5 12 Cell Area * 5		225.0 cm2 *	Electrode Heat *	46.50 KW *				
33	13	Current Density (Amperes/cm^2) *		0.6355 *					
34	14	Current (Amperes) *		143.0 *					
35	15	Molar Flow of Oxygen *	19	4.9 gmole/s *					
36	<u>16</u> 17	Area Specific Resistance (ohm*cm*2) * Nernst Potential (Volts) *		0.4000 * 1.0373 *					
38	18	Operating Voltage (Volts) *		1.2915 *	<empty> *</empty>				
39	19	Electrolysis Power *	-9.71	4e+004 kW *	1.7				
40	20	Process Heat *		2.762 kW *	<empty> *</empty>				
41		E	F	110.4	G	H			
42	1 2	y H2O * 0.6999 *		y H2 * 0.3001 *	y O2 * 0.0008 *	y A * 5.663e-002 *			
44	3	0.3000 *		0.7000 *	0.4995 *	35.42 *			
45	4	-0.3999 *		0.3999 *	0.4987 *	35.36 *			
46	5	0.2885 *	·	-0.2884 *	-0.8397 *	91.15 *			
47 48	<u>6</u> 7								
40	8	<empty> *</empty>							
50	9	· · · · ·							
51	10			<empty> *</empty>					
52	11								
53 54	12 13								
55		13							
56	15								
57	16								
58									
59 60	59 18 60 19								
61	19 20		<empty> *</empty>						
62		I	J		К				
63		en Technology Inc.	Aspen HYS	YS Version	7.3 (25.0.0.7336)	Page 26 of 34			
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1				×	Case Name:	NA COOLED HTSE w SU	JPER CRITICAL RANKINE V1.	ISC
2 3 4 5	(1	aspentech Burlin	ELLE ENERG gton, MA	Y ALLIANCE	Unit Set:	AFR		
4		USA	USA		Date/Time:	Fri Mar 28 11:16:39 2014		
6			-					
7 8		Spread	sheet:	High Ten	nperature	Electrolysis	@TPL4 Units Set:	Electrolysis_
9					Spreadsheet			
10 11	1	De	elta G *	Integra	Delta G dT *	Nernst Vo	Itage *	
12	2	1.887e+005 J/g		2.321e+00	3 J/gmole-K *	0.	8721 *	
12 13 14	3	1.887e+005 J/g	;mole *	2.321e+00	3 J/gmole-K *		1.099 *	
14	4 5							
15 16	6	1.887e+005 J/g	;mole *		Isothermal *	1.	0373 *	
17	7				Average *		1.032 *	
18	8							
19	9 10							
20	11	<er< th=""><th>npty> *</th><th></th><th></th><th></th><th></th><th></th></er<>	npty> *					
22	12							
23	13							
24	14 15							
26	16							
27	17							
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19 20 21 22 23 24 25 26 27 28 29 30	19							
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54 55 57 58 59 60								
59								
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62								
63		en Technology Inc.		Aspen HYS	YS Version 7.3 (25.0.0.7336		age 27 of 34
	Licens	ed to: BATTELLE ENERGY ALLIAN	CE				* Sner	ified by user.

1	_		Case Name: NA COOLED HT:	SE w SUPER CRITICAL RA	NKINE V1.hsc			
2		BATTELLE ENERGY ALLIANCE Burlington, MA	Unit Set: AFR					
4	Ca	spentech ^{Burlington, MA} USA						
5								
6								
7		Spreadsneet: Temp	Average ASR @TPL4		Units Set: Electrolysis_			
9								
10	CONNECTIONS							
11 12			Imported Variables					
13	Cell	Object	Variable Descriptior	1	Value			
14	A3		emperature		1073 K			
15	E15	Material Stream: Cathode @TPL4	Temperature		1073 K			
17		Expor	ted Variables' Formula Results					
18	Cell	Object	Variable Description)	Value			
19			PARAMETERS					
20 21								
22			Exportable Variables					
23	Cell	Visible Name	Variable Description	Variable Type	Value			
24	B13	B13:			0.4000			
25 26	B14 B15	B14: B15:			0.4000			
27	B16	B16:			0.4000			
28	B17	B17:			0.4000			
29	B18	B18:			0.4000			
30 31	B19 D15	B19: D15:			0.4000			
32	C16	C16:		Temperature	1073 K			
33	D16	D16:			0.4000			
34	C17	C17:		Temperature	1073 K			
35 36	D17 C18	D17: C18:		 Temperature	0.4000 1073 K			
37	E14	E14:		Temperature	1073 K			
38	F15	F15:			0.4000			
39 40	F16 F1	F16: F1:		Temperature	4.638e-013 K 0.4000			
40	D2	D2:			0.4000			
42	C3	C3:		Temperature	1073 K			
43	D3	D3:			0.4000			
44 45	C4 D4	C4: D4:		Temperature	1073 K 0.4000			
46	C5	C5:		Temperature	1073 K			
47	D5	D5:			0.4000			
48	A12	A12:		Temperature	1073 K			
49 50	A13 A14	A13: A14:		Temperature Temperature	1073 K 1073 K			
51	A15	A15:		Temperature	1073 K			
52	A16	A16:		Temperature	1073 K			
53	A17	A17:		Temperature	1073 K			
54 55	A18 F3	A18: F3:		Temperature	1073 K 0.4000			
56	F4	F4:			0.4000			
57	F5	F5:			0.4000			
58	F6	F6:			0.4000			
59 60	F7 F8	F7: F8:			0.4000			
61	F9	F9:			0.4000			
62	D12	D12:			0.4000			
63		Echnology Inc. Asper	HYSYS Version 7.3 (25.0.0.7336)		Page 28 of 34 * Specified by user.			
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1	\sim		Case Name: NA COOLED HTSE V	V SUPER CRITICAL RAN	KINE V1.hsc									
2		BATTELLE ENERGY ALLIANCE Spentech Burlington, MA USA	Unit Set: AFR											
4	<u> </u>	Spenteen USA	Date/Time: Fri Mar 28 11:16:39 2014											
5 6														
7		Spreadsheet: Temp Av	erage ASR @TPL4 (continued) u	Inits Set: Electrolysis_									
8 9														
10			PARAMETERS											
11	Exportable Variables													
12	Cell	Visible Name	Variable Description	Variable Type	Value									
14	C13	C13:		Temperature	1073 K									
15	D13	D13:			0.4000									
16	C14	C14:		Temperature	1073 K									
17 18	D14 C15	D14: C15:		 Temperature	0.4000 1073 K									
19	F10	F10:			0.4000									
20	F11	F11:			0.4000									
21	F12	F12:			0.4000									
22 23	F13	F13:			0.4000									
23	F14 B20	E14: B20:			0.4000 19.20									
25	B7	B7:			0.4000									
26	B8	B8:			0.4000									
27	В9	B9:			0.4000									
28	B10	B10:			0.4000									
29	B11	B11:			0.4000									
30	B12 A6	B12: A6:		Tomporatura	0.4000 1073 K									
32	A0 A7	A0. A7:		Temperature Temperature	1073 K									
33	A8	A8:		Temperature	1073 K									
34	A9	A9:		Temperature	1073 K									
35	A10	A10:		Temperature	1073 K									
36	A11	A11:		Temperature	1073 K									
37 38	E1 E2	E1: E2:		Temperature	1073 K 1073 K									
39	F2	F2:		Temperature	0.4000									
40	C1	C1:		Temperature	1073 K									
41	D1	D1:			0.4000									
42	C2	C2:		Temperature	1073 K									
43 44	C9	C9:		Temperature	1073 K									
44	D9 C10	D9: C10:		 Temperature	0.4000 1073 K									
46	D10	D10:			0.4000									
47	C11	C11:		Temperature	1073 K									
48	D11	D11:			0.4000									
49	C12	C12:		Temperature	1073 K									
50 51	A19 A20	A19: A20:		Temperature	1073 K 40.00									
52	E3	E3:		Temperature	1073 K									
53	E4	E4:		Temperature	1073 K									
54	E5	E5:		Temperature	1073 K									
55	E6	E6:		Temperature	1073 K									
56 57	E7	E7:		Temperature	1073 K									
58	E8 E9	E8: E9:		Temperature Temperature	1073 K 1073 K									
59	E10	E10:		Temperature	1073 K									
60	E11	E11:		Temperature	1073 K									
61	E12	E12:		Temperature	1073 K									
62	E13	E13:		Temperature	1073 K									
63		ECHNOLOGY INC. Aspen HYS BATTELLE ENERGY ALLIANCE	YS Version 7.3 (25.0.0.7336)		Page 29 of 34 * Specified by user.									
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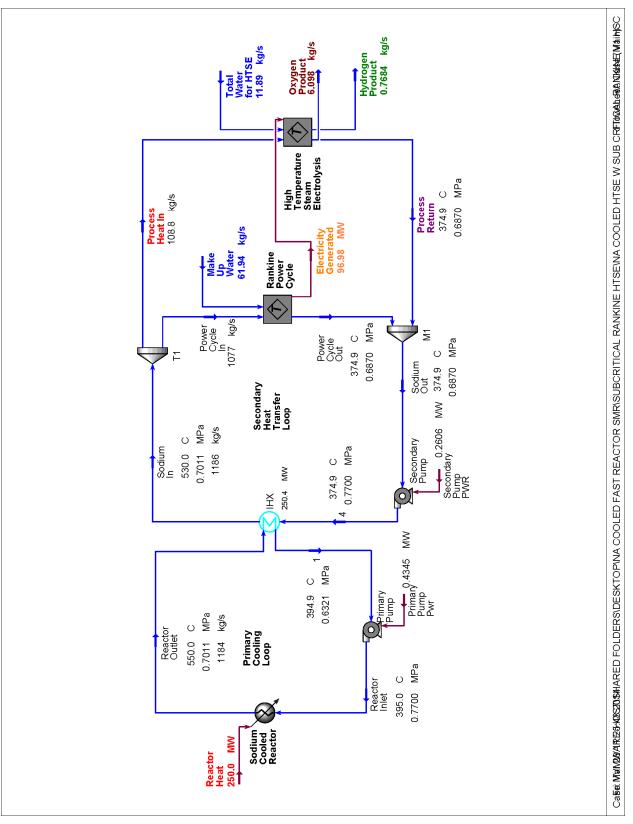
1			Case Name: NA COOLED HTS	E w SUPER CRITICAL RAI	NKINE V1.hsc
2		BATTELLE ENERGY ALLIANCE Burlington, MA	Unit Set: AFR		
4	Ja	spentech ^{Burlington, MA} USA			
5			Date/Time: Fri Mar 28 11:16:3	9 2014	
6		· · · · · -		/ / n	
7		Spreadsheet: Temp	Average ASR @TPL4	(continued)	Units Set: Electrolysis_
9					
10			PARAMETERS		
11			Exportable Variables		
12 13	Cell	Visible Name	• Variable Description	Variable Type	Value
14	C6	C6:	Variable Description	Temperature	1073 K
15	D6	D6:			0.4000
16	C7	C7:		Temperature	1073 K
17	D7	D7:			0.4000
18	C8	C8:		Temperature	1073 K
19	D8	D8:			0.4000
20	B1		B5: ASR @ 1100 K (ohms*cm*2)		0.2776
21 22	B2		Temp Aver ASR		0.4000
22	B3	B3: B4:			0.4000
24	B4 B5	B4. B5:			0.4000
25	B6	B6:			0.4000
26	D18	D18:			0.4000
27	C19	C19:		Temperature	1073 K
28	D19	D19:			0.4000
29	A4	A4:		Temperature	1073 K
30	A5	A5:		Temperature	1073 K
31			User Variables		
32 33					
33 34			FORMULAS		
35	Cell		Formula		Result
36	A4	=A3+F16			1073 K
37	A5	=A4+F16			1073 K
38	A6	=A5+F16			1073 K
39	A7	=A6+F16			1073 K
40	A8	=A7+F16			1073 K
41	A9	=A8+F16			1073 K
42 43	A10	=A9+F16			1073 K
43	A11 A12	=A10+F16 =A11+F16			1073 K 1073 K
45	A13	=A12+F16			1073 K
46	A14	=A13+F16			1073 K
47	A15	=A14+F16			1073 K
48	A16	=A15+F16			1073 K
49	A17	=A16+F16			1073 K
50	A18	=A17+F16			1073 K
51	A19	=A18+F16			1073 K
52	A20	=4*(B4+B6+B8+B10+B12+B14+B16+B18+D1+D3+[=6+F8+F10+F12+F14)	40.00
53	B2	@if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E	15-A3))		0.4000
54 55	B3	@EXP(10300/A3)*0.00003973+(B1-0.463)			0.4000
55 56	B4	@EXP(10300/A4)*0.00003973+(B1-0.463)			0.4000
56 57	B5 B6	@EXP(10300/A5)*0.00003973+(B1-0.463) @EXP(10300/A6)*0.00003973+(B1-0.463)			0.4000
58	B6 B7	@EXP(10300/A6)*0.00003973+(B1-0.463) @EXP(10300/A7)*0.00003973+(B1-0.463)			0.4000
59	B8	@EXP(10300/A8)*0.00003973+(B1-0.463) @EXP(10300/A8)*0.00003973+(B1-0.463)			0.4000
60	B9	@EXP(10300/A9)*0.00003973+(B1-0.463)			0.4000
61	B10	@EXP(10300/A10)*0.00003973+(B1-0.463)			0.4000
-	B11	@EXP(10300/A11)*0.00003973+(B1-0.463)			0.4000
62					
62 63	Aspen 1	Fechnology Inc. Aspe	n HYSYS Version 7.3 (25.0.0.7336)		Page 30 of 34 * Specified by user.

1	_		Case Name: NA COOLED HTSE w SUPER CRITICAL RA	NKINE V1.hsc											
2		BATTELLE ENERGY ALLIANCE Burlington, MA	Unit Set: AFR												
4	d	Date/Time: Fri Mar 28 11:16:39 2014													
5 6			Date/Time. Pri Mar 26 11, 16, 59 2014												
7		Spreadsheet: Temp A	verage ASR @TPL4 (continued)	Units Set: Electrolysis_											
8 9															
10			FORMULAS												
11	Cell		Formula	Result											
12	B12	@EXP(10300/A12)*0.00003973+(B1-0.463)		0.4000											
13	B13 B14	@EXP(10300/A13)*0.00003973+(B1-0.463) @EXP(10300/A14)*0.00003973+(B1-0.463)		0.4000											
14	B14 B15	@EXP(10300/A15)*0.00003973+(B1-0.463) @EXP(10300/A15)*0.00003973+(B1-0.463)		0.4000											
16	B16	@EXP(10300/A16)*0.00003973+(B1-0.463)		0.4000											
17	B17	@EXP(10300/A17)*0.00003973+(B1-0.463)		0.4000											
18	B18	@EXP(10300/A18)*0.00003973+(B1-0.463)		0.4000											
19	B19	@EXP(10300/A19)*0.00003973+(B1-0.463)		0.4000											
20	B20	=2*(B5+B7+B9+B11+B13+B15+B17+B19+D2+D4+D6+D	8+D10+D12+D14+D16+D18+F1+F3+F5+F7+F9+F11+F13)	19.20											
21	C1	=A19+F16		1073 K											
22	C2	=C1+F16		1073 K											
23	C3	=C2+F16		1073 K											
24	C4	=C3+F16		1073 K											
25	C5	=C4+F16		1073 K											
26 27	C6 C7	=C5+F18		1073 K											
28	C8	=C6+F16 =C7+F16		1073 K 1073 K											
29	C9	=C8+F16		1073 K											
30	C10	=C9+F16		1073 K											
31	C11	=C10+F16		1073 K											
32	C12	=C11+F16		1073 K											
33	C13	=C12+F16		1073 K											
34	C14	=C13+F16		1073 K											
35	C15	=C14+F18		1073 K											
36	C16	=C15+F16		1073 K											
37	C17	=C16+F16		1073 K											
38	C18	=C17+F16		1073 K											
39	C19	=C18+F16		1073 K											
40 41	D1	@EXP(10300/C1)*0.00003973+(B1-0.463)		0.4000											
41	D2 D3	@EXP(10300/C2)*0.00003973+(B1-0.463) @EXP(10300/C3)*0.00003973+(B1-0.463)		0.4000											
43	D3	@EXP(10300/C4)*0.00003973+(B1-0.463)		0.4000											
44	D5	@EXP(10300/C5)*0.00003973+(B1-0.463)		0.4000											
45	D6	@EXP(10300/C6)*0.00003973+(B1-0.463)		0.4000											
46	D7	@EXP(10300/C7)*0.00003973+(B1-0.463)		0.4000											
47	D8	@EXP(10300/C8)*0.00003973+(B1-0.463)		0.4000											
48	D9	@EXP(10300/C9)*0.00003973+(B1-0.463)		0.4000											
49	D10	@EXP(10300/C10)*0.00003973+(B1-0.463)		0.4000											
50	D11	@EXP(10300/C11)*0.00003973+(B1-0.463)		0.4000											
51	D12	@EXP(10300/C12)*0.00003973+(B1-0.463)		0.4000											
52 53	D13	@EXP(10300/C13)*0.00003973+(B1-0.463)		0.4000											
53 54	D14 D15	@EXP(10300/C14)*0.00003973+(B1-0.463) @EXP(10300/C15)*0.00003973+(B1-0.463)		0.4000											
54 55	D15 D16	@EXP(10300/C16)*0.00003973+(B1-0.463) @EXP(10300/C16)*0.00003973+(B1-0.463)		0.4000											
56	D18 D17	@EXP(10300/C17)*0.00003973+(B1-0.463)		0.4000											
57	D18	@EXP(10300/C18)*0.00003973+(B1-0.463)		0.4000											
58	D19	@EXP(10300/C19)*0.00003973+(B1-0.463)		0.4000											
59	E1	=C19+F16		1073 K											
60	E2	=E1+F16		1073 K											
61	E3	=E2+F16		1073 K											
62	E4	=E3+F16		1073 K											
63			'SYS Version 7.3 (25.0.0.7336)	Page 31 of 34											
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1	0			Case Name:	NA COOLED HTSE w SUPER	CRITICAL RA	ANKINE V1.hs	B
3	(1)	spentach Burlington, M	NERGY ALLIANCE A	Unit Set:	AFR			
4	<u> </u>	Spenteen USA		Date/Time:	Fri Mar 28 11:16:39 2014			
5 6								
7 8		Spreadshee	et: Temp Av	verage A	SR @TPL4 (cont	inued)	Units Set:	Electrolysis_
9				FORMULA	c			
10 11	Cell			Formula			R	esult
12	E5	=E4+F16		ormana			1073 K	coult
13	E6	=E5+F16					1073 K	
14	E7	=E6+F16					1073 K	
15	E8	=E7+F16					1073 K	
16	E9	=E8+F16					1073 K	
17 18	E10	=E9+F16					1073 K	
19	E11 E12	=E10+F16 =E11+F16					1073 K 1073 K	
20	E12	=E12+F16					1073 K	
21	E14	=E13+F16					1073 K	
22	F1	@EXP(10300/E1)*0.00003973+(E	31-0.463)				0.4000	
23	F2	@EXP(10300/E2)*0.00003973+(E					0.4000	
24	F3	@EXP(10300/E3)*0.00003973+(E	31-0.463)				0.4000	
25	F4	@EXP(10300/E4)*0.00003973+(E					0.4000	
26	F5	@EXP(10300/E5)*0.00003973+(E					0.4000	
27	F6	@EXP(10300/E6)*0.00003973+(E	,				0.4000	
28	F7	@EXP(10300/E7)*0.00003973+(E					0.4000	
29 30	F8 F9	@EXP(10300/E8)*0.00003973+(E					0.4000	
31	F10	@EXP(10300/E9)*0.00003973+(E @EXP(10300/E10)*0.00003973+					0.4000	
32	F11	@EXP(10300/E11)*0.00003973+					0.4000	
33	F12	@EXP(10300/E12)*0.00003973+					0.4000	
34	F13	@EXP(10300/E13)*0.00003973+					0.4000	
35	F14	@EXP(10300/E14)*0.00003973+					0.4000	
36	F15	@EXP(10300/E15)*0.00003973+	(B1-0.463)				0.4000	
37	F16	=(E15-A3)/50					4.638e-0	13 K
38 39				Spreadshe	et			
40		A	В		С		D	
41	1	ASR @ 1100 K *		0.2776 *	1073 K			0.4000 *
42	2	Temp Average ASR *		0.4000 *	1073 K			0.4000 *
43 44	3	1073 K *		0.4000 *	1073 K			0.4000 *
44	<u>4</u> 5	1073 K * 1073 K *		0.4000 *	1073 K 1073 K	-		0.4000 *
40	6	1073 K *		0.4000 *	1073 K	1		0.4000 *
47	7	1073 K *		0.4000 *	1073 K	1		0.4000 *
48	8	1073 K *		0.4000 *	1073 K	1		0.4000 *
49	9	1073 K *		0.4000 *	1073 K			0.4000 *
50	10	1073 K *		0.4000 *	1073 K			0.4000 *
51	11	1073 K*		0.4000 *	1073 K	*		0.4000 *
52	12	1073 K*		0.4000 *	1073 K	*		0.4000 *
53	13 14	1073 K*		0.4000 *	1073 K			0.4000 * 0.4000 *
04 55	15	1073 K * 1073 K *		0.4000 *	1073 K 1073 K			0.4000 *
56	16	1073 K *		0.4000 *	1073 K			0.4000 *
57	17	1073 K*		0.4000 *	1073 K			0.4000 *
58	18	1073 K *		0.4000 *	1073 K			0.4000 *
59	19	1073 K *		0.4000 *	1073 K	*		0.4000 *
60	20	40.00 *		19.20 *				
61		E	F					
62 63	1	1073 K *	A	0.4000 *	1 (05.0.0.7330)		-	- 10 -5 - 1
63		Technology Inc. D: BATTELLE ENERGY ALLIANCE	Aspen HYS	or 5 version /.	3 (25.0.0.7336)			ed by user.
	U						opoolii	

1	0		Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
2 3 4	(1	BATTELLE ENERGY ALLIANCE aspentech USA	Unit Set:	AFR
4 5		USA	Date/Time:	Fri Mar 28 11:16:39 2014
6				
7 8		Spreadsheet: Temp A	verage AS	SR @TPL4 (continued) Units Set: Electrolysis
9			Spreadsheet	t
10 11	2	1073 K *	0.4000 *	
12	3	1073 K*	0.4000 *	
12 13 14 15 16	4	1073 K*	0.4000 *	
14	5 6	1073 K * 1073 K *	0.4000 * 0.4000 *	
16	7	1073 K *	0.4000 *	
17 18	8	1073 K *	0.4000 *	
18	9	1073 K *	0.4000 *	
19	10	1073 K *	0.4000 *	
20	11 12	1073 K * 1073 K *	0.4000 * 0.4000 *	
22	13	1073 K*	0.4000 *	
23	14	1073 K *	0.4000 *	
24	15	1073 K *	0.4000 *	
25	16 17	delta T *	4.638e-013 K *	
19 20 21 22 23 24 25 26 27	18			
28 29	19			
29	20			
30				
32				
33				
34				
35				
37				
38				
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43				
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30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51				
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54				
53 54 55 56 57 58 59 60 61				
5 57				
58				
59				
60				
61 62				
63	Asp	en Technology Inc. Aspen HY	SYS Version 7.3	(25.0.0.7336) Page 33 of 34
		ed to: BATTELLE ENERGY ALLIANCE		* Specified by user.

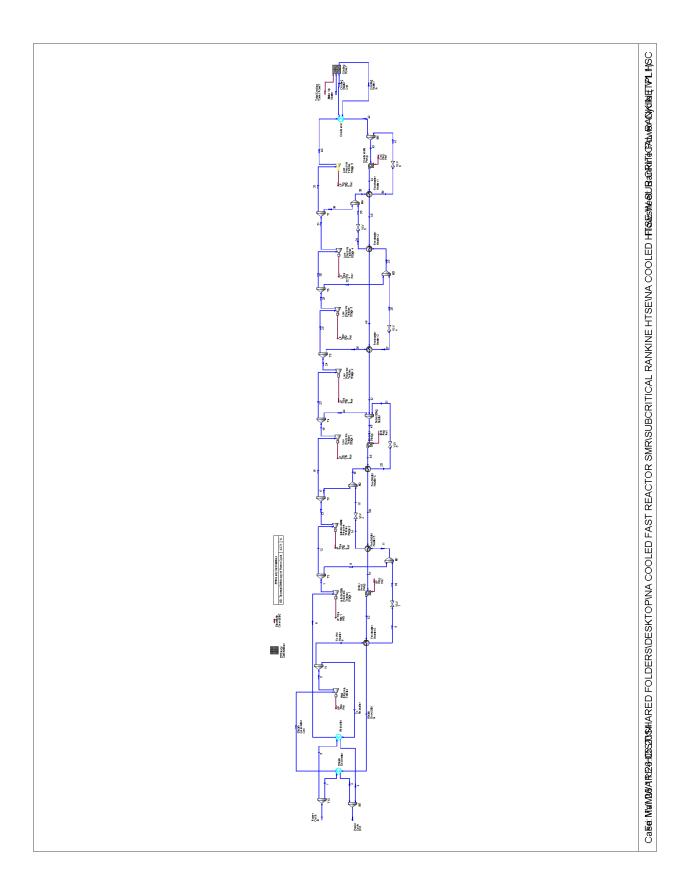
1	<u> </u>			Case Name:	NA COOLED HT	SE w SUPER (CRITICAL RANKINE V1.hsc	
3	Burling	LLE ENERGY ton, MA	ALLIANCE	Unit Set:	AFR			
4 5				Date/Time:	Fri Mar 28 11:16:	39 2014		
6 7	Δ.							
8	A	ajust: /	ADJ-1 @	IPL4				
9 10	Adjusted	d Variable				Measured	l Variable	
11	OBJECT		VARIABLE		OBJECT		VARIABLE	
12 13	3		Mass Flow		Anode		Molar Flow	
14				olving Para				
15 16	Source for Target Value: Value Solving Method:	from Object Secant	Object: Tolerance:	ır Flo	w of Oxygen @TPL4 0.9000 kgmole/h	Offset: Maximum Ite	0.0000 kgm erations:	iole/h * 100 *
17	Step Size:	0.1000 kg/s *	Maximum:			Minimum:	statorio.	
18 19				User Varia	bles			
20								
21 22								
23								
24								
25 26								
27								
28 29								
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31 32								
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35 36								
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38 39								
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44 45 46 47 48								
48 49								
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51								
52 53								
54								
55 56								
56 57								
58 59								
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61								
62 63	Aspen Technology Inc.		Aspen HYS	SYS Version 1	7.3 (25.0.0.7336)		Page 34 c	of <u>3</u> 4
	Licensed to: BATTELLE ENERGY ALLIANCI	E					* Specified by us	



6.5 Subcritical Rankine HTSE Model

1				Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1. HSC					
2	aspentech	Burlington	E ENERGY ALLIANCE , MA	Unit Set:	AFR				
4		USA		Date/Time:	Fri Mar 28 11:35:17 201	4			
6									
7 8	Wor	kbook	: Case (Mai	n)					
9 10				Material Stream	IS	Fluid Pkg: A			
11	Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1		
12	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000		
13	Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *		
14	Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321		
10	Molar Flow Mass Flow	(kgmole/h) (kg/s)	1.857e+005 1186	1.857e+005 1186	1.854e+005 1184	1.854e+005 1184	1.854e+005 1184		
17	Liquid Volume Flow	(kg/s) (m3/h)	4544	4544	4537	4537	4537		
18	Heat Flow	(MVV)	818.8	568.3	849.9	599.9	599.5		
19	Name	(Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE		
20	Vapour Fraction		0.0000	0.0000	1.0000	1.0000	0.0000		
21	Temperature	(C)	374.9	20.00	54.44	54.44	21.11		
22	Pressure	(MPa)	0.6870	0.1013	6.901	6.901	0.1013		
23	Molar Flow	(kgmole/h)	1.857e+005	1.238e+004	1372	686.0	2376		
24	Mass Flow	(kg/s)	1186	61.94	0.7684	6.098	11.89		
25	Liquid Volume Flow	(m3/h)	4544	223.4	39.60	19.30	42.90		
26	Heat Flow	(MVV)	568.1	-981.1	0.3244	6.653e-002	-189.1		
27	Name		Process Heat In	Process Return	Power Cycle In	Power Cycle Out			
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000.0			
29 30	Temperature	(C)	530.0	374.9	530.0	374.9			
30	Pressure Molar Flow	(MPa)	0.7011 1.704e+004	0.6870 1.704e+004	0.7011 1.687e+005	0.6870 1.687e+005			
32	Mass Flow	(kgmole/h) (kg/s)	108.8	108.8	100781003	100781003			
33	Liquid Volume Flow	(m3/h)	416.8	416.8	4127	4127			
34	Heat Flow	(MVV)	75.11	52.11	743.7	516.0			
35									
				Compositions	i	Fluid Pk	g: All		
36 37	Name		Sodium In	-			g: All		
36	Name Comp Mole Frac (H2O)		Sodium In	Compositions 4	Reactor Outlet	Fluid Pk	g: All 1		
36 37	Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen)			4	Reactor Outlet	Reactor Inlet	1		
36 37 38	Comp Mole Frac (H2O)		***	4 ***	Reactor Outlet	Reactor Inlet	- 1 ***		
36 37 38 39	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen))	***	4	Reactor Outlet ***	Reactor Inlet	- 1 ***		
36 37 38 39 40	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen))	*** *** *** *** ***	4 *** *** ***	Reactor Outlet *** *** *** *** *** *** *** *** *** *	Reactor Inlet *** *** *** *** *** *** ***	1 *** *** *** ***		
36 37 38 39 40 41 42 43	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO))	*** *** *** *** ***	4 *** *** *** ***	Reactor Outlet	Reactor Inlet ****	- 1 		
36 37 38 40 41 42 43 44	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium))	*** *** *** *** *** 1.0000	4 *** *** *** *** *** *** *** *** *** *	Reactor Outlet	Reactor Inlet **** *** *** *** *** *** *** *** ***	1 **** **** **** **** **** 1.0000		
36 37 38 39 40 41 42 43 44 45	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air))	**** *** *** *** 1.0000	4 *** *** *** *** 1.0000 *	Reactor Outlet	Reactor inlet **** **** **** **** **** 1.0000 * ****	1 **** **** **** **** **** 1.0000 ****		
36 37 38 39 40 41 42 43 44 45 46	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name)	*** *** *** *** *** 1.0000	4 **** **** **** **** **** 1.0000* Make Up Water	Reactor Outlet	Reactor Inlet	1		
36 37 38 39 40 41 42 43 44 45	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O))	**** **** **** **** **** 1.0000 *** Sodium Out	4 *** *** *** *** 1.0000 *	Reactor Outlet	Reactor Inlet *** *** *** *** *** *** *** *** *** Oxygen Product 0.0000	1 *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000		
36 37 38 39 40 41 42 43 44 45 46 47	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen))	**** **** **** **** 1.0000 *** Sodium Out ***	4 **** **** **** *** *** *** *** *** **	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.0000		
36 37 38 39 40 41 42 43 44 45 46 47 48	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Hydrogen Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O)		**** **** **** **** 1.0000 **** Sodium Out **** ****	4 **** *** *** *** *** 1.0000 *** Make Up Water 1.0000 ***	Reactor Outlet	Reactor Inlet *** *** *** *** *** *** *** *** *** Oxygen Product 0.0000	1 *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oyygen) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		**** **** **** **** **** **** **** **** ****	4 **** *** *** *** 1.0000 *** Make Up Water 1.0000 ***	Reactor Outlet **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000	Reactor Inlet	1 *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.0000 0.0000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nydrogen)		**** **** **** **** 1.0000 **** Sodium Out *** *** **** **** ****	4 *** *** *** *** 1.0000 * *** Make Up Water 1.0000 ***	Heactor Outlet **** **** **** **** 1.0000 **** Hydrogen Product 0.0000 0.0000 0.0000 1.0000	Reactor inlet	1 *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Co2)		**** **** **** **** Sodium Out **** **** **** **** **** **** **** *	4 **** **** **** **** **** **** Make Up Water 1.0000 **** **** **** **** **** **** **	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** 1.000 *** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000 0.0000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Air) Name Comp Mole Frac (Air) Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Cygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2)		****	4 **** **** **** **** **** **** **** *	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** *** *		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)		**** **** **** **** **** **** **** **** ****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COxygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Naygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO3) Comp Mole Frac (CO3) Comp Mole Frac (CO3) Comp Mole Frac (Air)		****	4 *** *** *** *** *** *** *** *** *** *	Reactor Outlet	Reactor Inlet	1 **** **** **** **** **** 1.0000 **** Total Water for HTSE 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 *** ***		
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (COy Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Acr) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (O2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium))	****	4 **** **** ***** ***** ******	Reactor Outlet	Reactor Inlet	1 *** *** *** *** *** *** *** *** 1.0000 *** Total Water for HTSE 1.0000 0.00000 0.000		

1	_				Case Name:	N	A COOLED HTSE W	SUB CRITI	CAL RANKINE	V1.HSC	
3	aspentech	Burlington	E ENERGY ALLIANC , MA	CE	Unit Set:	A	FR				
4		USA			Date/Time:	Fr	ri Mar 28 11:35:17 201	4			
6						_					
7	Work	book	: Case (M	lair	n) (continue	ed)				
9				Co	mpositions (conti	inı	ued)		Fluid Pkg:		
10 11	Name		Process Heat In		Process Return	_	Power Cycle In	Power C	ycle Out		
12	Comp Mole Frac (H2O)			***	***		***		***		
13	Comp Mole Frac (Nitrogen)			***	***		***		***		
14	Comp Mole Frac (Oxygen)			***	***		***		***		
15 16	Comp Mole Frac (Hydrogen)			***	***		***		***		
17	Comp Mole Frac (CO2) Comp Mole Frac (CO)			***	***		***		***		
18	Comp Mole Frac (Sodium)		1.00	nn	1.0000		1.0000		1.0000		
19	Comp Mole Frac (Air)			***	***		***		***		
20			•		Energy Stream	s			Fluid Pkg:	All	
21						_					
22	Name Heat Flow	(MVV)	Reactor Heat 250	10 *	Electricity Generated 96.98		Primary Pump Pwr 0.4345	Seconda	ary Pump PWF 0.2606		
23	Heat Flow	(MVV)	200	1.0			0.4340		0.2000		
25					Unit Ops						
26	Operation Name	Ope	eration Type		Feeds		Products		Ignored	Calc Level	
27	Sodium Cooled Reactor	Heater		-	actor Inlet actor Heat	_	Reactor Outlet		No	500.0	
29				-	wer Cycle In		Power Cycle Out				
30	Rankine Power Cycle	Standard	Sub-Flowsheet	Make Up Water		Electricity Generated		No	2500 *		
31				Process Heat In		Hydrogen Product					
32	High Temperature Steam Elec	Standard	Sub-Flowsheet	Total Water for HTSE			Oxygen Product		No	2500 *	
33				Ele	ectricity Generated		Process Return				
34 35	Efficiency Calcs	Spreadsh	eet		actor Outlat	_	1		No	500.0 *	
36	IHX	Heat Excl	nanger		Reactor Outlet 1 4 Sodium In				No	500.0	
37				1			Reactor Inlet				
38	Primary Pump	Pump		Pri	mary Pump Pwr				No	500.0	
39 40	Secondary Pump	Pump			dium Out		4		No	500.0	
40					condary Pump PWR dium In	-	Power Cycle In				
42	Τ1	Tee		- 50	alamm	_	Process Heat In		No	500.0	
43	M1	Mixer		Pro	ocess Return		Sodium Out		No	500.0	
44 45	MI	Wixer		Po	wer Cycle Out				IND	500.0	
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62											
63	Aspen Technology Inc.		Asp	en H	IYSYS Version 7.3 ()	25.	.0.0.7336			Page 2 of 33	
	Licensed to: BATTELLE ENERGY	ALLIANCE								* Specified by user.	



1	~			Case Name:	NA COOLED HTSE W S	SUB CRITICAL RANKINI	EV1.HSC
2 3	aspentec	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 11:35:17 201	4	
5 6				1			
7 8	Wo	orkbook:	Rankine P	ower Cycle	(TPL1)		
9 10				Streams		Fluid Pk	g: All
11	Name		Steam Generator Out	To Reheater @TPL1	To FW Heater 6 @TPI	6 @TPL1	9@TPL1
12	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000
13	Temperature	(C)	510.0	354.8	354.8	510.0	251.1
14	Pressure	(MPa)	17.00	5.850	5.850	5.733	5.733
15	Molar Flow	(kgmole/h)	1.824e+004	1.714e+004	1096	1.714e+004	1096
16	Mass Flow	(kg/s)	91.28	85.79	5.486	85.79	5.486
17	Std I deal Liq Vol Flow	(m3/h)	329.3	309.5	19.79	309.5	19.79
10	Heat Flow Molar Eatholmy	(MVV) (kJ/kgmole)	-1151 -2.272e+005	-1104 -2.318e+005	-70.57 -2.318e+005	-1070 -2.247e+005	-81.37 -2.672e+005
20	Molar Enthalpy Name	(Karkymule)	-2.272e+005 52 @TPL1	-2.318e+005 Steam Generator In @	-2.318e+005 51@TPL1	-2.247e+005 8@TPL1	-2.672e+005 12@TPL1
20	Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
22	Temperature	(C)	245.6	270.4	241.0	445.6	445.6
23	Pressure	(MPa)	17.70 *	17.35	3.409	3.760	3.760
24	Molar Flow	(kgmole/h)	1.824e+004	1.824e+004	1.824e+004	1030	1.611e+004
25	Mass Flow	(kg/s)	91.28	91.28	91.28	5.156	80.64
26	Std I deal Liq Vol Flow	(m3/h)	329.3	329.3	329.3	18.60	290.9
27	Heat Flow	(MVV)	-1356	-1346	-1358	-64.97	-1016
28	Molar Enthalpy	(kJ/kgmole)	-2.677e+005	-2.655e+005	-2.681e+005	-2.270e+005	-2.270e+005
29	Name		11 @TPL1	16@TPL1	18@TPL1	23 @TPL1	22@TPL1
30	Vapour Fraction		0.6368	1.0000	0.3742	1.0000	1.0000
31	Temperature	(C)	246.7	365.7	215.4	274.7	274.7
32	Pressure	(MPa)	3.760	2.120	2.120	0.9299	0.9299
33	Molar Flow	(kgmole/h)	2127	1.515e+004	3095	1.424e+004	910.3
34	Mass Flow	(kg/s)	10.64	75.79	15.49	71.24	4.555
35	Std I deal Liq Vol Flow	(m3/h)	38.39	273.4	55.87	257.0	16.43
36	Heat Flow Meler Esthelm	(MVV)	-146.3 -2.477e+005	-966.7 -2.298e+005	-221.5	-920.8 -2.329e+005	-58.88 -2.329e+005
38	Molar Enthalpy Name	(kJ/kgmole)	49 @TPL1	-2.2868+005	-2.576e+005 20 @TPL1	47 @TPL1	48@TPL1
39	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
40	Temperature	(C)	177.2	215.1	182.7	142.0	176.6
41	Pressure	(MPa)	3.550 *	3.760	2.078	0.9299	0.9299
42	Molar Flow	(kgmole/h)	1.824e+004	2127	3095	1.424e+004	1.824e+004
43	Mass Flow	(kg/s)	91.28	10.64	15.49	71.24	91.28
44	Std I deal Liq Vol Flow	(m3/h)	329.3	38.39	55.87	257.0	329.3
45	Heat Flow	(M <i>\</i> V)	-1385	-159.7	-234.6	-1092	-1385
46	Molar Enthalpy	(kJ/kgmole)	-2.733e+005	-2.703e+005	-2.729e+005	-2.761e+005	-2.734e+005
47	Name		21 @TPL1	25@TPL1	26 @TPL1	27 @TPL1	30@TPL1
48	Vapour Fraction		0.0132	1.0000	1.0000	0.0000	1.0000
49	Temperature	(C)	176.8	202.0	202.0	113.9	126.4
50 51	Pressure Molar Flow	(MPa)	0.9299 3095	0.4380 1.338e+004	0.4380 855.5	0.4292 855.5	0.1660 1.258e+004
		(kgmole/h)					
52 53	Mass Flow Std I deal Liq Vol Flow	(kg/s) (m3/h)	15.49 55.87	66.96 241.5	4.281 15.44	4.281	62.93 227.0
54	Heat Flow	(MVV)	-234.6	-874.5	-55.92	-66.13	-830.8
55	Molar Enthalpy	(kJ/kgmole)	-2.729e+005	-2.353e+005	-2.353e+005	-2.783e+005	-2.378e+005
56	moral Entrany	(nonightore)	2.1.200 000	210300 003	2.0000 000	2.1000 000	2.0100 000
57 58 59 60							
61 62 63	Aspen Technology In		Asnen -	IYSYS Version 7.3 ()	25.0.0.7336		Page 3 of 33
	Licensed to: BATTELLE ENE		Aspell r		20.0.0.7000		* Specified by user.
							opcomed by deer.

2 Description BATTELIE DENOY ALLANCE UNA Data Time APR 1 Data Time Find and 11.05 17.2014 Data Time Find and 11.05 17.2014 1 Name 20.0017 Point Find Out One Streams (continued) 1 Name 20.0017 Find and 21.1000 Streams (continued) Streams (continued) 1 Name 0.0010 0.0000 0.0000 0.0000 4.430 0.0000 1 Temperature (C) 1.024 0.0122 7.77.7 4.534 0.000 1 Temperature (C) 1.024 0.012 4.884 0.012 1 Temperature (MPs) 0.1600 4.182 0.012 4.288 0.011 4.288 0.011 0.022 2.884 0.012 7.288 0.001 2.288 0.001 2.288 0.001 2.288 0.001 2.288 0.001 2.288 0.001 2.288 0.001 2.288 0.001 0.000 0.000 0.000 <	1				Case Name:	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC						
Construction DataseTime Pick Mar 28 11 35: 17 2014 Workbook: Rankine Power Cycle (TPL1) (continued) Streams (continued) Pick Mar 28 11 35: 17 2014 Streams (continued) Pick Mar 28 11 35: 17 2014 Dispan="2">Dispan="2">Dispan="2">Pick Mar 28 11 35: 17 2014 Tergentation Colspan="2">Pick Mar 28 11 35: 17 2014 Tergentation Oligo 20 20 20 20 20 20 20 20 20 20 20 20 20	З		Burlington,			AFR						
Image: Second			USA			Eri Mar 28 11-35-17-201	4					
Image: Second					Date/Time.	111 Mai 20 11:33:17 201	-					
B Streams (continued) Fuid Pkg 11 Name 32 gTPL1 37 gTPL1 38 gTPL1 38 gTPL1 38 gTPL1 44 gTPL1 12 Vagour Fraction (C) 1244 80.22 10.1071 46.84.92 0.88 13 Temperature (C) 1.284 80.22 0.1027 4.084.902 0.88 14 Pressave (M*A) 0.1600 4.7886-002 0.1027 4.084.902 0.28 15 Mater Flow (MyA) 5.31 2 -710.6 -72.95 -119.0 2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.2384-105 -2.238-10 0.000 0.000 0.000 4.0805 1.2 -1.18 4.035 1.2 -1.18 4.035 1.2 -1.18 4.035 1.2 -1.18 4.035 1.2 -1.18 4.035 1.2 -1.18 4.041 0.000 -0.000 0.000 0.000 0.000 0.000 <th></th> <th>Wo</th> <th>orkbook:</th> <th>Rankine P</th> <th>ower Cvcle</th> <th>(TPL1) (con</th> <th>tinued)</th> <th></th>		Wo	orkbook:	Rankine P	ower Cvcle	(TPL1) (con	tinued)					
Difference Difference <thdifference< th=""> Difference Differen</thdifference<>					····· · , ····	()(·····,					
1 1 1 1 0					Streams (continu	ed)	Fluid Pk	g: All				
Imperature CC 126 momental 9777 44.74 44.74 Persone (Main Flow (Agmoleth) 0.160 1102 0.1620 0.83 10 Main Flow (Agmoleth) 0.04.1 1.102e-004 1.660 2.416 1.424e-00 10 Main Flow (Agmoleth) 0.04.1 2.338.12 2.700.6 128.5 1.00.2 2.288e-005 2.288e-005 2.288e-005 2.288e-005 2.288e-005 2.288e-005 2.288e-005 0.2.288e-005 2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 0.2.288e-005 7.2.388e-005 0.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.288e-005 7.2.2.288e-005 7.2.2.288e-005 7.2.2.288e-005 7.2.2.288e-005 7.2.2.2.288e-005 7.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2	11	Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1				
Image Pressure (M*9) 0.660 4.700-002 0.1627 4.604-002 0.093 Mark Frew (iigmabh) 0.611 1.182+004 1600 2.402+02 0.93 Mark Frew (iigmabh) 0.611 1.182+004 1.600 2.402+02 1.100 2.128 1.100 2.128 1.100 2.111 1.111 Mark Entraty (iiffantic iiffantic iiiffantic iiiffantic iiffantic iiffantic iiffantic iiffantic iiffa	12	Vapour Fraction		1.0000	0.9633	0.0000	0.0000	0.0000				
10 Mase Flow (tigst) 88.4 1.122-004 1900 2.16 1.1424-01 10 Mase Flow (tigst) 4.224 5.01 8.05 1.200 1.77 11 Malar Env (tigst) 1.422 2.134 2.9.86 4.430 2.55 12 Malar Env (tigst) 2.2.354-015 -2.248-015 -2.248-015 -2.248-015 -2.255 0.2.356-01 .0.100 0.4995 0.000 12 Name 0.007Fration 0.9977 0.3009 0.0000 0.4995 0.000 12 Name (tigst) 7.438-003 0.1480 7.438-03 0.1480 7.438-03 12 Mass Flow (tigst) 5.916 1.802 3.4114 4.00 12 Mass Flow (tigst) 5.916 1.802 -1.418 1.429 14 Mass Flow (tigst) 5.916 1.829 1.438 1.429 1.438 12 Mass Flow (tigst) 5.910 <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>40.18</th>								40.18				
10 Mass Flow (gg/s) 4.4.24 6.8.15 8.305 17.00 7.7 17 Stb1deal Liq Val Flow (m3h) 14.52 2.13.4 29.88 44.860 25.5 18 Mare (May) -2.376e.005 -2.408e.005 -2.200e.005 -2.238e+005 -2.358e+005 -2.358e+005 <td< th=""><th>14</th><th></th><th>· · · ·</th><th></th><th></th><th></th><th></th><th>0.9880 *</th></td<>	14		· · · ·					0.9880 *				
17 Statissi Lig Vici Flow (m3m) 14 452 713.4 29.96 448.00 17.97 18 Heat Flow (MW) -53.12 -730.5 -128.55 -190.2 -111 19 Molar Finnhapy (Liggrad) -2.378+005 -2.408+005 -2.828+005 -2.828+005 -2.828+005 -0.1805 20 Name 40.027FL1 38.027FL1 42.027FL1 43.027FL1 44.027FL1 -0.0000 0.04985 0.000 21 Vapour Fraction 0.0977 0.3000 0.04000 -0.4985 0.010 22 Tremperature (C) -0.4051 1.0202 7.338-00 -0.1860 7.433-00 23 Mass Flow (kg/s) 59.15 1.282 6.915 8.385 1.12 24 Mats Flow (kg/s) -2.184+00 -2.187+00 -2.887+00 -2.287+00 -2.287+00 -2.287+00 -2.287+00 -2.287+00 -2.287+00 -2.287+00 0.070 0.070 0.070 0.070 0.070 0.071 0.8870 0.877 -2.877+00 0.2.287+00 0.2.287+00 <t< th=""><th>15</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>	15											
B Heat Flow (MW) 6.3 12								71.24				
19 Mainer Enthalpy (µ/µ/µ/µ/µ) ·2.2 (38µ+005) ·2.2 (38µ+005) ·2.2 (38µ+005) ·2.2 (38µ+005) ·2.2 (38µ+015) ·2.2 (38µ+01) ·2.2 (38µ+01)<	18							257.0 -1122				
DNme 40 @TPL1 32 @TPL1 42 @TPL1 33 @TPL1 41 @TPL1 1 Vapor Fration 0.0002 0.0000 0.04855 0.000 21 Temperature (C) 4.0 0.0002 7.433-0.03 0.1860 7.433-0.03 22 Molar Flaw (grouth) 1.182+004 2.415 1.122+004 1.6800 2.24 23 Sati deal Lytel Flow (m/m) 2.948 4.4380 0.2134 4.9386 4.9323 24 Sati deal Lytel Flow (m/m) 2.246+005 2.638+005 -2.259+005 -2.597+005 -2.938+00 23 Mare 1.077+1 3.077+1 2.077+11 4.077+1 2.077+11 4.077+1 2.077+1 4.077+1 2.077+1 4.077+1 2.077+11 4.077+1 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.001 1.011+004 1.011+004 1.011+004 1.011+004 1.011+004 1.011+004 1.011+004 1.010+004 1.010+004	19							-2.838e+005				
21 Vapour Fraction 0.9072 0.3088 0.0000 0.4865 0.000 22 Temperature (C) 44.051 88.022 7.83.862 1.114.4 44.00 21 Mass Flow (kgmole/h) 1.122.4004 2.415 1.1122.4014 1.860 7.433.e0 22 Mass Flow (kgmole/h) 2.123.4 4.43.60 2.123.4 2.99.65 4.232.6 24 Heat Flow (MMV) 402.2 4.80.0 4.932.3 -119.2 -188.0 20 Maler Enthalpy (kJ/kgmole) 2.2.446e+005 2.2.828e+005 2.2.827e+005 -2.587e+005	20		(norriginoloy									
22 Temperature (C) 44 01 8022 38.92 11.44 44.04 20 Pressure (MPa) 7.584-003 4.7806-002 7.433-003 0.1660 7.433-0 21 Molar Flow ((gronlerh) 1.182e-004 2.433-00 1.102e-004 1.806 0.243 22 Stal feal Liq Vol Flow (mA) 2.13.4 4.43.80 2.13.4 2.988 4.43 21 Har Flow (mA) -2.43.84:005 -2.838:005 -2.838:005 -2.838:005 -2.838:005 -2.838:005 -2.838:005 -2.838:005 -2.838:005 0.0000	21							0.0098				
23 Pressure (MP) 7.584-003 4.780-002 7.438-003 0.1800 7.433-00 24 Molar Flow (liggmole/h) 1.192e+004 2415 1.182e+004 1.802 7.433-00 25 Mass Flow (liggmole/h) 2.1912 1.812e+004 1.802 7.432-003 7.432-003 7.432-004 7.532-074 7.533 7.5330.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.530.0 7.5330.0 7.530.0 <th>22</th> <th></th> <th>(C)</th> <th></th> <th></th> <th></th> <th></th> <th>40.13</th>	22		(C)					40.13				
Mass Flow (ig/s) 5915 12.09 6915 8.305 12.2 StatiesL Lq Vol Flow (m/n) 2134 4.4360 2.134 2.286 4.3 21 Heat Flow (M/N) 9028 180.0 6233=+005 2.838+e05 2.838+e05 2.838+e05 2.838+e05 2.859e+005 2.838+e05 2.859e+005 2.838+e05 2.859e+005 2.859e+006 2.859e+006 1.827e+014 .1.827e+014 1.827e+014 1.827e+014 1.827e+014 1.827e+014 1.827e+014 1.827	23			7.584e-003*	4.780e-002	7.433e-003	0.1660	7.433e-003				
Std ideal Liq Vol Flow (m3/n) 2134 44380 2134 2936 443 21 Heat Flow (M/N) -8028 -180.0 -9233 -1192 -1191 21 Malar Enthalpy (kJ/kgmole) -2445e+005 -2638e+005 -2389e+005 -2587e+006 -2838e+00 -2637e+006 -02089 00000 0.0010 0.012 1.016:00 1.016:00 Mais Fibw (kgmole) 1.587e+004 1.101e+004 1.010e+004 1.587e+004 1.010e+004 1.010e+004 1.587e+004 1.010e+004 1.010e+004 1.587e+004 1.010e+004 1.010e+004 1.587e+004 1.010e+004 1.587e+004	24	Molar Flow	(kgmole/h)	1.182e+004	2415	1.182e+004	1660	2415				
22 Heat Flow (MM) -802.8 -180.0 -932.3 -119.2 -130.2 28 Maire Enthalpy (LJIG)mole) -2.448e+105 -2.638=+005 -2.638=+005 -2.638=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 -2.838=+005 0.0000 1.0011 0.0870 0.8770 0.774 30 Mair Enthalpy (kJirkg) 9181 1.581 0.911 1.011+004 1.587+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+04 1.687+	25	Mass Flow	(kg/s)	59.15	12.09	59.15		12.09				
Malar Enthalpy (kJ/kgmole) 2.445e+005 J2.883e+005 J2.838e+005 J2.838e+005 J2.838e+005 J2.838e+005 J2.838e+006 J2.838e+007 J2.837e+004 J2.837e+006 J2.837e+004 J2.837e+006 J2.837e+004 J1.837e+006 J2.837e+007 J2.837e+007 <thj2.837e+007< th=""> <thj2.837e+007< th=""></thj2.837e+007<></thj2.837e+007<>	26							43.60				
22 Name 1 @TFL1 3 @TFL1 2 @TFL1 4 @TFL1 Power Cycle in @ 30 Vapour Fraction 0.0000 0.0070 0.0701 0.0870 0.8870 0.0701 0.0870 0.8870 0.0701 0.0870 0.8870 0.0700 1.087+00 1.087+00 1.087+00 1.087+00 1.0014 1.011+0104 1.012+0104 1.012+0104 1.012+0104 1.012+0104 1.012+0104 1.012+0104 1.0000 1.0010 1.0010 1.0000 1.0010 1.0012+014 1.012+0104 1.012+0104 1.012+0104 1.012+0104 1.012+0104 1.010+0104 1.027+11 1.020+1104 1.010+0104 1.000+11000 1.000+11000 1.000+11000 1.000+11000 1.000+11000+1100+110	27							-190.2				
30 Vapour Fraction 0.0000 1.001e+004 1.887e+004 1.887e+004 1.001e+004 1.587e+01 1.001e+004 1.587e+01 1.002FPL1 7.02FL1 1.02FPL1 1.002FPL1 7.02FL1 1.302FPL1 1.002FPL1 7.0000 1.0000 1.0000 0.0000 1.0000 0.0122 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 </th <th></th> <th></th> <th>(kJ/kgmole)</th> <th></th> <th></th> <th></th> <th></th> <th>-2.834e+005</th>			(kJ/kgmole)					-2.834e+005				
31 Temperature (C) 630.0 530.0 374.9 374.9 531 32 Pressure (MPa) 0.7011 0.7011 0.6870 0.0870 0.770 33 Molar Flow (kgmole/h) 1.439e+005 2.475e+004 1.439e+005 2.475e+004 1.878e+004 34 Mass Flow (kg/s) 919.1 158.1 919.1 168.1 101 35 Std Ideal Liq Vol Flow (m2/h) 352.1 605.6 41 36 Heat Flow (WV) 634.6 109.1 440.3 75.72 74' 37 Molar Enthalpy (k.J/kgmole) 1.587e+004 1.101e+004 1.101e+004 1.587e+00 38 Name Power Cycle Out @T 5 @TPL1 10 @TPL1 7 @TPL1 13 @TPL1 39 Vapour Fraction 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000								-				
2 Pressure (MPa) 0.7011 0.7011 0.6870 0.6870 0.701 33 Molar Flow (kgmole/h) 1.438e+005 2.475e+004 1.438e+005 2.475e+004 1.887e+00 34 Mass Flow (kg/s) 0.911 1.581 919.1 1.59.1 1.00 35 Std ideal Lig Vol Flow (mAV) 634.5 1.09.1 440.3 7.57.2 7.44 36 Heat Flow (MAV) 634.5 1.09.1 440.3 7.57.2 7.44 37 Malar Enthalpy (k.J/kgmole) 1.587e+004 1.101e+004 1.101e+004 1.587e+004 38 Mare Power Cycle Out @T 5.67PL 10.027L 7.027L 1.302TPL1 39 Vapour Fraction 0.0000 1.0000 0.0122 1.0000 1.001 40 Pressure (MPa) 0.6870 5.650 3.760 2.21 41 Pressure (MPa) 0.8970 5.458 9.5284 9.01								0.0000				
33 Molar Flow (kgmole/h) 1 439e+005 2.475e+004 1 439e+005 2.475e+004 1 887e+00 34 Mass Flow (kg/s) 919.1 1158.1 919.1 1158.1 919.1 35 Std ideal Lig Vol Flow (m3h) 35521 805.6 3521 805.6 3521 36 Heat Flow (MV) 634.5 109.1 440.3 75.72 744 37 Molar Enhaloy (kJ/kgmole) 1.587e+004 1.587e+004 1.001e+004 1.101e+004 1.101e+004 1.587e+00 38 Vapour Fraction 0.0000 0.1000 0.0122 1.0000 1.000 40 Temperature (C) 374.9 354.8 246.7 445.6 386 41 Pressure (MPa) 0.6870 5.850 3.760 3.760 2.11 43 Mass Flow (kgmole/h) 1.187e+005 1.824e+004 1088 1.714e+004 1.818e+01 44 Mass Flow (kgmole/h) 1.	31											
34 Mass Flow (lqg's) 919.1 158.1 919.1 158.1 110 35 Stil deal Liq Vol Flow (m3/n) 3521 605.6 3521 605.6 41 36 Heat Flow (MW) 634.5 1091 440.3 75.72 744 37 Molar Enthalpy (kJ/kgmole) 1.587e+004 1.101e+004 1.101e+004 1.101e+004 1.587e+00 38 Name Power Cycle Out@TT 5@TPL1 10@TPL1 7@TPL1 13@TPL1 39 Vapour Fraction 0.0000 1.0000 0.0122 1.0000 1.000 40 Temperature (C) 374.9 354.8 246.7 445.6 366 41 Pressure (MPa) 0.8870 5.850.5 3.760 3.780.* 2.21 42 Molar Flow (lignole/n) 1.887e+005 1.824e+004 1098 1.714e+004 1.811e+0 44 Heat Flow (MWy) 518.0 -1174 -8.378 -2.2	33		, ,									
38 Std Ideal Liq Vol Flow (m3/h) 3521 665 6 3521 605 6 41 38 Heat Flow (MVV) 634 5 109 1 440.3 75.72 744 30 Molar Enthalpy (kJ/kgmole) 1.587e+004 1.101e+004 1.101e+004 1.587e+004 31 Molar Enthalpy (kJ/kgmole) 5.000 1.0000 0.0122 1.0000 1.00 32 Vapour Fraction 0.0000 1.0000 0.0122 1.0000 1.00 40 Temperature (C) 3749 3548 246.7 445.6 366 41 Pressure (MPa) 0.8870 5.850 3.760 3.760 2.1 42 Molar Flow (kgmole/h) 1.887e+005 1.824e+004 1.096 1.714e+004 1.811e+00 43 Mass Flow (kgmole/h) 4187 3238 19.79 309.5 2.20 44 Heat Flow (MV) 516.0 -1.174 -8.137 -1.1081 -1.0 45 Heat Flow (MV) 516.0 -1.174 <th>34</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>1077</th>	34							1077				
Bet Flow (MW) 634.5 109.1 440.3 75.72 743 37 Molar Enthalpy (kJ/kgmole) 1.587e4004 1.101e4004 1.101e4004 1.101e4004 1.167e400 38 Name Power Cycle Out QTT 5 @TPL1 10 @TPL1 7 @TPL1 13 @TPL1 30 Vapour Fraction 0.0000 1.0000 0.0122 1.0000 1.687e40 40 Temperature (C) 374.9 354.8 246.7 445.6 386 41 Pressure (MPa) 0.6870 5.850*//0.580 3.760 3.760*//0.21.1 21 42 Molar Entwalky (kgmole/h) 1.687e+005 1.824e+004 1098 1.714e+004 1.811e+0 43 Mass Flow (kgro) 1077 9.128 5.486 6.85.79 8.00 44 Heat Flow (MW) 516.0 -1174 -81.37 -1081 -10 45 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.270e+005 <th>35</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>4127</th>	35							4127				
33 Name Power Cycle Out @TF 5 @TPL1 10 @TPL1 7 @TPL1 13 @TPL1 39 Vapour Fraction 0.0000 1.000 0.0122 1.0000 1.000 40 Temperature (C) 374.8 354.8 246.7 445.6 386 41 Pressure (MPa) 0.6870 5.850* 3.760 3.760 2.1 42 Molar Flow (kgmole/h) 1.867e+005 1.824e+004 1.096 1.714e+004 1.611e+0 43 Mass Flow (kg/s) 1.077 91.28 5.486 98.79 80. 44 Heat Flow (m3/h) 4.127 3.293 1.9.78 3.09.5 2.280e+0 45 Heat Flow (MW) 516.0 -1.174 -81.37 -1.081 -1.0 46 Male Enthalpy (kJ/kgmole) 1.101e+004 -2.218e+005 -2.270e+005 -2.270e+005 -2.270e+005 -2.270e+005 -2.270e+005 -2.270e+005 -2.270e+005 -2.280e+0 4.86	36							743.7				
39 Vapour Fraction 0.0000 1.0000 0.0122 1.0000 1.000 40 Temperature (C) 374.9 364.8 246.7 445.6 386 41 Pressure (MPa) 0.6870 5.850* 3.760 3.760 2.1 41 Molar Flow (kg/mcl/h) 1.874e1005 1.824e1004 1.0186 1.714e104 1.811e40 43 Mass Flow (kg/s) 1.077 91.28 5.486 86.78 80.0 44 Std1 deal Liq Vol Flow (m3/h) 4127 329.3 19.79 309.5 2.296.40 45 Heat Flow (MW) 616.0 -1174 -81.37 -1081 -10 46 Molar Enthalpy (kJ/kgmole) 1.101e404 -2.318e+005 -2.270e+005 -2.298e+0 47 Name 19.@TPL1 24.@TPL1 29.@TPL1 31.@TPL1 45.@TPL1 48 Vapour Fraction 1.0000 1.0000 1.00000 0.0883 0.01680*	37	Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004				
Index Index <th< th=""><th>38</th><th>Name</th><th></th><th>Power Cycle Out @TF</th><th>5@TPL1</th><th>10@TPL1</th><th>7 @TPL1</th><th>13@TPL1</th></th<>	38	Name		Power Cycle Out @TF	5@TPL1	10@TPL1	7 @TPL1	13@TPL1				
41 Pressure (MPa) 0.6870 5.850* 3.760 3.760* 2.1 42 Molar Flow (kgmole/h) 1.887e+005 1.824e+004 1096 1.714e+004 1.811e+0 43 Mass Flow (kg/s) 1077 91.28 5.486 85.79 80. 44 Std Ideal Liq Vol Flow (m3/h) 4127 329.3 19.79 308.5 290 45 Heat Flow (MV) 516.0 -1174 -81.37 -1081 -110 46 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.270-005 -2.228e+005 -2.270e+015 -2.228e+005 47 Name 19@TPL1 24@TPL1 29@TPL1 31@TPL1 45@TPL1 48 Vapour Fraction 1.0000 1.0000 1.0000 0.9863 0.000 49 Temperature (C) 27.77 202.0 1264 80.22 74. 50 Pressure (MPa) 0.9299 0.4380* 0.16	39	Vapour Fraction		0.0000	1.0000	0.0122	1.0000	1.0000				
Abdul Flow (kgmole/h) 1.87e-005 1.824e+004 1086 1.714e+004 1.811e+00 43 Mass Flow (kg/s) 1.077 91.28 5.486 85.79 80. 44 Std Ideal Liq Vol Flow (m3/h) 4127 329.3 19.79 309.5 2.99 45 Heat Flow (MV) 518.0 -1174 -81.37 -1081 -100 46 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.270e+005 -2.270e+002 * 0.483 0.00 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.9633 0.000 47 Name 19.00TPL1 24.00TPL1 29.00TPL1 31.00TPL1 45.00TPL1 45.00TPL1 48 Vapour Fraction 1.01000	40	Temperature	(C)	374.9	354.8	246.7	445.6	365.7				
43 Mass Flow (kg/s) 1077 91.28 5.486 85.79 80. 44 Std Ideal Liq Vol Flow (m3/h) 4127 329.3 19.79 309.5 229 45 Heat Flow (MV) 516.0 1174 81.37 .1081 101 46 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.672e+005 -2.270e+005 -2.280e+00 47 Name 18 @TPL1 24 @TPL1 29 @TPL1 31 @TPL1 45 @TPL1 48 Vapour Fraction 1.0000 1.0000 1.0000 0.9633 0.000 49 Temperature (C) 274.7 202.0 1264 08.22 74. 50 Pressure (MPa) 0.9299 0.4380* 0.1660* 4.780e-002* 0.966 51 Molar Flow (kg/s) 75.79 71.24 66.96 62.93 71. 52 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 2.415 22.408e+005 -2.318e+005 53 Std Ideal Liq Vol Flow (MV) <t< th=""><th>41</th><th>Pressure</th><th>(MPa)</th><th>0.6870</th><th></th><th>3.760</th><th></th><th>2.120 *</th></t<>	41	Pressure	(MPa)	0.6870		3.760		2.120 *				
Mode Construction Construction <thconstruction< th=""> Construction</thconstruction<>								1.611e+004				
45 Heat Flow (MVV) 518.0 -1174 -81.37 -1081 -10 46 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.672e+005 -2.270e+005 -2.298e+0 47 Name 19 @TPL1 24 @TPL1 29 @TPL1 31 @TPL1 45 @TPL1 48 Vapour Fraction 1.0000 1.0000 1.0000 0.9833 0.000 49 Temperature (C) 274.7 202.0 126.4 80.22 74. 40 Pressure (MPa) 0.9298 0.4380* 0.1680* 4.780e-002* 0.988 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+0 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 2.416.5 227.0 2.255 54 Heat Flow (MVV) -979.7 -830.5 -883.9 -841.1 -111 55 Molar Enthalpy (kJ/kgmole)	43							80.64				
46 Molar Enthalpy (kJ/kgmole) 1.101e+004 -2.318e+005 -2.672e+005 -2.270e+005 -2.238e+00 47 Name 19 @TPL1 24 @TPL1 29 @TPL1 31 @TPL1 45 @TPL1 48 Vapour Fraction 1.0000 1.0000 1.0000 1.0000 0.9833 0.000 49 Temperature (C) 274.7 202.0 126.4 80.22 74. 50 Pressure (MPa) 0.9299 0.4380* 0.1660* 4.780e-002* 0.983 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+00 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71.1 53 Std Ideal Liq Vol Flow (MV) -979.7 -930.5 -983.9 -941.1 -111 54 Heat Flow (M/V) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 98 98 94.11 <th>44</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>290.9</th>	44							290.9				
47 Name 19 @TPL1 24 @TPL1 29 @TPL1 31 @TPL1 45 @TPL1 48 Vapour Fraction 1.0000 1.0000 1.0000 0.9633 0.00 49 Temperature (C) 274.7 202.0 126.4 80.22 74. 50 Pressure (MPa) 0.9298 0.4380 * 0.1680 * 4.780e-002 * 0.98 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+00 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 265 54 Heat Flow (MV) -979.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 61 62 61 62 63 Aspen Technology Inc.								-1029				
48 Vapour Fraction 1.0000 1.0000 1.0000 0.9833 0.00 49 Temperature (C) 274.7 202.0 126.4 80.22 74. 50 Pressure (MPa) 0.9299 0.4380 * 0.1860 * 4.780e-002 * 0.98 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+00 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 257.5 54 Heat Flow (MVV) -979.7 -930.5 -883.9 -841.1 -11 55 54 Heat Flow (MVV) -2.329e+005 -2.378e+005 -2.408e+005 -2.813e+00 56 61 62 61 62 61 62 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 4 of 55 55	_		(Karkymule)									
Insperature CO 274.7 202.0 126.4 80.22 74.4 50 Pressure (MPa) 0.9299 0.4380 * 0.1660 * 4.780e-002 * 0.96 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+0 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 255 54 Heat Flow (MVV) -979.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.378e+005 -2.408e+005 -2.813e+00 56 57 58 59 -2.378e+005 -2.408e+005 -2.408e+005 -2.813e+00 58 59 59 -2.378e+005 -2.378e+005 -2.408e+005 -2.408e+005 -2.813e+00 58 59 59 59 59 -2.378e+005 <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>0.0000</th>								0.0000				
50 Pressure (MPa) 0.9299 0.4380 * 0.1660 * 4.780e-002 * 0.986 51 Molar Flow (kgmole/h) 1.515e+004 1.424e+004 1.338e+004 1.258e+004 1.424e+0 52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 255 54 Heat Flow (MV) -879.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.408e+005 -2.408e+005 -2.813e+0 56 61 62 63 64			(C)					74.22				
52 Mass Flow (kg/s) 75.79 71.24 66.96 62.93 71. 53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 255 54 Heat Flow (MVV) -979.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 57 58 59 - - - - - - -2.813e+0 - -2.813e+0 - -2.813e+0 - -2.813e+0 - -2.813e+0 - - - - -2.813e+0 - - - - - - 2.813e+0 -	50							0.9682				
53 Std Ideal Liq Vol Flow (m3/h) 273.4 257.0 241.5 227.0 255 54 Heat Flow (MVV) -979.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 57 58 59 56 57 58 57 58 56 56 57 58 57 58 57 58 57 58 56 57 58 56 57 58 57 58 57 58 57 58 57 58 57 58 57 58 57 58 57 58 57 58 57 58 58 58 57 58 58 59 58 57 58 57 58 57 58 57 58 57 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58	51	Molar Flow	(kgmole/h)	1.515e+004	1.424e+004	1.338e+004	1.258e+004	1.424e+004				
54 Heat Flow (MVV) -979.7 -930.5 -883.9 -841.1 -11 55 Molar Enthalpy (k.J/kgmole) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 57 58 -	52	Mass Flow	(kg/s)	75.79	71.24	66.96	62.93	71.24				
55 Molar Enthalpy (kJ/kgmole) -2.329e+005 -2.353e+005 -2.378e+005 -2.408e+005 -2.813e+0 56 57 58 59 59 59 50 <th>53</th> <th>Std I deal Liq Vol Flow</th> <th>(m3/h)</th> <th>273.4</th> <th></th> <th>241.5</th> <th>227.0</th> <th>257.0</th>	53	Std I deal Liq Vol Flow	(m3/h)	273.4		241.5	227.0	257.0				
56 57 58 59 60 61 62 63 63 63 Aspen Technology Inc. Aspen Type 4 of	54							-1112				
57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 4 of		Molar Enthalpy	(kJ/kgmole)	-2.329e+005	-2.353e+005	-2.378e+005	-2.408e+005	-2.813e+005				
58 59 60 61 62 63 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 4 of Joint												
	57											
	58											
	59 60											
	61											
	62											
	63	Aspen Technology In	IC.	Aspen H	YSYS Version 7.3 (25.0.0.7336		Page 4 of 33				
						-		* Specified by user.				

1	~			Case Name:	NA COOLED HTSE W	SUB CRITICAL RANKINI	E V1.HSC	
2	aspenteo	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR			
4 5		USA		Date/Time:	Fri Mar 28 11:35:17 201	4		
6								
7 8	W	orkbook:	Rankine P	ower Cycle	(TPL1) (con	tinued)		
9				Streams (continu	ed)	Fluid Pkg: All		
11	Name		46 @TPL1	50 @TPL1	17@TPL1	15@TPL1 28@TPL1		
12	Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000	
13	Temperature	(C)	108.4	209.6	365.7	215.2	114.0	
14	Pressure	(MPa)	0.9489	3.479	2.120	2.120	0.1660	
15	Molar Flow	(kgmole/h)	1.424e+004	1.824e+004	968.5	2127	855.5	
16	Mass Flow	(kg/s)	71.24	91.28	4.846	10.64	4.281	
17	Std I deal Liq Vol Flow	(m3/h)	257.0	329.3	17.48	38.39	15.44	
18	Heat Flow	(MVV)	-1102	-1372	-61.81	-159.7	-66.13	
19 20	Molar Enthalpy	(kJ/kgmole)	-2.787e+005 36 @TPL1	-2.707e+005 35 @TPL1	-2.298e+005 43 @TPL1	-2.703e+005 HP Trbn Pwr @TPL1	-2.783e+005 IP Trbn Stg 1 Pwr @T	
20	Name Vapour Fraction		36 (@TPL1 0.9633	35 @ IPL1 0.0000	43 @TPL1 0.0000	HP Irbn Pwr @IPL1	IP Irbn Stg I Pwr @I	
22	Temperature	(C)	80.22	79.80	40.07			
23	Pressure	(C) (MPa)	4.780e-002	4.780e-002	7.433e-003			
24	Molar Flow	(kgmole/h)	755.8	4.7008-002	1.424e+004			
25	Mass Flow	(kg/s)	3.782	8.305	71.24			
26	Std I deal Liq Vol Flow	(m3/h)	13.64	29.96	257.0			
27	Heat Flow	(MVV)	-50.55	-129.5	-1122	23.04	10.77	
28	Molar Enthalpy	(kJ/kgmole)	-2.408e+005	-2.809e+005	-2.838e+005			
29	Name		IP Trbn Stg 2 Pwr @T	LP Trb Stg 1 Pwr @TF	Bstr Pmp Pwr @TPL1	LP Trbn Stg 2 Pwr @T	LP Trbn Stg 3 Pwr @	
30	Vapour Fraction							
31	Temperature	(C)						
32	Pressure	(MPa)						
33	Molar Flow	(kgmole/h)						
34	Mass Flow	(kg/s)						
35	Std I deal Liq Vol Flow	(m3/h)						
36	Heat Flow	(MVV)	12.45	12.97	0.3576	9.674	9.336	
37	Molar Enthalpy	(kJ/kgmole)						
38 39	Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated (
39 40	Vapour Fraction Temperature	(0)						
40	Pressure	(C) (MPa)						
41	Molar Flow	(kgmole/h)						
43	Mass Flow	(kg/s)						
44	Std I deal Liq Vol Flow	(m3/h)						
45	Heat Flow	(M <i>V</i> V)	10.32	12.28	2.121	9.384e-002	96.98	
46	Molar Enthalpy	(kJ/kgmole)						
47	Name		Cooling Water Out @1	Cooling Water In @TF	Make Up Water @TPL	Total Cooling Tower P		
48	Vapour Fraction		0.0000	0.0000	0.0000			
49	Temperature	(C)	34.96	25.00	20.00			
50	Pressure	(MPa)	0.1015	0.1035	0.1013			
51	Molar Flow	(kgmole/h)	6.023e+005	6.023e+005	1.238e+004			
52	Mass Flow	(kg/s)	3014	3014	61.94			
53	Std I deal Liq Vol Flow	(m3/h)	1.087e+004	1.087e+004	223.4			
04 55	Heat Flow Molar Enthalpy	(MVV) (kJ/kgmole)	-4.776e+004 -2.854e+005	-4.788e+004 -2.862e+005	-981.1 -2.854e+005	0.5878		
55 56	мотаг ститатру	(KU KYMUR)	-2.0048+005	-2.8020+005	-2.8948+005			
57								
58								
59								
60								
61								
62								
63	Aspen Technology I		Aspen H	HYSYS Version 7.3 (25.0.0.7336)		Page 5 of 33	
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1	\sim			_	Case Name:	NA	COOLED HTSE W :	SUB CRITI	CAL RANKINE	V1.HSC
3	(aspentech	Burlington,	E ENERGY ALLIANCE , MA	=	Unit Set:	AFI	R			
4 5	- ach eiteen	USA			Date/Time:	Fri	Mar 28 11:35:17 201	4		
6 7 8	Work	(book:	Rankine	Ροι	wer Cycle	(Т	PL1) (con	tinue	ed)	
9 10					Expanders				Fluid Pkg	ç. All
11	Name		High Pressure Turk	nine Ir	termdiate Pressure 1	In	termediatte Pressure	Low Pre	ssure Turbine	Low Pressure Turbine
12	Power	(MVV)	23.04		10.77		12.45	2011110	12.97	9.674
13	Capacity (act feed vol flow) (A		603		1.864e+004		2.460e+004	:	3.662e+004	6.779e+004
14	Feed Pressure	 (MPa)	17.0		5.733		3.760		2.120	0.9299
15	Product Pressure	(MPa)	5.85		3.760 *		2.120 *		0.9299	0.4380 *
16	Product Temperature	(C)	354.1		445.6		365.7		274.7	202.0
17	Adiabatic Efficiency			5 *	90 *		90 *		80 *	80 *
18	Name		Low Pressure Turb		ow Pressure Turbine	Lo	ow Pressure Turbine			
19	Power	(MVV)	9.33	1	10.32		12.28			
20	Capacity (act feed vol flow) (A		1.179e+00:		2.470e+005		6.934e+005			
21	Feed Pressure	(MPa)	0.438		0.1660		4.780e-002			
22	Product Pressure	(MPa)	0.166		4.780e-002 *		7.584e-003 *			
23	Product Temperature	(C)	126.		80.22		40.51			
24	Adiabatic Efficiency	(-)	7:		80 *		80 *			
25					Pumps				Fluid Pkg	e All
26 27	Name		Boiler Feed Pump	at p	ooster Pump @TPL1	0	ondensate Pump @1			
28		(14)40	2.12	~	0.3576		9.384e-002			
29	Power	(MVV)								
30	Capacity(Actual Vol. Flow)	(m3/h)	404.1		368.9 0.9299		258.5			
31	Feed Pressure Product Pressure	(MPa)	3.40				7.433e-003			
		(MPa)	17.7		3.550 *		0.9880 *			
32 33	Product Temperature	(C)	245.		177.2		40.18			
34	Adiabatic Efficiency	(%)	75.0	0	75.00 *		75.00 *			
35				H	Heat Exchanger	S			Fluid Pkg	e All
36	Name		Feedwater Heater	6@ F	eedwater Heater 5 @	Fε	eedwater Heater 4 @	Feedwat	ter Heater 3 @	Feedwater Heater 2 @
37	Duty	(MVV)	10.8	0	13.31		13.15		10.21	10.23
38	Tube Side Feed Mass Flow	(kg/s)	91.2	8	91.28		91.28		71.24	71.24
39	Shell Side Feed Mass Flow	(kg/s)	5.48	6	10.64		15.49		4.281	8.305
40	Tube Inlet Temperature	(C)	245.	6	209.6		177.2		108.4	74.22
41	Tube Outlet Temperature	(C)	270.4	4	241.0		209.6		142.0	108.4
42	Shell Inlet Temperature	(C)	354.	8	246.7		215.4		202.0	1 14.4
43	Shell Outlet Temperature	(C)	251.	1	215.1		182.7		113.9	79.77
44	LMTD	(C)	15.1	7	15.61		15.24		17.42	16.65
45	Minimum Approach	(C)	5.55	6	5.556		5.556		5.556	5.556
46	UA	(kJ/C-h)	2.562e+00		3.071e+006		3.106e+006		2.109e+006	2.212e+006
47	Name		Feedwater Heater	1@ S	team Generator @TF	R	eheater @TPL1	Condens	ser @TPL1	
48	Duty	(MVV)	10.14	4	194.3		33.42		129.4	
49	Tube Side Feed Mass Flow	(kg/s)	71.24	4	919.1		158.1		3014	
50	Shell Side Feed Mass Flow	(kg/s)	12.0	9	91.28		85.79		59.15	
51	Tube Inlet Temperature	(C)	40.1	8	530.0		530.0		25.00	
52	Tube Outlet Temperature	(C)		2	374.9		374.9 *		34.96	
53	Shell Inlet Temperature	(C)		2	270.4		354.8		40.51	
54	Shell Outlet Temperature	(C)	45.74	4	510.0		510.0		38.92	
55	LMTD	(C)	16.0:	2	78.05		22.08		9.555	
56	Minimum Approach	(C)	5.55	6	20.00		20.00		5.556	
57	UA	(kJ/C-h)	2.278e+00	6	8.961e+006		5.449e+006		4.876e+007	
58 59					Unit Ops					
60	Operation Name	Оре	eration Type		Feeds		Products		Ignored	Calc Level
61	High Pressure Turbine @TPL	Expander	Ţ	Steam	n Generator Out @TP	L1	5 @TPL1		No	500.0 *
62		LApanuer					HP Trbn Pwr @TPL	.1	0/1	
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY		Aspe	en HYS	SYS Version 7.3 (2	25.0	1.0.7336			Page 6 of 33 * Specified by user.

to: BATTELLE ENERGY ALLI.

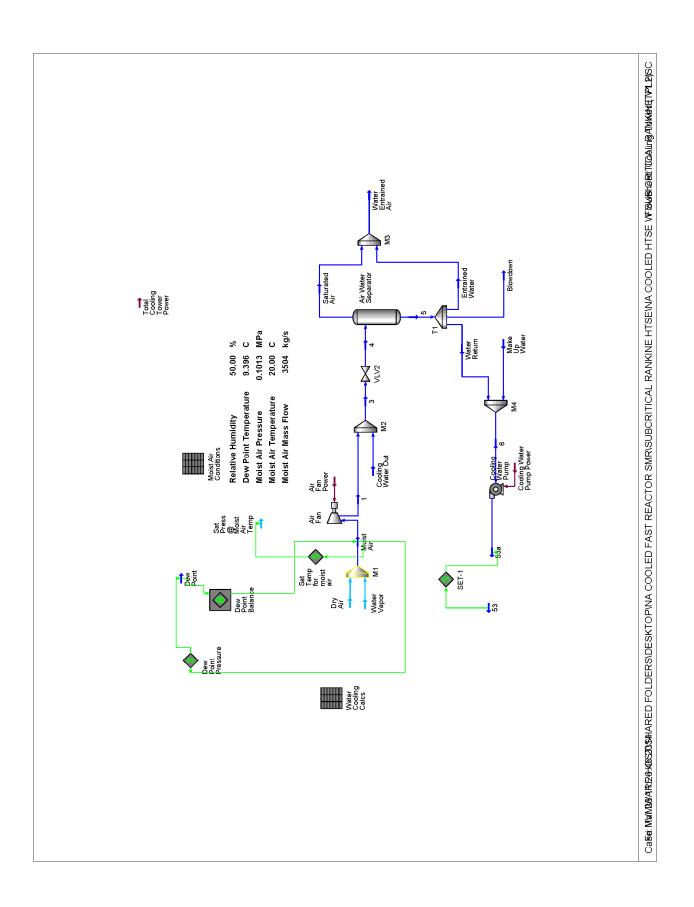
1				Case Name:	NA COOLED HTSE W SUB CRITI	CAL RANKINE V1	.HSC
3	aspentech	BATTELLE ENERGY ALLIANC Burlington, MA	CE	Unit Set: A	AFR		
4	aspenteen	USA		Date/Time:	Fri Mar 28 11:35:17 2014		
5 6							
7 8	Work	book: Rankine	e Po۱	wer Cycle (TPL1) (continue	d)	
9			Un	it Ops (continue	:d)		
11	Operation Name	Operation Type		Feeds	Products	Ignored	Calc Level
12	Intermdiate Pressure Turbine	E×pander	6 @ T F	ԴL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *
14	Intermediatte Pressure Turbin	Expander	12 @T	'PL1	13@TPL1	No	500.0 *
16	Low Pressure Turbine Stage 1	Expander	16 @T	'PL1	IP Trbn Stg 2 Pwr @TPL1 19 @TPL1	No	500.0 *
17	Low Pressure Turbine Stage 2	Expander	23 @T	PL1	LP Trb Stg 1 Pwr @TPL1 24 @TPL1	No	500.0 *
19 20	Low Pressure Turbine Stage 3	Expander	25 @T	'PL1	LP Trbn Stg 2 Pwr @TPL1 29 @TPL1	No	500.0 *
21	Low Fressure Turbine Stage 3	Expander			LP Trbn Stg 3 Pwr @TPL1	NU	500.0
22	Low Pressure Turbine Stage 4	Expander	30 @T	PL1	31@TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *
24 25	Low Pressure Turbine Stage 5	Expander	37 @T	PL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *
26 27	Feedwater Heater 6 @TPL1	Heat Exchanger	52 @T To FV	'PL1 /Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *
28 29	Feedwater Heater 5 @TPL1	Heat Exchanger	50 @T 11 @T	PL1	51@TPL1 14@TPL1	No	500.0 *
30	Feedwater Heater 4 @TPL1	Heat Exchanger	49 @T 18 @T	PL1	50 @TPL1 20 @TPL1	No	500.0 *
32	Feedwater Heater 3 @TPL1	Heat Exchanger	46 @T	PL1	47@TPL1	No	500.0 *
33 34	Feedwater Heater 2 @TPL1	Heat Exchanger	26 @T 45 @T		27@TPL1 46@TPL1	No	500.0 *
35 36			33 @T 44 @T		34@TPL1 45@TPL1		
37 38	Feedwater Heater 1 @TPL1	Heat Exchanger	38 @T 1 @TF		39@TPL1 2@TPL1	No	500.0 *
39	Steam Generator @TPL1	Heat Exchanger	Steam	Generator In @TPL1	Steam Generator Out @TPL1	No	500.0 *
40 41	Reheater @TPL1	Heat Exchanger	3 @TF To Re	PL1 heater@TPL1	4 @TPL1 6 @TPL1	No	500.0 *
42 43	Condenser @TPL1	Heat Exchanger	Coolin 40 @T	g Water In @TPL1 'PI 1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *
44	Boiler Feed Pump @TPL1	Pump	51 @T		52@TPL1	No	500.0 *
46	Booster Pump @TPL1	Pump	48 @T	PL1	49@TPL1	No	500.0 *
47 48	Condensate Pump @TPL1	Pump	43 @T		44 @TPL1	No	500.0 *
49 50	M1 @TPL1		10 @T		11@TPL1	No	500.0 *
51 52	-	Mixer	8@TF 17@T		18 @TPL1		
53 54	M2 @TPL1	Mixer	15 @T 47 @T	'PL1		No	500.0 *
55	Deaerating Heater @TPL1	Mixer	21 @T	PL1	48 @TPL1	No	500.0 *
56 57	M4 @TPL1	Mixer	22 @T 36 @T	PL1	38@TPL1	No	500.0 *
58 59			35 @T 32 @T		33 @TPL1		
60 61	M3 @TPL1	Mixer	28 @T 41 @T		43@TPL1	No	500.0 *
62	M5 @TPL1	Mixer	42 @T	PL1		No	500.0 *
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY		en HYS	YS Version 7.3 (2)	5.0.0.7336)	*	Page 7 of 33 Specified by user.

1	\sim			VA COOLED HTSE W SUB CRIT	ICAL RANKINE V1	.HSC
3	aspentech	BATTELLE ENERGY ALLIAN Burlington , MA		\FR		
4 5	- aspontoon	USA	Date/Time: F	Fri Mar 28 11:35:17 2014		
6						
7 8	Work	book: Rankin	e Power Cycle (TPL1) (continue	ed)	
8 9			Unit Ops (continue	d)		
10	0	а <i>к</i> т		,		
11 12	Operation Name	Operation Type	Feeds 2@TPL1	Products Power Cycle Out @TPL1	Ignored	Calc Level
13	M7 @TPL1	Mixer	4@TPL1		No	500.0 *
14	VLV 3 @TPL1	Valve	20 @TPL1	21@TPL1	No	500.0 *
15	VLV 4 @TPL1	Valve	27 @TPL1	28@TPL1	No	500.0 *
16	VLV 5 @TPL1	Valve	34 @TPL1	35@TPL1	No	500.0 *
17	VLV 1 @TPL1	Valve	9@TPL1	10@TPL1	No	500.0 *
18	VLV 2 @TPL1	Valve	14 @TPL1	15@TPL1	No	500.0 *
19	VLV 6 @TPL1 SG tb dP @TPL1	Valve Set	39 @TPL1	41@TPL1	No No	500.0 * 500.0 *
20	SG sh dP @TPL1	Set	1		NO	500.0 *
22	FW6 tb dP @TPL1	Set			No	500.0 *
23	FW6 sh dP @TPL1	Set			No	500.0 *
24	FW4 tb dP @TPL1	Set			No	500.0 *
25	FW5 tb dP @TPL1	Set			No	500.0 *
26	FW5 sh dP @TPL1	Set			No	500.0 *
27	FW4 sh dP@TPL1	Set			No	500.0 *
28	Cnd sh dP @TPL1	Set			No	500.0 *
29	FW1 tb dP @TPL1	Set			No	500.0 *
30	FW1 sh dP @TPL1	Set			No	500.0 *
31	FW2 tb dP @TPL1	Set			No	500.0 *
32 33	FW2 sh dP @TPL1	Set			No	500.0 *
33 34	FW3 tb dP @TPL1 FW3 sh dP @TPL1	Set			No No	<u> </u>
35	Rht tb dP @TPL1	Set Set			No	500.0 *
36	SET-1@TPL1	Set			No	500.0 *
37	Cnd Tb dP @TPL1	Set			No	500.0 *
38	SET-3@TPL1	Set			No	500.0 *
39	SET-4 @TPL1	Set			No	500.0 *
40	SET-5@TPL1	Set			No	500.0 *
41	SET-6 @TPL1	Set			No	500.0 *
42	SET-7@TPL1	Set			No	500.0 *
43	SET-8@TPL1	Set			No	500.0 *
44	T1@TPL1	Тее	5@TPL1	To FW Heater 6 @TPL1	No	500.0 *
45)		3.07014	To Reheater @TPL1		
46	T2@TPL1	Тее	7 @TPL1	8 @TPL1	No	500.0 *
47 48		L	13 @TPL1	12@TPL1		
40 10	T3@TPL1	Tee		17@TPL1 16@TPL1	No	500.0 *
49 50			19 @TPL1	22@TPL1		
51	T4@TPL1	Tee		23 @TPL1	No	500.0 *
52			24 @TPL1	26@TPL1		
53	T5@TPL1	Тее		25@TPL1	No	500.0 *
54	TR ATD 1	Tee	29 @TPL1	32@TPL1	N-	500 0 ÷
55	T6@TPL1	Tee		30 @TPL1	No	500.0 *
56	T7@TPL1	Тее	31 @TPL1	36 @TPL1	No	500.0 *
57		100		37 @TPL1	140	000.0
58	T13 @TPL1	Тее	Power Cycle In @TPL1	3@TPL1	No	500.0 *
59	_			1 @TPL1		
60	Efficiency Calculations@TPL	Spreadsheet	Cooling Meter Out OTP! 1	Cooling Mater 12 (2000) 4	No	500.0 *
61 62	Cooling Tower @TPL1	Standard Sub-Flowsheet	Cooling Water Out @TPL1 Make Up Water @TPL1	Cooling Water In @TPL1	No	2500 *
63	Aspen Technology Inc.	Δ.e	pen HYSYS Version 7.3 (25	0.0.7336	•	Page 8 of 33
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1				_	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC						
3	(the aspentech	Burlington, M	ENERGY ALLIANCI IA	=	Unit Set:	AFR					
4 5		USA			Date/Time:	Fri Mar	28 11:35:17 2014				
6		hoole	Donkine	Dar			1) (continue	od)			
8	VVOR	(DOOK:	Rankine	P0\		e (TPI	L1) (continue	ea)			
9 10				Un	it Ops (conti	nued)					
11	Operation Name		tion Type		Feeds		Products	Ignored	Calc Level		
12 13	Cooling Tower @TPL1	Standard Su	ıb-Flowsheet	Total (Cooling Tower Pov	wer @		No	2500 *		
14											
15 16											
17 18											
19											
20 21											
22											
23 24											
24 25											
26 27											
28											
29 30											
31 32											
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34 35											
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37 38											
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40 41											
42 43											
43 44											
44 45 46											
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48 49											
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51 52											
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54 55											
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57 58											
59											
60 61											
62 63	Aspon Tochnology In-		Acres		VS Vorsion 7	3 (25 0 0 -	7336)		Dago 0 of 22		
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	ALLIANCE	ASpe	n n í S	YS Version 7.3	0120.0.0.1	330.		Page 9 of 33 Specified by user.		

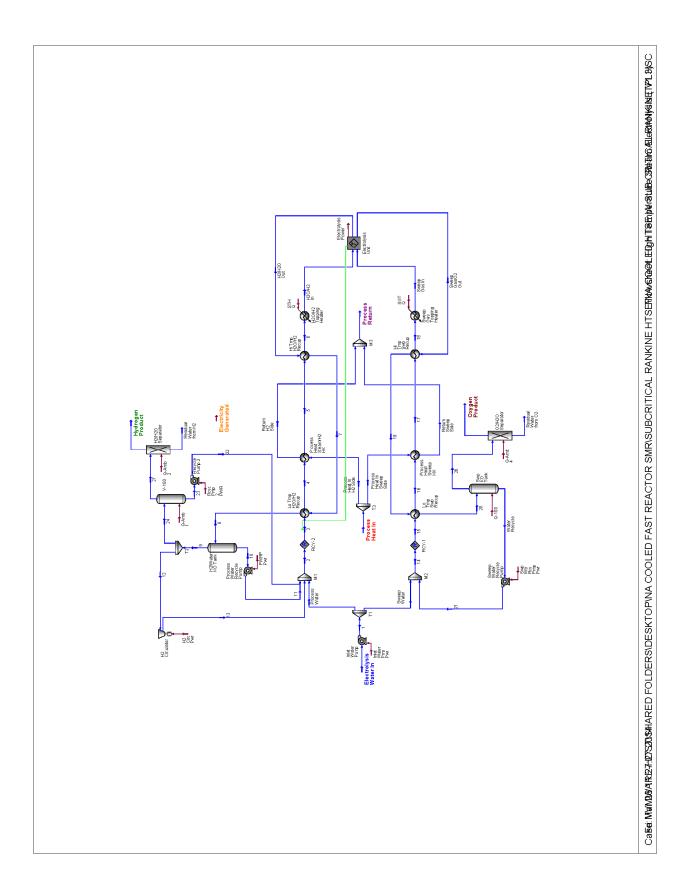
1			Case N	ame: NA COOLED HTSE	EW SUB CRITICAL RA	NKINE V1.HSC
2 3		BATTELLE ENERGY Burlington, MA	ALLIANCE Unit Se	AFR		
4	00	ISPENTECH USA	Date/Ti		2014	
5 6			Datorri		2011	
7		Spreadsheet:	Efficiency Cal	culations @TF	PL1	Units Set: NuScale2
8 9						
10			CONNE	CHONS		
11			Imported	Variables		
13	Cell	Object		Variable Description		Value
14	B1	Energy Stream: HP Trbn Pwr @T				23.04 MW
15	B2 B3	Energy Stream: IP Trbn Stg 1 Pw Energy Stream: IP Trbn Stg 2 Pw				10.77 MW 12.45 MW
17	B4	Energy Stream: LP Trb Stg 1 Pw				12.97 MVV
18	B5	Energy Stream: LP Trbn Stg 2 Pv				9.674 MVV
19	B6	Energy Stream: LP Trbn Stg 3 Pv	vr@TPL' Power			9.336 MVV
20	B7	Energy Stream: LP Trbn Stg 4 Pv				10.32 MW
21	B8	Energy Stream: LP Trg Stg 5 Pw				12.28 MW
22 23	B9	Energy Stream: Cnd Pmp Pwr @ Energy Stream: Bstr Pmp Pwr @				9.384e-002 MW
23	B10 D1	Energy Stream: Bstr Pmp Pwr @ Energy Stream: BF Pmp Pwr @T				0.3576 MVV 2.121 MVV
25	D2	Energy Stream: Primary Pump P				0.4345 MVV
26	D3	Energy Stream: Secondary Pump				0.2606 MVV
27	D4	Energy Stream: Total Cooling To	ver Powe Power			0.5878 MVV
28	D5	Energy Stream: Reactor Heat	Heat Flow			250.0 MVV
29	C9	Tee: T1	Flow Ratio (Flow	Ratio_1)		0.9083
30 31			Exported Variable	s' Formula Results		
32	Cell	Object		Variable Description		Value
33	D7	Electricity Generated @TPL1	Power			96.98 MVV
34	F1	Steam Generator In @TPL1	Mass Flow			91.28 kg/s
35			PARAN	ETERS		
36 37			For a stabl			
38			Exportable			
39 40	Cell D6	Visible Name D6: Total Turbine Power	Var Total Turbine Pov	able Description	Variable Type Power	Value 100.8 MVV
40	D0	D7: Power	Power		Power	96.98 MW
42	D8	D8: Thermal Efficiency of Power Cycle	Thermal Efficienc	/ of Power Cycle	Percent	42.71
43	D10	D10: Power	Power		Mass Flow	100.5 kg/s
44	F1	F1: Mass Flow	Mass Flow		Mass Flow	91.28 kg/s
45 46			User Va	riables		
47			FORM	ULAS		
48	0-"	1				Denvila
49 50	Cell D6	=B1+B2+B3+B4+B5+B6+B7+B8	Formula			Result 100.8 MW
51	D0	=D6-B9-B10-D1-D2-D3-D4				96.98 MVV
52	D8	=D7/(D5*C9)*100				42.71
53	F1	=C9*D10				91.28 kg/s
54			Sprea	lsheet		
55 56		Δ	•			
55	1	A HP Trb Pwr *	B 23.04 MV	С V* В	F Pmp Pwr *	2.121 MW*
58	2	IP Trb Stg 1 Pvvr *	10.77 M		ump Power *	0.4345 MVV *
59	3	IP Trb Stg 2 Pwr *	12.45 M			0.2606 MVV *
60	4	LP Trb Stg 1 Pvvr *	12.97 M	V* Cooling To	ower Power *	0.5878 MVV *
61	5	LP Trb Stg 2 Pwr *	9.674 M		eactor Heat *	250.0 MVV *
62	6	LP Trb Stg 3 Pwr *	9.336 M		bine Power *	100.8 MW*
63		Technology Inc. D: BATTELLE ENERGY ALLIANCE	Aspen HYSYS Vers	on 7.3 (25.0.0.7336)		Page 10 of 33 * Specified by user.
						-,,

1			Case Name:	NA COOLED HTSE W SUB CRIT	TCAL RANKINE V1.HSC
2 3 4		ENERGY ALLIANCE //A	Unit Set:	AFR	
4	USA USA		Date/Time:	Fri Mar 28 11:35:17 2014	
6					
7	Spreadshe	et: Efficienc	cy Calcu	lations @TPL1 (co	ntini Units Set: NuScale2
8 9			<u> </u>		
10			Spreadshe		
11 7 12 8	LP Trb Stg 4 Pwr 1 LP Trb Stg 5 Pwr 1	1	10.32 MVV * 12.28 MVV *	Electricity Generated * Thermal Efficiency of Power Cycle *	96.98 MVV * 42.71 *
13 9	Cnd Pmp Pwr	* 9.3	84e-002 MW *	0.9083 *	Power flow split *
14 10	Bstr Pmp Pwr ⁻ E	F	0.3576 MW *	100% Rankine Flow *	100.5 kg/s *
16 1	Mass Flow @ Steam Generator In *		91.28 kg/s *		
17 2 18 3					
18 3 19 4					
20 5					
21 6 22 7					
23 8					
24 9 25 10					
26					
27					
27 28 29 30 31 32					
30					
31					
32					
33					
34					
36					
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34 35 36 37 38 39					
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53 54 55 56 57 58 59 60					
60 61					
62					
	en Technology Inc.	Aspen HY:	SYS Version 7	.3 (25.0.0.7336)	Page 11 of 33
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1				Case Name:	NA COOLED HTSE W	SUB CRITICAL RANKINE	EV1.HSC	
2	aspentech		E ENERGY ALLIANCE , MA	Unit Set:	AFR			
4 5	aspentech	USA		Date/Time:	Fri Mar 28 11:35:17 201	4		
5								
7 8	Wo	rkbook	: Cooling To	ower (TPL2)				
9				Material Stream	IS	Fluid Pkg: All		
10 11	Name		Cooling Water Out @1	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2	
12	Vapour Fraction		0.0000	0.0000			1.0000	
13	Temperature	(C)	34.96	25.00 *			20.00 *	
14	Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *	
15	Molar Flow	(kgmole/h)	6.023e+005	6.023e+005	4.341e+005	5051	4.392e+005	
16	Mass Flow	(kg/s)	3014	3014	3479	25.28	3504 *	
17	Liquid Volume Flow	(m3/h)	1.087e+004	1.087e+004	1.448e+004	91.18	1.457e+004	
18	Heat Flow	(MVV)	-4.776e+004	-4.788e+004			-358.2	
19	Name		Sat Press@ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2	
20	Vapour Fraction		1.0000 *	1.0000	0.4303	1.0000 *	0.4303	
21	Temperature	(C)	20.00	20.16	25.11	9.396	25.10	
22	Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013	
23	Molar Flow	(kgmole/h)		4.392e+005	1.041e+006	4.392e+005	1.041e+006	
24	Mass Flow	(kg/s)		3504	6518	3504	6518	
25	Liquid Volume Flow	(m3/h)		1.457e+004	2.544e+004	1.457e+004	2.544e+004	
26	Heat Flow	(MVV)		-357.6	-4.811e+004	-396.0	-4.811e+004	
27	Name		Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2	
28	Vapour Fraction		1.0000	0.0000	0.0000	0.000	0.0000	
29	Temperature	(C)	25.10	25.10	25.10	25.10	25.10	
30	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013	
31	Molar Flow	(kgmole/h)	4.481e+005	5.933e+005	602.3	2804	5.899e+005	
32	Mass Flow	(kg/s)	3549	2969	3.014	14.03	2952	
33	Liquid Volume Flow	(m3/h)	1.473e+004	1.071e+004	10.87	50.63	1.065e+004	
34	Heat Flow	(MVV)	-942.8	-4.717e+004	-47.88	-223.0	-4.690e+004	
35	Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2		
36	Vapour Fraction	(0)	0.9987 25.10	0.0000	0.0000	0.0000		
38	Temperature	(C)	0.1013	20.00 * 0.1013	25.00 0.1013	25.00 0.1035		
39	Pressure Molar Flow	(MPa) (kgmole/h)	4.487e+005	1.238e+004	6.023e+005	6.023e+005		
40	Mass Flow	(kg/s)	3552	61.94	3014	3014		
40	Liquid Volume Flow	(rg/s) (m3/h)	1.474e+004	223.4	1.087e+004	1.087e+004		
42	Heat Flow	(MVV)	-990.7	-985.4	-4.788e+004	-4.788e+004		
43	The de l'how	(1111)	000.1					
44				Compositions	:	Fluid Pkg	g: All	
45	Name		Cooling Water Out @1	53@TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2	
46	Comp Mole Frac (H2O)		1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115	
47	Comp Mole Frac (Nitrogen))	0.000	0.0000 *	0.7900 *	* 0.0000 *	0.7809	
48	Comp Mole Frac (Oxygen)		0.0000	0.0000 *	0.2100 *	* 0.000 *	0.2076	
49	Comp Mole Frac (Hydroger	n)	0.0000	0.0000 *	0.0000 *	* 0.000 *	0.0000	
50	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000 *	* 0.000 *	0.0000	
51	Comp Mole Frac (CO)		0.0000	0.0000 *	0.0000 *	* 0.000 *	0.0000	
52	Comp Mole Frac (Sodium)		***	***	***	***	***	
53	Comp Mole Frac (Air)		0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000	
54	Name		Sat Press@ Moist Air	1@TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2	
55	Comp Mole Frac (H2O)	、 、	1.0000 *	0.0115	0.5832	0.0115	0.5832	
56	Comp Mole Frac (Nitrogen)	,	***	0.7809	0.3293	0.7809	0.3293	
57	Comp Mole Frac (Oxygen)			0.2076	0.0875	0.2076	0.0875	
58	Comp Mole Frac (Hydroger	n)	***	0.0000	0.0000	0.0000	0.0000	
59	Comp Mole Frac (CO2)		***	0.0000	0.0000	0.0000	0.0000	
60	Comp Mole Frac (CO)		***	0.0000	0.0000	0.0000	0.0000	
61	Comp Mole Frac (Sodium)		***				0.0000	
62	Comp Mole Frac (Air)			0.0000	0.0000	0.0000		
03	Aspen Technology Inc Licensed to: BATTELLE ENER		Aspen F	HYSYS Version 7.3 ()	23.0.0.1330		* Specified by user.	
							speemed by user.	

1					Case Name:	NA COOLED HTSE W :	SUB CRITI	CAL RANKINE	V1.HSC	
2	aspentech	BATTELLE Burlington,	ENERGY ALLIANC	E	Unit Set:	AFR				
4	aspentech	USA			Date/Time:	Fri Mar 28 11:35:17 201	4			
5 6										
7 8	Work	book:	Cooling	Τον	ver (TPL2)	(continued))			
9				Com	npositions (continued) Fluid Pkg:					
10 11	Name		Saturated Air @TF		@TPL2	Entrained Water @TP	Blowdow	m@TPL2	: All Water Return @TPL2	
12	Comp Mole Frac (H2O)		0.031		1.0000	1.0000		1.0000	1.0000	
13	Comp Mole Frac (Nitrogen)		0.765	3	0.0000	0.0000		0.0000	0.0000	
14	Comp Mole Frac (Oxygen)		0.203	4	0.0000	0.0000		0.0000	0.0000	
15	Comp Mole Frac (Hydrogen)		0.000	0	0.0000	0.0000		0.0000	0.0000	
16	Comp Mole Frac (CO2)		0.000	0	0.0000	0.0000		0.0000	0.0000	
17	Comp Mole Frac (CO)		0.000		0.0000	0.0000		0.0000	0.0000	
18	Comp Mole Frac (Sodium)		±1		***	***		***	***	
19	Comp Mole Frac (Air)		0.000	_	0.0000	0.0000	F0. 000	0.0000	0.0000	
20	Name		Water Entrained A		ake Up Water @TPL	6 @TPL2	53a @TF			
21	Comp Mole Frac (H2O)		0.032	- 1	1.0000 *	1.0000		1.0000		
22	Comp Mole Frac (Nitrogen)		0.764		0.0000 *	0.0000		0.0000		
23 24	Comp Mole Frac (Oxygen)		0.203		0.0000 * 0.0000 *	0.0000		0.0000		
24	Comp Mole Frac (Hydrogen)		0.000		0.0000 *	0.0000 0.0000		0.0000		
20	Comp Mole Frac (CO2) Comp Mole Frac (CO)		0.000		0.0000 *	0.0000		0.0000		
20	Comp Mole Frac (CO)		0.000	-	0.0000	0.0000		***		
28	Comp Mole Frac (Air)		0.000		0.0000 *	0.0000		0.0000		
29			0.000							
30					Energy Streams	;		Fluid Pkg	i: All	
31	Name		Air Fan Power@T	PL2 C	ooling Water Pump F	Total Cooling Tower P				
32	Heat Flow	(MVV)	0.579	1	8.687e-003	0.5878				
33 34					Unit Ops					
35	Operation Name	Oper	ration Type		Feeds	Products		Ignored	Calc Level	
36	·			Dry Ai	r@TPL2	Moist Air @TPL2				
37	M1 @TPL2	Mixer		Water	Vapor @TPL2			No	500.0 *	
38	M2 @TPL2	Mixer		1 @TF	PL2	3 @TPL2		No	500.0 *	
39	Miz Gen Ez	WINCI			g Water Out @TPL2			140	555.5	
40	M3 @TPL2	Mixer	-		ated Air @TPL2	Water Entrained Air	@TPL2	No	500.0 *	
41					ned Water @TPL2					
42	M4 @TPL2	Mixer	-		Return @TPL2	6 @TPL2		No	500.0 *	
43 44	_	Coreadal -	unt I	Make	Up Water @TPL2	+		No	500.0 *	
44	Moist Air Conditions @TPL2 Water Cooling Calcs @TPL2	Spreadshe Spreadshe						No	500.0 *	
40	Sat Temp for moist air @TPL2	Set				1		No	500.0 *	
40	Dew Point Pressure @TPL2	Set				1		No	500.0 *	
48	Amb Press Set @TPL2	Set	i			1		No	500.0 *	
49										
50										
51										
52										
53										
54										
55						+				
56			-							
57										
58 59						+			+	
59 60			-							
00									-	
61										
61 62										
	Aspen Technology Inc.		Aspe	n HYS	SYS Version 7.3 (2	5.0.0.7336			Page 13 of 33	



1				Case Name:	NA COOLED HTSE W	SUB CRITICAL RANKIN	EV1.HSC
2 3	aspentech	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR		
4 5		USA		Date/Time:	Fri Mar 28 11:35:17 201	4	
5 6							
7	Wo	rkbook:	High Temp	perature Ste	am Electrol	ysis (TPL3)	
9 10				Material Stream	s	Fluid Pk	g: All
11	Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
12	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
13	Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6
14	Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042
15	Molar Flow	(kgmole/h)	3431	3431	1373	687.2	3431
16 17	Mass Flow	(kg/s)	12.59	6.495	9.539	3.441	6.495
17	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	73.06 -135.7	87.88 -45.57	31.71 -35.84	-40.71	87.88 -54.71
19	Name	(101 V V)	6 @TPL3	5 @TPL3	-55.64 18 @TPL3	19 @TPL3	17 @TPL3
20	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
21	Temperature	(C)	757.2	510.0 *	794.4	641.3	510.0 *
22	Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482
23	Molar Flow	(kgmole/h)	3431	3431	687.2	1373	687.2
24	Mass Flow	(kg/s)	12.59	12.59	3.441	9.539	3.441
25	Liquid Volume Flow	(m3/h)	73.06	73.06	12.41	31.71	12.41
26	Heat Flow	(M <i>\</i> V)	-137.3	-146.4	-40.76	-38.19	-43.12
27	Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000	0.6276
29	Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5
30	Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634
31	Molar Flow	(kgmole/h)	1.525e+004	1.525e+004	1788	1788	3431
32	Mass Flow	(kg/s)	97.37	97.37	11.42	11.42	12.59
33	Liquid Volume Flow	(m3/h)	373.1	373.1	43.75	43.75	73.06
34 35	Heat Flow Name	(MVV)	67.23 20 @TPL3	46.64 26 @TPL3	7.885 Water Recycle @TPL3	5.471 Sweep Water @TPL3	-167.0 21@TPL3
36	Vapour Fraction		0.8417	1.0000	0.0000	0.0000	21@1FL3
37	Temperature	(C)	222.7	100.0 *	100.0	21.77	100.1
38	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
39	Molar Flow	(kgmole/h)	1373	700.4	672.8	14.42	672.8
40	Mass Flow	(kg/s)	9.539	6.170	3.369	7.216e-002	3.369
41	Liquid Volume Flow	(m3/h)	31.71	19.56	12.15	0.2603	12.15
42	Heat Flow	(MW)	-46.14	-0.6218	-52.33	-1.147	-52.32
43	Name		14 @TPL3	15@TPL3	16 @TPL3	8 @TPL3	9 @TPL3
44	Vapour Fraction		0.0000	0.0000	0.9076	0.7769	1.0000
45	Temperature	(C)	98.49	98.42 *	290.8	158.5	158.5
46	Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901
47 48	Molar Flow	(kgmole/h)	687.2	687.2	687.2	3431	2665
48 49	Mass Flow Liquid Volume Flow	(kg/s) (m3/b)	3.441	3.441 * 12.41	3.441	6.495	2.668 74.06
43 50	Heat Flow	(m3/h) (MVV)	-53.47	-53.47	-45.53	-73.48	-14.96
51	Name	7.111 X Y	10 @TPL3	12@TPL3	24 @TPL3	13 @TPL3	11@TPL3
52	Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000
53	Temperature	(C)	158.5	158.5	158.5	178.6	158.6
54	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
55	Molar Flow	(kgmole/h)	765.5	1142	1523	1142	765.5
56	Mass Flow	(kg/s)	3.827	1.143	1.525	1.143	3.827
57	Liquid Volume Flow	(m3/h)	13.83	31.73	42.33	31.73	13.83
58	Heat Flow	(M <i>\</i> V)	-58.52	-6.410	-8.551	-6.221	-58.51
59							
60							
61 62							
63	Aspen Technology Inc		Acnon	HYSYS Version 7.3 (2	25 0 0 7336		Page 14 of 33
50	Licensed to: BATTELLE ENERG		Aspell r		20.0.0.7000		* Specified by user.
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2 BATTELLE ENERGY ALLIANCE 3 Burdington, MA 4 Unit Set: 5 Date/Time: 6 Workbook: 7 Workbook:	INE V1.HSC
4 000 5 Date/Time: Fri Mar 28 11:35:17 2014 6	
6	
) (continued)
8	,(,
9 Material Streams (continued) Fluid	Pkg: All
11 Name Electrolysis Water In @ 3@TPL3 2@TPL3 1@TPL3	Process Water @TPL
12 Vapour Fraction 0.0000 0.3055 0.3055 0.000	
13 Temperature (C) 21.11* 104.8* 104.8 21.7	21.77
14 Pressure (MPa) 0.1013* 7.790* 7.790 7.791	* 7.790
15 Molar Flow (kgmole/h) 1390 3431 3431 1390	1376
16 Mass Flow (kg/s) 6.958 12.59 12.59 6.958	
17 Liquid Volume Flow (m3/h) 25.10 73.06 73.06 25.11	
18 Heat Flow (MW) -110.7 -185.8 -185.8 -110.1	
19 Name Hydrogen Product @T 23 @TPL3 Oxygen Product @TP Residual Water from A 9999 0 00000 1 00000 0 00000	
20 Vapour Fraction 1.0000 0.0000 1.0000 0.0000 24 Transactor C4.44.1 C4.44.1 C4.44.1 C4.44.1	
21 Temperature (C) 54.44 * 54.44 * 54.44 * 20 Description 0.004 0.004 0.004 0.004	
22 Pressure (MPa) 6.901 6.901 6.901 0.1013 23 Malar Elaw (laggedable) 1373 147.2 606.0 144.4	
23 Molar Flow (kgmole/h) 1372 147.3 686.0 1443 24 Mass Flow (kg/s) 0.7684 0.7373 6.098 7.216e-003	
24 Mass Flow (kg/s) 0.7684 0.7373 6.098 7.216e-003 25 Liquid Volume Flow (m3/h) 39.60 2.660 19.30 0.2603	
20 Light volume Flow (MSN) 33.60 2.600 13.50 0.200 26 Heat Flow (MW) 0.3244 -11.61 6.653e-002 -11.33	
27 Name Process Return @TPL 22 @TPL3 27 @TPL3 Residual Water from	
21 Name Process Return (greg 22 (gregs 27 (gregs Resultativaterino) 28 Vapour Fraction 0.0000 0.0000 1.0000 0.0000	
29 Temperature (C) 374.9 54.53 54.44 54.44	
30 Pressure (MPa) 0.6870 7.790 6.901 0.101	
31 Molar Flow (kgmole/h) 1.704e+004 147.3 1376 3.893	
32 Mass Flow (kg/s) 108.8 0.7373 0.7879 1.948e-00	
33 Liquid Volume Flow (m3/h) 416.8 2.660 39.67 7.027e-000	
34 Heat Flow (MW) 52.11 -11.61 6.236e-002 -0.307	
35 Compositions Fluid	Pkg: All
36 37 Name H20/H2 In @TPL3 H2/H2O Out @TPL3 Sweep Gas/O2 Out @ Sweep Gas In @TF	L3 7 @TPL3
38 Comp Mole Frac (H2O) 0.6999 0.3000 0.5000 0.999	0.3000
39 Comp Mole Frac (Nitrogen) 0.0000 0.0000 0.0000 0.0000	0.0000
40 Comp Mole Frac (Oxygen) 0.0000 0.0000 0.5000 0.0000	0.0000
41 Comp Mole Frac (Hydrogen) 0.3001 0.7000 0.0000 0.0001	0.7000
42 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000	0.0000
43 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000	0.0000
44 Comp Mole Frac (Sodium) *** *** *** ***	***
45 Comp Mole Frac (Air) *** *** *** ***	
46 Name 6 @TPL3 5 @TPL3 18 @TPL3 19 @TPL3	17@TPL3
47 Comp Mole Frac (H2O) 0.6999 0.6999 0.9992 0.500	
48 Comp Mole Frac (Nitrogen) 0.0000 0.0000 0.0000 0.0000	
49 Comp Mole Frac (Oxygen) 0.0000 0.0000 0.0008 0.5001	
50 Ocean Mala Erro (Underson) 0.0001 0.0001 0.0000	
50 Comp Mole Frac (Hydrogen) 0.3001 0.3001 0.0000 0.0000 51 Comp Mole Frac (CO3) 0.0000 0.0000 0.0000 0.0000	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	
51 Comp Mole Frac (CO2) 0.0000 0.0000 0.0000 0.0000 52 Comp Mole Frac (CO) 0.0000 0.0000 0.0000 0.0000 53 Comp Mole Frac (Sodium) *** *** *** *** 54 Comp Mole Frac (Air) *** *** *** ***	Page 15 of 33 * Specified by user.

1	_		Case Name:	NA COOLED HTSE W	SUB CRITICAL RANKINE	V1.HSC
3	Burlington,	E ENERGY ALLIANCE , MA	Unit Set:	AFR		
4 5			Date/Time:	Fri Mar 28 11:35:17 201	4	
5 6						
7 8	Workbook	: High Temp	perature Ste	am Electrol	ysis (TPL3)	(continued)
9 10		Co	mpositions (conti	inued)	Fluid Pkg	;: All
11	Name	Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
12	Comp Mole Frac (H2O)	***	***	***	***	0.6999
13	Comp Mole Frac (Nitrogen)	***	***	***	***	0.0000
14	Comp Mole Frac (Oxygen)	***	***	***	***	0.0000
15	Comp Mole Frac (Hydrogen)	***	***	***	***	0.3001
16	Comp Mole Frac (CO2)	***	***	***	***	0.0000
18	Comp Mole Frac (CO)	1.0000	1.0000	1.0000	1.0000	0.0000
19	Comp Mole Frac (Sodium) Comp Mole Frac (Air)	1.0000	1.0000	1.0000	1.0000	***
20	Name	20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21@TPL3
20	Comp Mole Frac (H2O)	0.5000	0.0206	0.9992	1.0000 *	0.9992
22	Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
23	Comp Mole Frac (Oxygen)	0.5000	0.9794	0.0008	0.0000 *	0.0008
24	Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
25	Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000 *	0.0000
26	Comp Mole Frac (CO)	0.0000	0.0000	0.0000	* 0.000.0	0.0000
27	Comp Mole Frac (Sodium)	***	***	***	***	***
28	Comp Mole Frac (Air)	***	***	***	***	***
29	Name	14 @TPL3	15@TPL3	16 @TPL3	8@TPL3	9 @TPL3
30	Comp Mole Frac (H2O)	0.9992	0.9992 *	0.9992	0.3000	0.0993
31	Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.0000	0.0000	0.0000
32	Comp Mole Frac (Oxygen)	0.0008	0.0008 *	0.0008	0.0000	0.0000
33	Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.7000	0.9007
34	Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	0.0000
35	Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	0.0000
36 37	Comp Mole Frac (Sodium)	***	***	***	***	***
38	Comp Mole Frac (Air) Name	10 @TPL3	12 @TPL3	24 @TPL3	13 @TPL3	11@TPL3
39	Comp Mole Frac (H2O)	0.9989	0.0993	0.0993	0.0993	0.9989
40	Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
41	Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
42	Comp Mole Frac (Hydrogen)	0.0011	0.9007	0.9007	0.9007	0.0011
43	Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.000	0.0000
44	Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
45	Comp Mole Frac (Sodium)	***	***	***	***	***
46	Comp Mole Frac (Air)	***	***	***	***	***
47	Name	Electrolysis Water In @	3 @TPL3	2 @TPL3	1@TPL3	Process Water @TPL
48	Comp Mole Frac (H2O)	1.0000 *	0.6999 *	0.6999	1.0000	1.0000 *
49	Comp Mole Frac (Nitrogen)	* 00000	0.0000 *	0.0000	0.0000	0.0000 *
50	Comp Mole Frac (Oxygen)	* 0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
01 50	Comp Mole Frac (Hydrogen)	0.0000 *	0.3001 *	0.3001	0.0000	0.0000 *
53	Comp Mole Frac (CO2) Comp Mole Frac (CO)	* 0.0000 * 0.0000 *	0.0000 *	0.0000 0.0000	0.0000 0.0000	* 0.0000 * 0.0000
54	Comp Mole Frac (CO)		***	***	***	***
55	Comp Mole Frac (Air)	***	***	***	***	***
56						
57						
58						
59						
60						
61						
62						
63	Aspen Technology Inc.	Aspen H	YSYS Version 7.3 (25.0.0.7336)		Page 16 of 33
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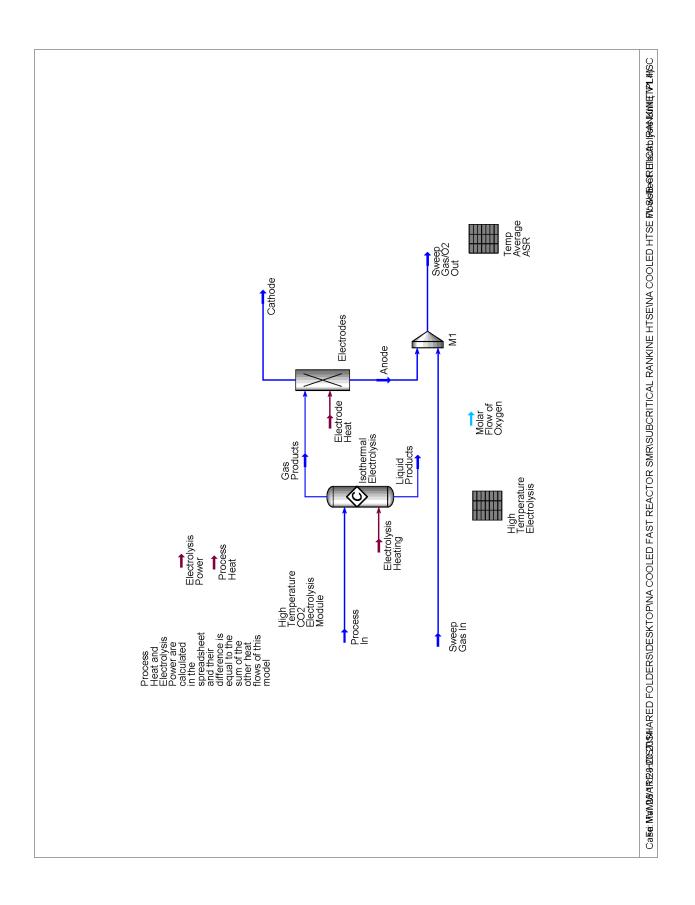
1				_	Case Name:	NA	A COOLED HTSE W S	SUB CRITI	CAL RANKINE	V1.HSC
3		BATTELLE Burlington,	ENERGY ALLIANC	E	Unit Set:	ΔF	R			
4	C aspentech	USA	10075							
5					Date/Time:	Fr	i Mar 28 11:35:17 201	4		
6					_					
7	Work	book:	High Te	mpe	erature Ste	a	m Electrol	ysis ((TPL3)	(continued)
8								_		
9 10				Com	positions (conti	nι	ued)		Fluid Pkg	: All
11	Name		Hydrogen Product	@Т 2	23 @TPL3 Oxygen Product @TPl			-		Process Heat In @TPI
12	Comp Mole Frac (H2O)		0.000		0.9998		0.0000	rtcolucu	1.0000	***
13	Comp Mole Frac (Nitrogen)		0.000		0.0000		0.0000		0.0000	***
14	Comp Mole Frac (Oxygen)		0.000		0.0000		1.0000		0.0000	***
15	Comp Mole Frac (Hydrogen)		1.000	00	0.0002		0.0000		0.0000	***
16	Comp Mole Frac (CO2)		0.00(00	0.0000		0.0000		0.0000	***
17	Comp Mole Frac (CO)		0.00(00	0.0000		0.0000		0.0000	***
18	Comp Mole Frac (Sodium)		*	**	***		***		***	1.0000
19	Comp Mole Frac (Air)		*	**	***		***		***	***
20	Name		Process Return @	TPL 2	2@TPL3	2	?7 @TPL3	Residua	l Water from H	Total Water for HTSE
21	Comp Mole Frac (H2O)		*	**	0.9998		0.0028		1.0000	1.0000 *
22	Comp Mole Frac (Nitrogen)		*	**	0.0000		0.0000		0.0000	0.0000 *
23	Comp Mole Frac (Oxygen)		*	**	0.0000		0.0000		0.0000	0.0000 *
24	Comp Mole Frac (Hydrogen)			**	0.0002		0.9972		0.0000	0.0000 *
25	Comp Mole Frac (CO2)			**	0.0000		0.0000		0.0000	0.0000 *
26	Comp Mole Frac (CO)		*	**	0.0000		0.0000		0.0000	0.0000 *
27	Comp Mole Frac (Sodium)		1.000		***		***		***	***
28	Comp Mole Frac (Air)		*	**	***		***		***	***
29					Energy Streams	s			Fluid Pkg	: All
30										
31	Name		Process Heat @T		lectrolysis Power @1	5	GT Q @TPL3		Rcy Pmp Pw	H2 Circ Pwr @TPL3
32	Heat Flow	(MVV)	-1.050e-00		-94.99		4.956e-002		4.201e-003	0.1892
33	Name		PWRP Pwr @TPL		STH Q @TPL3	1	nlet Water Pmp Pwr @	Electricit	y Generated (Q-Amb 2 @TPL3
34	Heat Flow	(MVV)	5.054e-00		1.620	~	7.060e-002	0.400.6	96.98	-4.492e-002
35 36	Name	(54) 60	Q-Amb 4 @TPL3 -0.449		Royc Pmp 2 PWR @T 8.859e-004	G	2-Amb 1 @TPL3 -3.002	Q-100 @	-6.815	
36	Heat Flow	(MVV)	-0.443	10	8.859e-004		-3.002		-6.815	
38					Unit Ops					
39	Operation Name	Ope	ration Type		Feeds		Products		Ignored	Calc Level
40				H2O/ł	H2 In @TPL3		H2/H2O Out @TPL	3		
41	Electrolysis Unit @TPL3	Standard S	Sub-Flowsheet		p Gas In @TPL3		Sweep Gas/O2 Out		No	2500 *
42								Electrolysis Power @TPL3		
43				6@T	PL3	Ì	H2O/H2 In @TPL3	_	N	500.0.1
44	H2O/H2 Topping Heater @TP	Heater		STH (Q @TPL3				No	500.0 *
45	Sween Can Tenning Leater @	Heater		18 @	TPL3		Sweep Gas In @TP	L3	No	500.0 *
46	Sweep Gas Topping Heater @	Healei		SGT (Q @TPL3				NU	500.0
47	Hi Tmp H2O/H2 Recup @TPL	Heat Exch	anger	5@T	PL3		6 @TPL3		No	500.0 *
48	ni niprizovi z riedup @ n c	Theat Excit	angei	H2/H2	20 Out @TPL3		7 @TPL3		140	500.0
49	Hi Tmp Swp Recup @TPL3	Heat Exch	anger	17 @			18 @TPL3		No	500.0 *
50	ni niip onp receip @ ii zo	THOUL EXCIT	angoi		p Gas/O2 Out @TPL3	3	19 @TPL3		140	000.0
51	Process Heat Steam/H2 HX @	Heat Exch	anger	4@T			5 @TPL3		No	500.0 *
52					ess Heat In H2 Side @	2.TF		PL3		
53	Process Heat Sweep HX @TF	Heat Exch	anger	16 @		_	17 @TPL3		No	500.0 *
54			Treat Excitatiger		ess Heat In Sweep Sid	ie (Return Sweep Side	@TPL3		
55	Lo Tmp Swp Recup @TPL3	Heat Exchanger		15@		_	16 @TPL3		No	500.0 *
56 57		Ŭ.		19@		\neg	20 @TPL3			
58	Lo Tmp H2O/H2 Recup @TPL	Heat Exch	anger	3@T			4 @TPL3		No	500.0 *
50				7 @T 20 @			8 @TPL3 Water Recycle @TF	21.2		
59 60	Swp KO Tank @TPL3	Separator		_) @TPL3		26 @TPL3	L3	No	500.0 *
61	ompino rank @IFL3	Separator		Gendu			Q-100 @TPL3		110	500.0
62	H2/Water KO Tank @TPL3	Separator		8 @ T	PL3	╡	10 @TPL3		No	500.0 *
63	Aspen Technology Inc.	coparator	Asn		SYS Version 7.3 (2	25				Page 17 of 33
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	LICEISEU D. BATTELLE ENERGT.	ALLIANCE								specified by user.

1				A COOLED HTSE W SUB CRITIC	CAL RANKINE V1	.HSC				
3	aspentech	BATTELLE ENERGY ALLIANC Burlington, MA	E Unit Set: AF	R						
4 5		USA	Date/Time: Fr	i Mar 28 11:35:17 2014						
5 6										
7	Work	book: High Ter	nperature Stea	m Electrolysis (TPL3) (c	ontinued)				
8 9										
10			Unit Ops (continued	,	law and Oala Law I					
11 12	Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level				
12	H2/Water KO Tank @TPL3	Separator	24 @TPL3	9 @TPL3 23 @TPL3	No	500.0 *				
14	V-100 @TPL3	Separator	Q-Amb 1@TPL3	27 @TPL3	No	500.0 *				
15	0			Q-Amb 1@TPL3						
16	Sweep Water Recycle Pump (Pump	Water Recycle @TPL3	21@TPL3	No	500.0 *				
17	Sweep water recycle r unip (i unp	Swp Wtr Rcy Pmp Pwr @TPL		140	500.0				
18	Process Water Recycle Pump	Pump	10 @TPL3	11@TPL3	No	500.0 *				
19 20	ý		PWRP Pwr @TPL3			_				
20	Inlet Water Pump @TPL3	Pump	Electrolysis Water In @TPL3 Inlet Water Pmp Pwr @TPL3	1 @TPL3	No	500.0 *				
22			23 @TPL3	22 @TPL3						
23	Recycle Pump 2 @TPL3	Pump	Rcyc Pmp 2 PWR @TPL3		No	500.0 *				
24	M2 ATEL 2	Mixor	Sweep Water @TPL3	14@TPL3	Ne	E00.0 *				
25	M2 @TPL3	Mixer	21 @TPL3		No	500.0 *				
26			13 @TPL3	2 @TPL3						
27	M1 @TPL3	Mixer	11 @TPL3		No	500.0 *				
28	Ŭ		Process Water @TPL3							
29 30			22 @TPL3 Return Sweep Side @TPL3	Process Return @TPL3						
31	M3 @TPL3	Mixer	Return H2 Side @TPL3	FIDLESS RECUIL WIFES	No	500.0 *				
32	RCY-1 @TPL3	Recycle	14 @TPL3	15 @TPL3	No	3500 *				
33	RCY-2@TPL3	Recycle	2 @TPL3	3 @TPL3	No	3500 *				
34	H2 Circulator @TPL3	Compressor	12 @TPL3	13 @TPL3	No	500.0 *				
35	Hz Circulator @TFL3	Compressor	H2 Circ Pwr @TPL3		INU	500.0				
36	T2@TPL3	Tee	9@TPL3	24 @TPL3	No	500.0 *				
37 38			4.07010	12@TPL3						
30 39	T1@TPL3	Tee	1@TPL3	Sweep Water @TPL3 Process Water @TPL3	No	500.0 *				
40			Process Heat In @TPL3	Process Heat In H2 Side @TF						
41	T3 @TPL3	Tee	Theess heat in Gen Es	Process Heat In Sweep Side (No	500.0 *				
42	HTE Calcs @TPL3	Spreadsheet			No	500.0 *				
43	LTHR Tb dP @TPL3	Set			No	500.0 *				
44	PHSH Tb dP @TPL3	Set			No	500.0 *				
45	HTHR Tb dP @TPL3	Set			No	500.0 *				
46	HTH dP @TPL3	Set			No	500.0 *				
47 48	HTHR ShidP @TPL3	Set Set			No No	500.0 * 500.0 *				
48 49	LTSR Sh dP @TPL3 LTSR Tb dP @TPL3	Set			No	500.0 *				
49 50	PHSH Sh dP @TPL3	Set			No	500.0 *				
51	SET-1@TPL3	Set			No	500.0 *				
52	SET-2@TPL3	Set			No	500.0 *				
53	HTSR Sh dP @TPL3	Set			No	500.0 *				
54										
55										
56 57										
57 58										
59										
60										
61										
62										
	Aspen Technology Inc.	Ann	en HYSYS Version 7.3 (25.	0 0 7336		Page 18 of 33				

1			Case Name:	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC								
2 3	(the aspentech)	BATTELLE ENERGY ALLIANC Burlington, MA	Unit Set:	Unit Set: AFR								
4 5		USA	Date/Time:	Fri Mar 28 11:35:17 2014								
6 7	\A/			toom Electrolus								
8	VVOF	kbook: High Tel	mperature S	team Electrolysis	s (TPL3) (continue	a)						
9 10	Unit Ops (continued)											
11	Operation Name	Operation Type	Feeds	Products	Ignored Calc Level							
12 13												
14												
15 16												
17												
18 19												
20												
21 22												
23												
24 25												
26 27												
28												
29 30												
31												
32 33												
34												
35 36												
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38 39												
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41 42												
43 44												
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46 47												
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49 50												
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52 53												
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55 56												
57												
58 59												
60												
61 62												
63	Aspen Technology Inc. Licensed to: BATTELLE ENERGY	Asp ALLIANCE	en HYSYS Version 7	.3 (25.0.0.7336)	Page 19 of 3 * Specified by user.	33						

1			Case Name: NA COOLED I	HTSE W SUB CRITICAL RANK	INE V1.HSC							
2 3		BATTELLE ENERGY ALLIAN Burlington, MA	CE Unit Set: AFR									
4	a	spentech Burlington, MA USA	Date/Time: Fri Mar 28 11:3	35: 17 2014								
5 6	6											
7		Spreadsheet: HTE	Calcs @TPL3	1	Jnits Set: NuScale							
8 9		-										
10	CONNECTIONS											
11	Imported Variables											
12 13												
14	B1	Material Stream: Residual Water from H2 @	Mass Flow		Value 1.948e-002 kg/s							
15	B2	Material Stream: Residual Water from O2 @	Mass Flow		7.216e-002 kg/s							
16	B3	Material Stream: H2O/H2 In @TPL3	Master Comp Mass Flow (H2O)		43259.1010 kg/h							
17	B4	Material Stream: H2/H2O Out @TPL3	Master Comp Mass Flow (H2O)		18540.8507 kg/h							
18	D1	Energy Stream: Rcyc Pmp 2 PWR @TPL3	Power		8.859e-004 MVV							
19	D2	Energy Stream: H2 Circ Pwr @TPL3	Power		0.1892 MVV							
20 21	D3	Energy Stream: PWRP Pwr @TPL3	Power		5.054e-003 MW							
21	D4	Energy Stream: Inlet Water Pmp Pwr @TF	Power		7.060e-002 MW							
22	D5	Energy Stream: Swp Wtr Rcy Pmp Pwr @1	Power		4.201e-003 MW							
23	D7 D8	Energy Stream: STH Q @TPL3 Energy Stream: SGT Q @TPL3	Heat Flow Heat Flow		1.620 MVV 4.956e-002 MVV							
24	D10	Energy Stream: Electrolysis Power @TPL3	Power		-94.99 MVV							
26	B6	Heat Exchanger: Process Heat Steam/H2 H	Exchanger Cold Duty		20.58 MVV							
27	B7	Heat Exchanger: Process Heat Sweep HX (Exchanger Cold Duty		2.413 MVV							
28	B10	Energy Stream: Electricity Generated @TF	Power		96.98 MVV							
29	E1	Energy Stream: Q-100 @TPL3	Heat Flow	-6.815 MW								
30	E2	Energy Stream: Q-Amb 1 @TPL3	Heat Flow		-3.002 MW							
31	E3	Energy Stream: Q-Amb 2 @TPL3	Heat Flow	-4.492e-002 MW								
32	E4	Energy Stream: Q-Amb 4 @TPL3	Heat Flow		-0.4490 MW							
33	F6	Heat Exchanger: Condenser @TPL1	Exchanger Cold Duty		129.4 MW							
34	F7	Energy Stream: Total Cooling Tower Powe	Power	0.5878 MVV								
35	F8	Material Stream: Make Up Water @TPL2	Mass Flow		61.94 kg/s							
36	F1	Material Stream: Hydrogen Product @TPL3	Mass Higher Heating Value		1.404e+005 kJ/kg							
37 38	F2	Material Stream: Hydrogen Product @TPL3	Mass Flow		0.7684 kg/s							
30 39	F3	Energy Stream: Reactor Heat	Heat Flow		250.0 MVV							
40		Exp	orted Variables' Formula Results	i								
41	Cell	Object	Variable Descrip	tion	Value							
42	F11	Total Water for HTSE @TPL3	Mass Flow		11.89 kg/s							
43 44			PARAMETERS									
44												
46		1	Exportable Variables		1							
47	Cell	Visible Name	Variable Description	Variable Type	Value							
48	B5	B5: Water Loss	Water Loss	Mass Flow	6.958 kg/s							
49	D6	D6: Total Power for flow	Total Power for flow	Power	0.2699 MVV							
50 51	D9 B8	D9: Total Topping Heat B8:	Total Topping Heat	Energy	1.669 MVV 23.00 MVV							
52	<u>В</u> 9	B8: B9:		Energy Power	96.98 MVV							
53	B11	B3. B11:		Power	2.993e-003 MW							
54	C11	C11:		Power	2.993 MVV							
55	F5	F5:		Energy	10.31 MVV							
56	F9	F9:		Power	4.682e-002 MW							
57	F10	F10:		Mass Flow	4.934 kg/s							
58	F11	F11: Mass Flow	Mass Flow	Mass Flow	11.89 kg/s							
59	D11	D11:		Power	8.075e-002 MW							
60	F4	F4:			43.14							
61			User Variables									
63	Aspen	Fechnology Inc. Asp	en HYSYS Version 7.3 (25.0.0.7336)		Page 20 of 33							
00		: BATTELLE ENERGY ALLIANCE	en 11 01 0 Version 7.0 (20.0.0.7 000)		* Specified by user.							
					aparticida by abort							

1				Case Name:	NA COOLED HTSE W SUB CRIT	TCAL RANKII	NE V1.HSC			
2			NERGY ALLIANCE	Unit Set:	AFR					
4	0	aspentech ^{Burlington, M,} USA		Date/Time:	Fri Mar 28 11:35:17 2014					
5 6				Dato, Hine.						
7		Spreadshee	et: HTE Cal	cs @TPL3	(continued)	L	Inits Set: NuScale			
8 9				FORMULAS						
10	<u> </u>	n					Deput			
12	Ce B5			Formula			Result 6.958 kg/s			
13	BE						23.00 MW			
14	BS) =D6+D9-D10+F9					96.98 MVV			
15	B1	1 =B10-B9					2.993e-003 MW			
16	C1						2.993 MVV			
17	De						0.2699 MVV			
18	D9						1.669 MVV			
19 20	D1 F4						8.075e-002 MW 43.14			
20	F5						10.31 MW			
22	F9						4.682e-002 MW			
23	F1						4.934 kg/s			
24	F1						11.89 kg/s			
25		·		Corroadabaat						
26				Spreadsheet						
27		Α	В		С		D			
28	1	Resid H2O from H2 *		18e-002 kg/s *	Rcyc Pmp 2 PWR *		8.859e-004 MVV *			
29 30	2	Resid H2O from O2 *		16e-002 kg/s * 59.1010 kg/h *	H2 Circ Pwr *		0.1892 MW *			
30	3 4	Water into Cells * Water out of Cells *		10.8507 kg/h *	PWR Pwr * Inlet Water Pmp Pwr *		5.054e-003 MVV * 7.060e-002 MVV *			
32	5	Water loss *	100-	6.958 kg/s *	Swp Wtr Pmp Pwr *		4.201e-003 MVV *			
33	6	Process Heat Steam/H2 HX Duty *		20.58 MW *	Total Power for flow *		0.2699 MVV *			
34	7	Process Heat Sweep HX Duty *		2.413 MVV *	STH Q *		1.620 MVV *			
35	8	Total Heat from Reactor *		23.00 MVV *	SGT Q *		4.956e-002 MVV *			
36	9	Power Needed for Electrolysis *		96.98 MVV *	Total Topping Heat *		1.669 MVV *			
37	10	Electricity Generated *		96.98 MVV *	Electrolysis Power *		-94.99 MVV *			
38	11	Excess Electricity *	2.99 F	33e-003 MVV *	2.993 MVV *		8.075e-002 MVV *			
39 40	1	E -6.815 MVV *		e+005 kJ/kg *						
41	2	-3.002 MVV *	1.404	0.7684 kg/s *						
42	3	-4.492e-002 MVV *		250.0 MVV *						
43	4	-0.4490 MVV *		43.14 *						
44	5	Total HTSE Ambient Heat *		10.31 MVV *						
45	6	Condenser Heat *		129.4 MVV *						
46	7	Cooling Tower Power *		0.5878 MVV *						
47	8 9	Cooling Tower Make up Water *	1.07	61.94 kg/s *						
40 29	9 10	HTSE Cooling Power * Water Needed to cool HTSE *	4.68	32e-002 MVV * 4.934 kg/s *						
50	11	Total Water for HTSE *		11.89 kg/s *						
51				ž i						
52										
53										
54										
55										
56										
57										
56 57 58 59										
60										
61										
62										
63	Asp	en Technology Inc.	Aspen HYS	SYS Version 7.3 (2	25.0.0.7336		Page 21 of 33			
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1				Case Name:	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC					
3	aspentech	Burlington, I	ENERGY ALLIANCE MA	Unit Set:	Unit Set: AFR					
4 5		USA		Date/Time:	Date/Time: Fri Mar 28 11:35:17 2014					
6					~					
7	VVOrk	(DOOK:	Electrolys	sis Unit (TPL	4)					
9 10				Streams		FI	uid Pkg	: All		
11	Name		Process in @TPL4	Sweep Gas In @TPL4	Cathode @TPL4	Sweep Gas/O2	Out @	Gas Products @TPL4		
12	Vapour Fraction		1.0000	1.0000	1.0000		0000	1.0000		
13	Temperature	(C)	800.0	800.0	800.0 *		00.0	800.0		
14	Pressure	(MPa)	7.185	7.185	7.185	7	.185	7.185		
15	Molar Flow ((kgmole/h)	3431	687.2	3431	1	373	4117		
16	Mass Flow	(kg/s)	12.59	3.441	6.495	9	.539	12.59		
17	Liquid Volume Flow	(m3/h)	73.06	12.41	87.88	3	1.71	107.2		
18	Heat Flow	(MVV)	-135.7	-40.71	-45.57	-3	5.84	-40.74		
19	Molar Enthalpy (k	(J/kgmole)	-1.424e+005	-2.133e+005	-4.781e+004	-9.396e+	-004	-3.563e+004		
20	Name		Liquid Products @TF	PL Anode @TPL4	Molar Flow of Oxygen	Electrolysis Hea	nting @	Electrode Heat @TPL		
21	Vapour Fraction		0.0000	1.0000						
22	Temperature	(C)	800.0	807.2						
23	Pressure	(MPa)	7.185	7.185						
24	Molar Flow ((kgmole/h)	0.0000	686.0	686.0					
25	Mass Flow	(kg/s)	0.0000	6.098	6.098					
26	Liquid Volume Flow	(m3/h)	0.0000	19.30	19.30					
27	Heat Flow	(MVV)	0.0000	4.874		9	4.94	4.541e-002		
28	28 Molar Enthalpy (kJ/kgmole)		-3.412e+004	2.558e+004						
29	Name		Process Heat @TPL	4 Electrolysis Power @1						
30	Vapour Fraction									
31	Temperature	(C)								
32	Pressure	(MPa)								
33		(kgmole/h)								
34	Mass Flow	(kg/s)								
35	Liquid Volume Flow	(m3/h)								
36	Heat Flow	(MVV)	-1.050e-002	-94.99						
37	Molar Enthalpy (k	(J/kgmole)								
38 39				Conversion React	ors	FI	uid Pkg	: All		
40	Name		Isothermal Electrolys	iis						
41	Separator Type									
42	Vessel Temperature	(C)	800.0							
43	Vessel Pressure	(MPa)	7.185							
44		(kgmole/h)	4117							
45		(kgmole/h)	0.0000							
46	Heat Flow	(MVV)	94.94							
47 48				Unit Ops						
49	Operation Name	Oper	ation Type	Feeds	Products	Ign	ored	Calc Level		
50			i	Process In @TPL4	Liquid Products @T	PL4				
51	Isothermal Electrolysis @TPL	Conversion	Reactor		4 Gas Products @TPL	4 1	No	500.0 *		
52					Electrolysis Heating	@TPL4				
53	3 Electrodes @TPL4 Companyont Solittor		1	Gas Products @TPL4	Cathode @TPL4			500.0.*		
54	Electrodes @TPL4			Electrode Heat @TPL4	Anode @TPL4		No	500.0 *		
55	Gas Product Temperature @T						No	500.0 *		
56	Outlet Temperature @TPL4	Set					No	500.0 *		
57	Inlet Temperature @TPL4	Set					No	500.0 *		
58	SET-1@TPL4	Set				1	No	500.0 *		
59	High Temperature Electrolysis	Spreadshe					No	500.0 *		
60	Temp Average ASR @TPL4	Spreadshe					No	500.0 *		
61 62	M1@TPL4 Mixer			Anode @TPL4 Sweep Gas In @TPL4	Sweep Gas/O2 Out	@TPL4 I	No	500.0 *		
62	Aspen Technology Inc.			HYSYS Version 7.3 (2	1 25.0.0.7336 ⁵			Page 22 of 33		
03	Licensed to: BATTELLE ENERGY	ALLIANCE	Aspen	THOTO VEISION 7.3 (2	.0.0.0.7000			* Specified by user.		

1			Case Name:	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC								
З	aspentech	BATTELLE ENERGY ALLIANC Burlington, MA	Unit Set:	AFR								
4 5		USA	Date/Time:	Date/Time: Fri Mar 28 11:35:17 2014								
6	\A/	de els Elsets-l	vaia Ursit (TP	(
7 8	VVOF	kbook: Electroly	sis Unit (TP	L4) (continued)								
9 10	Unit Ops (continued)											
11	Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level						
12 13	ADJ-1 @TPL4	Adjust			No	3500 *						
14												
15 16												
17												
18 19												
20 21												
22												
23 24												
25 26												
26 27												
28												
29 30												
31 32												
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34 35												
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48 49												
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51 52												
53 54												
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56 57												
58												
59 60												
61 62												
63	Aspen Technology Inc.	Aspe	en HYSYS Version 7.3	3 (25.0.0.7336)		Page 23 of 33						
	Licensed to: BATTELLE ENERGY	ALLIANCE				* Specified by user.						

1	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC								
3	(🕪 🚬	BATTELLE ENERGY ALLIAN Burlington, MA	UE	Unit Set: AFR					
4 5	<u> </u>	USA		Date/Time: Fri Mar 28 11:35:	17 2014				
6									
7 8		Spreadsheet: High	Ten	nperature Electroly	sis @TPL4	Units Set: Electrolysis_			
8 9									
10				CONNECTIONS					
11 12			In	nported Variables					
13	Cell	Object		Variable Description		Value			
14	D2	Material Stream: Process In @TPL4	Tempe			1073 K			
15	D3	Material Stream: Cathode @TPL4	Tempe			1073 K			
16	A8	Material Stream: Sweep Gas/O2 Out @TPL	Pressu			7.185e+006 N/m2			
17 18	E2	Material Stream: Process In @TPL4		Comp Mole Frac (H2O)		0.6999			
19	F2 G2	Material Stream: Process In @TPL4 Material Stream: Sweep Gas In @TPL4		Comp Mole Frac (Hydrogen) Comp Mole Frac (Oxygen)		0.3001			
20	E3	Material Stream: Cathode @TPL4		Comp Mole Frac (H2O)		0.3000			
21	F3	Material Stream: Cathode @TPL4		Comp Mole Frac (Hydrogen)		0.7000			
22	G3	Material Stream: Sweep Gas/O2 Out @TPL		Comp Mole Frac (Oxygen)		0.5000			
23	B16	SpreadSheetCell: Temp Average ASR@B2		mp Aver ASR		0.4000			
24	D11	Energy Stream: Electrolysis Heating @TPI	Heat Fl	ow		9.494e+004 kW			
25	D12	Energy Stream: Electrode Heat @TPL4	Heat Fl	ow		45.41 kW			
26 27		Exp	orted \	/ariables' Formula Results					
28	Cell	Object		Variable Description	1	Value			
29	B15	Molar Flow of Oxygen @TPL4	Molar F			190.6 gmole/s			
30	B19	Electrolysis Power @TPL4	Power			-9.499e+004 kW			
31	B20	Process Heat @TPL4	Heat Fl	ow		-10.50 kW			
32				PARAMETERS					
33 34									
34 35			Ex	portable Variables					
36	Cell	Visible Name		Variable Description	Variable Type	Value			
37	A1	A1: A1 for Gibbs Formation Energy	A1 for (Gibbs Formation Energy	Gibbs. Coeff. CA	2.382e+005 J/gmole			
38	A2	A2: A2 for Gibbs Formation Energy	A2 for Gibbs Formation Energy Gibbs. Coeff. CB			39.95 J/gmole-K			
39	A3	A3: A3 for Gibbs Formation Energy	A3 for Gibbs Formation Energy Gibbs. Coeff. CC			3.319e-003 kJ/gmol-K^			
40 41	A4	A4: A4 for Gibbs Formation Energy (kJ/gmol-K ^A 3)	A4 for Gibbs Formation Energy (kJ/gmol-K^3) A5 for Gibbs Formation Energy Gibbs. Coeff. CB			-3.532e-008			
41	A5	A5: A5 for Gibbs Formation Energy A6: Fa Faraday Number (J/Volt-gmole)			Gibbs, Coeff, CB	-12.85 J/gmole-K 9.649e+004			
43	A6 A7	A0: Fa Faraday Number (370 birghole)		aday Number (J/Volt-gmole) ersal Gas Constant	Entropy	8.314 J/gmole-K			
44	A9	A9: Standard Pressure		rd Pressure	Pressure	1.013e+005 N/m2			
45	H2	H2:				5.658e-002			
46	B11	B11: B2: Number of Cells	B2: Nu	mber of Cells		5.140e+005			
47	B12	B12: B3: Cell Area	B3: Ce		Small Area	225.0 cm2			
48	B13	B13: B4: Current Density (Amperes/cm ⁴ 2)	B4: Cu	rrent Density (Amperes/cm ^a 2)		0.6359			
49	B14	B14:				143.1			
50 51	B15 D4	B15: Molar Flow D4:	Molar F	IUW	Molar Flow	190.6 gmole/s			
52					Temperature	1073 K			
53	D6 12	D6: 12:			Molar Enthalpy	1.887e+005 J/gmole			
54	13	13:			Molar Enthalpy	1.887e+005 J/gmole			
55	16	16:			Molar Enthalpy	1.887e+005 J/gmole			
56	E4	E4:			Vapour Fraction	-0.3999			
57	F4	F4:			Vapour Fraction	0.3999			
58	G4	G4:			Vapour Fraction	0.4992			
59	H3	H3:				35.45			
60 61	H4	H4:				35.40			
61 62	E5 F5	E5: F5:			Vapour Fraction Vapour Fraction	0.2885			
63			en HYS	YS Version 7.3 (25.0.0.7336)		Page 24 of 33			
		BATTELLE ENERGY ALLIANCE				* Specified by user.			

ATTELLE FLER VALUANCE USA ATTELLE FLER VALUANCE USA ATTELLE FLER VALUANCE USA Und Set ATTELLE FLER VALUANCE USA Und Set ATTELLE USA Spreadsheet: High Temperature Electrolysis @TPL4 Und Set Electrolysis Electrolysis Electrolysis @TPL4 Und Set Electrolysis @TPL4 Und Set <thelectrolysis @TPL4 Und Set <thelectro< th=""><th>1</th><th colspan="9">Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC</th></thelectro<></thelectrolysis 	1	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC											
Data/Time Data/Time Pin Mar 201 113.017.2014 Spread/sheet: High Temperature Electrolysis @TPL4 Units of PARAMETERS Distribution Distribution 0 PARAMETERS Exportable Variables Variable Types	3	Unit Set AFR											
Spreadsheet: High Temperature Electrolysis @TPL4 Unts Str Electory is FARAMETERS Exportable Variables Colspan="2">Variable Texportable Variables Colspan="2">Variable Name Variable Variables Colspan="2">Variable Name Variable Variables Colspan="2">Variable Name Variable Variables Variable Variable Variable Variable Variable Trype Variable Variable Colspan="2">Variable Variable Variable Variables Colspan="2">Variable Variable Variable Variables Variable Variable Variable Variable Variable Variable Variable Variables Variable Variables Variables Variable Variables Variables Variables Variables Variables Variables Variables Variables <t< th=""><th>4</th><th>a</th><th></th><th></th><th>Data/Time:</th><th>Eri Mor 20, 11-25-17</th><th>2014</th><th></th></t<>	4	a			Data/Time:	Eri Mor 20, 11-25-17	2014						
Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: High Temperature Electrolysis @TPL4 Units Ster Decodysis Image: Spreadsheet: S					Date/Time.	FILMAL26 11.30.17	2014						
B FARAMETERS 10 Exportable Variables 11 Exportable Variables 12 Cell Visite Name Variable Description Variable Type Value 14 G5 G6			Spreadsheet: High	Tom	nerature	Flectrolys		Inits Set: Electrolysis					
Image: Second			opreadsheet. High	I CII	iperature	Liecuorys							
Image: Second		PARAMETERS											
Totalite Variable Name Exportable Variable Description Variable Type Value 10 Cell Visible Name Variable Description Variable Type Value 10 Jel H5													
1 0.5 0.5 Vapour Fraction 0.9 001 11 J2 J2				Exp	oortable Variab	es							
10 16 16 17	13	Cell	Visible Name		Variable Descr	iption	Variable Type	Value					
10 12													
Image Base Ethom 2.21 eH08.lgmdEx II K2 F2 — 0.973 II K3 K3 K3 — 0.973 II K3 K3 K3 — 0.973 II K6 K6 — Mage Mage II K7 K7 K7 T3.33 T3.33 II K6 K6 — — Self-007 III B18 B18 — — Self-007 III B19 B18 Power Power 9.986*/004 W/ III III H11 — — Semply2 III III H11 H11 — — Semply2 III III H11 H11 — — Semply2 III H11 H11 H11 — — Semply2 IIII H11 H11 H11 H11 H11 H11													
10 12 12 12 13 143 143 11 K3 143 143 1083 1083 21 K6 K6 10373 1083 21 K6 K6 10373 10373 21 K6 K6 10373													
10 K3 K4													
20 B17 B17. B							1						
1 K6 K8: K7													
22 R7 K7 K8 K8 K8 K8 K8 K8 K7													
22 B18 Call Valuer Fraction 1 2918 23 D8 C8: 3 681e-007 24 D9 C8: empty2 25 B19 B19. Deserter Power Power -9.438e+004 kW 26 B20. Heat Flow Heat Flow Energy empty2 26 E9 E8 empty2 27 E9 E8 empty2 empty2 26 E9 E8													
22 D8 D8 3.8818-007 23 D9 D8 24 D9 D8 25 B19 Power Power Power - 27 B20 E8 <empty> 25 E9 E8 E8 Temperature <empty> <empty> 26 F20 F20 F20 F20 S S B20 B20 S S S S S S <td< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th>Vapour Fraction</th><th></th></td<></empty></empty></empty>							Vapour Fraction						
25 D9 D9 <erretyio< td=""> 26 B19 B19. Power Power Power -9.499e+004 kVV 27 B20. Heat Flow Heat Flow Energy -10.50 kVV 28 B20 F30 F30 F30 <erretyio< td=""> 29 F10 T11 111 <erretyio< td=""> 20 C20 C20. C20. E8 <erretyio< td=""> 20 F10 F10 Temperature <erretyio< td=""> <erretyio< td=""> 23 F10 F10 <erretyio< td=""> <erretyio< td=""> 24 F20 F20 <erretyio< td=""> <erretyio< td=""> 25 C18 C18 <erretyio< td=""> 26 C20 F20 <erretyio< td=""> 27 F10 <erretyio< td=""> 28 C21 F20 <erretyio< td=""> 29 C21 #1711 <erretyio< td=""> 20 C81 <t< th=""><th>24</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<></erretyio<>	24												
26 B19 B19. Power Power 9.498±004 kW 27 B20 B20. Heat Flow Heat Flow Energy -10.50 kW 28 E3	25												
22 B20 B20 Heat Flow Heat Flow Energy -10.50 kW 21 111 111. <empty-< td=""> 23 E3 <empty-< td=""> 30 C20 C20. <empty-< td=""> 31 E8 E8 <empty-< td=""> 32 F10 F10. Vapour Fraction <empty-< td=""> 33 F20 F20 <empty-< td=""> 34 F20 F20 <empty-< td=""> 35 <empty-< td=""> 36 F20 F20 <empty-< td=""> 37 F20 F20 <empty-< td=""> 38 F21 F21 <empty-< td=""> 39 F20 F20 <empty-< td=""> 30 F21 F211414746) 143.1 31 B15 =811781414746) 19373 318 8174.947513<</empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<></empty-<>				Power			Power						
22 E9 E8 <=rpty> 30 C20 C20. C20. Energy <=rpty> 31 E8 E8 Temperature <=rpty> 32 F10 F10. Vapour Fraction <=rpty> 33 C18 C18. <=rpty> 34 F20 F20. <=rpty> 35 <=rpty> <=rpty> 36 <=rpty> <=rpty> 36 <=rpty> <=rpty> 36 <=rpty> <=rpty> 37 <=rpty> 38 Cell Formula Result 149.1 41 B15 =812*B13 149.1 190.6 gmoles 42 B17 @If@aBS(04)re-3/46K7) 10.373 10373 43 B18 =817*B13*B14/1000 49.498e*004 kW 49.498e*004 kW 45 B20 =819*D11*D12 -10.50 kW 0.00000 k	27		B20: Heat Flow	Heat Flo	W		Energy	-10.50 kW					
33 C20 C20: Energy	28	111	111:					<empty></empty>					
31 E8 E8 Temperature <empty> 32 F10 F10 F10 F10 <empty> 32 F10 F10 F10 <empty> 34 F20 F20 F20 <empty> 34 F20 F20 <empty> 35 <empty> <empty> 36 <empty> <empty> 37 37 <empty> 38 FORMULAS Result 40 B14 -811*B14/(47.6) 190.8 gmole's 190.8 gmole's 41 B15 =811*B14/(47.6) 190.3 73 190.8 gmole's 41 B18 =817*B13*B16 12.916 49.498+004 kW 42 B17 @effecAlseCu+1=3.468.7) 19.0373 49.498+004 kW 45 E0 =819*D11*D12 - 10.000 K 10.015 K 46 D4 =02-03</empty></empty></empty></empty></empty></empty></empty></empty></empty></empty>	29	E9	E9:					<empty></empty>					
32 F10 F10 F10 Vapour Fraction <empty> 33 C18 C18 </empty>	30	C20	C20:				Energy	<empty></empty>					
33 C18 C18 <empty> 34 F20 F20 F20 <empty> 35 User Variables <empty> 36 FOR MULAS <empty> 37 FOR MULAS 143.1 38 143.1 143.1 40 B14 =B127B13 100.6 gmole/s 41 B15 5911'B14(47A6) 100.6 gmole/s 42 B17 @F(@ABS(C4)<1e-3,k6,k7) 10373 43 B18 =B17.1B13/B16 44 B19 =B17.1B197B16 45 B20 =B19.D11+D12 45 D4 +D2-C3 46 D4 =D2.16 47 D6 =G02-P03/2</empty></empty></empty></empty>	31	E8	E8:				Temperature	<empty></empty>					
34 F20 F20.	32	F10	F10:				Vapour Fraction	<empty></empty>					
User Variables FORMULAS FORMULAS Second			C18:					<empty></empty>					
User Variables FORMULAS FORMULAS 20 Formula Result 40 B14 =B12*B13 143.1 41 B15 =B11*B14/(4*A6) 190.6 grandes/(5 42 B17 @IF@ABS(D4)×1e-3,K6,K7) 1 1373 43 B18 =B17+B13*B16 1 1373 44 B19 =B17+B13*B16/1000 -9.4948e+004 kWV 45 B18 =B17+B13*B16/1000 -9.4948e+004 kWV 45 B18 =B17+B13*B16/1000 -9.4948e+004 kWV 45 B18 =B17+B13*B16 1.050 kW 4 B19 -1.102*A6*H4*F4/1000 -9.498e+004 kWV 45 B2 -0.0000 K <t< th=""><th></th><th>F20</th><th>F20:</th><th></th><th></th><th></th><th></th><th><empty></empty></th></t<>		F20	F20:					<empty></empty>					
FORMULAS 39 Cell Formula Result 40 B14 =B12*B13 143.1 41 B15 =B12*B13 143.1 42 B17 @IF(@ABS(D4)<1e-3;K6;K7)	36			1	User Variables								
39 Cell Formula Result 40 B14 =B12*D13 143.1 41 B15 =B11*E14/(4*A6) 190.8 gmole/s 41 B15 =B11*E14/(4*A6) 190.8 gmole/s 42 B17 @F(@ABS(Cd)*1e-3;K6;K7) 1.0373 43 B18 =B1*E147(4*A6) 1.2916 44 B19 =B11*B18*B14/(4*A000 -9.4998+004 kW 45 B20 =B19*D11+D12 -10.50 kW 46 D4 -D2-C3 0.0000 K 47 D6 =(D2+D3)/2 1073 K 48 D8 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.3999 51 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2865 52 F4 =F3-F2 0.3999 53 F5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2865 <th></th> <th></th> <th></th> <th></th> <th>FORMULAS</th> <th></th> <th></th> <th></th>					FORMULAS								
40 B14 =B12*B13 143.1 41 B15 =B11*B14/(4*A6) 190.6 gmole/s 42 B17 @IF(@ABS(D4)<1e.3,K6,K7) 1.0373 43 B18 =B17*B13*B16 1.2916 44 B19 =B11*B18*B14/1000 -8.499e+004 kW 45 B20 =B19+D11+D12 -10.50 kW 46 D4 -D2-C3 0.0000 K 47 D6 =(02+03)/2 0.0000 K 48 D8 =1/(2*A6*H4*F4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 50 E4 =E3-E2 -0.3999 51 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2884 52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =03-62 0.4992 56 <		Cell		F	ormula			Result					
42 B17 @IF(@ABS(D4) <tle-3,k6,k7)< td=""> 1.0373 43 B18 =B17+B13*B16 1.2916 44 B19 =B11*B18*B14/1000 -9.499e+004 kW 45 B20 =B19+D11+D12 -9.499e+004 kW 46 D4 =D2-D3 0.0000 K 47 D6 =(D2+D3)/2 1073 K 48 D8 =11/2*A6*H4*F4) 3.661e-007 49 D9 =-1/2*A6*H4*F4/P4 3.661e-007 49 D9 =-1/2*A6*H4*F4/P4 3.661e-007 49 D9 =-1/2*A6*H4*F4/P4 3.661e-007 41 E5 =[G2*QLN(E3)-E3] - (E2*@LN(E2)-E2) -0.3999 51 E5 =[G3*QLN(E3)-E3] - (E2*@LN(E2)-E2) 0.2865 52 F4 =F3-F2 0.3999 53 F5 =[G3*QLN(G3)-G3] - (G2*QLN(E2)-E2) -0.2884 54 G4 =G3-G2 0.4992 55 =[G3*QLN(G3)-G3] - (G2*QLN(G2)-G2) -0.8401 56 H2 =G3*A8/A9 5658e-002 58 H2 =G3*A8/A9 5658e-002 <t< th=""><th>40</th><th></th><th>=B12*B13</th><th></th><th></th><th></th><th></th><th></th></t<></tle-3,k6,k7)<>	40		=B12*B13										
43 B18 =B17+B13*B16 1.2918 44 B19 =B11*B18*B14/1000 -9.499e+004 kW 45 B20 =B19+D11+D12 -10.50 kW 46 D4 =D2-D3 0.0000 K 47 D6 =(D2+D3)/2 1073 K 48 D8 =1/(2*A6*H4*F4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) <empty> 50 E4 =E3-E2 -0.3999 51 E5 =(E3*QLN(E3)-E3) - (E2*QLN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =(F3*QLN(F3)-F3) - (F2*QLN(F2)-F2) 0.2885 54 G4 =G3-G2 0.4992 55 g5 =G3*QLN(G3)-G3) - (G2*QLN(G2)-G2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =G3*QLN(G3)-G3) - (G2*QLN(G2)-G2) -0.8401 56 H2 =G2*A8/A9 5658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 51 =H4*A2*D2*A3*A3*D2*2 + A4*</empty>	41	B15	=B11*B14/(4*A6)					190.6 gmole/s					
44 B19 -B11*B18*B14/1000 -9.499e+004 kW 45 B20 =B19+D11+D12 -10.50 kW 46 D4 -D2-D3 0.0000 k 47 D6 =[02+D3)/2 1073 k 48 D8 =1/(2*A6*H4*F4) 3.681e-007 49 D9 =1/(2*A6*H4*F4) 3.681e-007 49 D9 =1/(2*A6*H4*F4) 3.681e-007 49 D9 =1/(2*A6*H4*F4) 3.681e-007 50 E4 =E3-E2 -0.3993 51 E5 =[C3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =[C3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-62 0.4992 55 G5 =[G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 H2 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A4*D2^A + A5*D2*@LN(D2) 1.887e+005 J/gmole <t< th=""><th></th><th>B17</th><th>@IF(@ABS(D4)<1e-3,K6,K7)</th><th></th><th></th><th></th><th></th><th>1.0373</th></t<>		B17	@IF(@ABS(D4)<1e-3,K6,K7)					1.0373					
45 B20 =B19+D11+D12 -10.50 kW 46 D4 =D2-D3 0.0000 K 47 D6 =[02+D3)/2 1073 K 48 D8 =1/(2*A6*H4*F4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) <empty> 50 E4 =E3-E2 -0.3999 51 E5 =[C3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =[F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.9401 56 H2 =G3*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@UN(H3)-H3)- (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A4*D2* + A4*D2* + A5*D3*@LN(D3) 1.887e+005 J/gmole 61 13 =A1 + A2*D2 + A4*D3* A 5*D3*@LN(D3) 1.887e+005 J/gm</empty>		B18	=B17+B13*B16					1.2916					
46 D4 =D2-D3 0.000 K 47 D6 =(D2+D3)/2 1073 K 48 D8 =1/(2*A6*H4*F4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) sempty> 50 E4 =E3-E2 -0.3939 51 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.28865 52 F4 =F3-F2 0.3899 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(F2)-F2) -0.2844 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 #14 =G3*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2+ A3*D2+2 + A4*D2*3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3+ A3*D3*2 + A4*D2*3 + A5*D3*@LN(D3) <t< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>													
47 D6 =(D2+D3)/2 1073 K 48 D8 =1/(2*A6*H4*F4) 3.681e-007 49 D9 =.1/(2*A6*H4*F4) 3.681e-007 49 D9 =.1/(2*A6*H4*F4*D4) <empty> 50 E4 =E3-E2 -0.3999 51 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) 0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 #14 =G3*A8/A9 5.658e-002 57 H3 =G3*A8/A9 5645 58 H4 =H3-H2 35.46 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2+A 3*D2*2 + A4*D2*3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3+A3*D3*2 + A4*D2*3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6+A3*D6*2 + A4*D6*</empty>													
48 D8 =1/(2*A6*H4*F4) 3.661e-007 49 D9 =1/(2*A6*H4*F4*D4) <empty> 50 E4 =E3-E2 -0.3999 51 E5 =E(3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) 0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 H2 =G2*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A3*D2^2 + A4*D2^3 + A5*D3*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3*2 + A4*D3*3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6* A3*D6*2 + A4*D6*3 + A5*D3*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33</empty>	46												
Do Interform Output 30 9 -1/(2*A6*H4*F4*D4) <empty> 50 E4 =E3-E2 -0.3939 51 E5 =(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 H2 =G2*A8/A8 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2* A A*D2*3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3*2 + A4*D3*3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6* A A*D6*3 + A5*D3*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33 </empty>	47												
50 E4 =E3-E2 -0.3939 51 E5 =(E3*@LN(E3)-E3)-(E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3)-(E2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3)-(G2*@LN(G2)-G2) -0.8401 56 H2 =G2*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3)-(H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A4*D2^A + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D2 + A4*D3^A + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6* + A4*D6*3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	40												
51 E5 =(E3*@LN(E3)-E3)-(E2*@LN(E2)-E2) 0.2885 52 F4 =F3-F2 0.3899 53 F5 =(F3*@LN(F3)-F3)-(F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4892 55 G5 =(G3*@LN(G3)-G3)-(G2*@LN(G2)-G2) -0.9401 56 H2 =G2*A8/A9 5658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3)-(H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A4*D2*A + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D2 + A4*D3*A + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6 + A3*D6*2 + A4*D6*A + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	50												
52 F4 =F3-F2 0.3999 53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 H2 =G2*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A3*D2*2 + A4*D2*3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3*2 + A4*D3*3 + A5*D3*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	51												
53 F5 =(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2) -0.2884 54 G4 =G3-G2 0.4992 55 G5 =(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2) -0.8401 56 H2 =G2*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A3*D2*2 + A4*D2*3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3*2 + A4*D3*3 + A5*D3*@LN(D6) 1.887e+005 J/gmole 62 I6 =A1 + A2*D6 + A3*D6*2 + A4*D6*3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	52												
54 G4 =63.62 0.4892 55 G5 =(G3*@LN(G3)-G3)-(G2*@LN(G2)-G2) -0.8401 56 H2 =52*A8/A9 5.658e-002 57 H3 =G3*A8/A9 35.45 58 H4 =H3.H2 35.45 58 H4 =H3.H2 35.45 59 H5 =(H3*@LN(H3)-H3)-(H2*@LN(H2)-H2) 91.27 60 I2 =A1 + A2*D2 + A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 I3 =A1 + A2*D3 + A3*D3*2 + A4*D3*3 + A5*D3*@LN(D6) 1.887e+005 J/gmole 62 I6 =A1 + A2*D6 + A3*D6*2 + A4*D6*3 + A5*D8*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	53												
56 H2 =62*A8/A9 5.658e-002 57 H3 =63*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@cLN(H3)-H3)- (H2*@cLN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A3*D2^2 + A4*D2^3 + A5*D2*@cLN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3^2 + A4*D3^3 + A5*D3*@cLN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6+ 2 + A4*D6*3 + A5*D6*@cLN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33	54	G4						0.4992					
57 H3 =63*A8/A9 35.45 58 H4 =H3-H2 35.40 59 H5 =(H3*@2UN(H3)-H3)- (H2*@LN(H2)-H2) 91.27 60 12 =A1 + A2*D2 + A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3 + A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6 + A3*D6^2 + A4*D6*3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33		G5	=(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2)					-0.8401					
58 H4 =H3-H2 35.40 59 H5 =(H3*@LN(H3)-H3)- (H2*@LN(H2)-H2) 91.27 60 I2 =A1 + A2*D2+ A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 I3 =A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 I6 =A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33													
59 H5 =(H3*@LN(H3)-H3)- (H2*@LN(H2)-H2) 91.27 60 I2 =A1 + A2*D2+ A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 I3 =A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 I6 =A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33													
60 12 =A1 + A2*D2+ A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2) 1.887e+005 J/gmole 61 13 =A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33													
61 13 =A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3) 1.887e+005 J/gmole 62 16 =A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33				201									
62 16 =A1 + A2*D6+ A3*D6*2 + A4*D6*3 + A5*D6*@LN(D6) 1.887e+005 J/gmole 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33													
Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 25 of 33													
	63				VS Version 7.2 (2	5 0 0 7336							
appended by user.	<u> </u>					0.0.0.7000		* Specified by user.					

1				Case Name	NA COOLED HTSE W SUB CRI	FICAL RANKINE V1.HSC
3	(1	Surlington, M	ENERGY ALLIANCE 1A	Unit Set:	AFR	
4		USA		Date/Time:	Fri Mar 28 11:35:17 2014	
6		Caroodoho	atı Llinh Tan		ra Electrolysia @T	DI 4 I Unite Cata Electrolucio
8		Spreadshe	et: High Ten	nperatu	re Electrolysis @T	PL4 (Units Set: Electrolysis_
9 10				FORMUL	AS	
11	Ce			Formula		Result
12	J2 J3				/	2.321e+008 J/gmole-K
13	 K2			^2"(@LN(D3)-(J.5)	2.321e+008 J/gmole-K 0.8721
15	K					1.099
16	K					1.0373
17	K	7 =D9*(A7/2*(D3^2-D2^2)*((E5+F5	5)*H4 + H5/2*F4) + F4*H4*I			<empty></empty>
19				Spreadsh	eet	
20		A	В		C	D
21	1	2.382e+005 J/gmole *	A1 for Gibbs Forma			Temperature *
22	23	39.95 J/gmole-K * 3.319e-003 kJ/gmol-K^2 *	A2 for Gibbs Forma A3 for Gibbs Forma		in *out *	1073 K * 1073 K *
24	4	-3.532e-008 *	Bibbs Formation Energy (k		Delta *	0.0000 K*
25	5	-12.85 J/gmole-K *	A5 for Gibbs Forma		Integration Coeff *	
26	6	9.649e+004 *	Fa Faraday Number (J		Average *	1073 K *
27 28	7 8	8.314 J/gmole-K * 7.185e+006 N/m2 *	R Universal G		0 i	0.001- 007 *
20	9	1.013e+005 N/m2 *	Standa	Pressure * rd Pressure *	C isothermal * C average *	3.661e-007 * <empty> *</empty>
30	10	1.0100-00014/112	Ctanda	ra i ressure	0 average	-cripty-
31	11	Number of Cells *		5.140e+005 *	Electrolysis Heating *	9.494e+004 kW *
32	12	Cell Area *		225.0 cm2 *	Electrode Heat *	45.41 KWV *
33	<u>13</u> 14	Current Density (Amperes/cm ⁴ 2) *		0.6359 *		
35	14	Current (Amperes) * Molar Flow of Oxygen *	19	143.1 * 0.6 gmole/s *		
36	16	Area Specific Resistance (ohm*cm*2) *		0.4000 *		
37	17	Nernst Potential (Volts) *		1.0373 *		
38	18	Operating Voltage (Volts) *	0.40	1.2916 * 9e+004 kW *	<empty> *</empty>	
39 40	<u>19</u> 20	Electrolysis Power * Process Heat *	-9.48	-10.50 kW *	<empty> *</empty>	
41		E	F		G	Н
42	1	y H2O *		y H2 *	y O2 *	y A *
43 44	2	0.6999 *		0.3001 *	0.0008 *	5.658e-002 *
44	<u>3</u> 4	0.3000 * -0.3999 *		0.7000 *	0.5000 * 0.4992 *	35.45 * 35.40 *
46	5	0.2885 *		-0.2884 *	-0.8401 *	91.27 *
47	6					
48	7 8					
49 50	9	<empty> * <empty> *</empty></empty>				
51	10	5pty.		<empty> *</empty>		
52	11					
53	12					
54 55	<u>13</u> 14					
56	15					
57	16					
58	17					
59 60	<u>18</u> 19					
61	20			<empty> *</empty>		
62		I	J		К	
63		en Technology Inc.	Aspen HYS	YS Version	7.3 (25.0.0.7336)	Page 26 of 33
	Licens	sed to: BATTELLE ENERGY ALLIANCE				* Specified by user.

1	-		LLE ENERGY A	LUNCE	Case Name:	NA COOLED HTSE W SUB CR	ITICAL RANKINE V1.HSC
2 3 4 5	(aspentech Burling	ton, MA	ILLIANCE	Unit Set:	AFR	
4		USA USA			Date/Time:	Fri Mar 28 11:35:17 2014	
6							
7		Spreads	heet: H	ligh Ten	nperature	Electrolysis @1	PL4 (Units Set: Electrolysis_
8 9					Spreadsheet		
10 11	1	Del	:aG *	Integra	Delta G dT *	Nernst Voltage *	,
11 12 13 14 15 16	2	1.887e+005 J/gr			3 J/gmole-K *	0.8721 *	7
13	3	1.887e+005 J/gr	nole *	2.321e+00	3 J/gmole-K *	1.099 *	·
14	4						
15	5 6	1.887e+005 J/gr	onle *		Isothermal *	1.0373 *	
17	7	1.0010-000 orgi	noic		Average *	<empty> *</empty>	
18	8						
19	9						
20	10						
21	11 12	<em< th=""><th>oty> *</th><th></th><th></th><th></th><th></th></em<>	oty> *				
18 19 20 21 22 23	13						
24	14						
25	15						
26	16						
27	17 18						
24 25 26 27 28 29 30	19						
30	20						
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63	Asp	en Technology Inc.		Aspen HYS	YS Version 7.3	(25.0.0.7336)	Page 27 of 33
_		ed to: BATTELLE ENERGY ALLIANC	F				* Specified by user.

2 3 4		BATTELLE ENERGY ALLIAN				KINE V1.HSC
4		spentech Burlington, MA	CE Unit Set	: AFR		
-	a	Spentech USA	Date/Tir	ne: Fri Mar 28 11:35	: 17 2014	
5 6			Batorri			
7		Spreadsheet: Tem	p Averag	e ASR @TPL4	4	Units Set: Electrolysis_
8 9				_		
10			CONNE	CTIONS		
11 12			Imported	Variables		
13	Cell	Object		Variable Description	n	Value
14	A3	Material Stream: Process In @TPL4	Temperature			1073 K
15 16	E15	Material Stream: Cathode @TPL4	Temperature			1073 K
17		Exp	orted Variable	s' Formula Results		
18 19	Cell	Object		Variable Description	n	Value
20			PARAN	IETERS		
21			Exportable	e Variables		
22 23	Cell	Visible Name	•	able Description	Variable Type	Value
24	B1	B1: B5: ASR @ 1100 K (ohms*cm*2)	B5: ASR @ 1100			0.2776
25	B2	B2: Temp Aver ASR	Temp Aver ASR			0.4000
26	B3	B3:				0.4000
27	B4 B5	B4: B5:				0.4000
29	B6	B6:				0.4000
30	В7	B7:				0.4000
31	B8	B8:				0.4000
32 33	B9	B9:				0.4000
33 34	B10 B11	B10: B11:				0.4000
35	B12	B12:				0.4000
36	B13	B13:				0.4000
37	B14	B14:				0.4000
38 39	B15 B16	B15: B16:				0.4000
40	B17	B17:				0.4000
41	B18	B18:				0.4000
42	B19	B19:				0.4000
43 44	E1 E2	E1: E2:			Temperature Temperature	1073 K 1073 K
45	F2	F2:				0.4000
46	C1	C1:			Temperature	1073 K
47	D1	D1:				0.4000
48 49	C2 D2	C2: D2:			Temperature	1073 K 0.4000
50	C3	C3:			Temperature	1073 K
51	D3	D3:				0.4000
52	C4	C4:			Temperature	1073 K
53 54	D4 C5	D4: C5:			 Temperature	0.4000 1073 K
55	D5	D5:				0.4000
56	C6	C8:			Temperature	1073 K
57	D6	D6:				0.4000
58 59	C7 D7	C7: D7:			Temperature	1073 K 0.4000
60	C8	C8:			Temperature	1073 K
61	D8	D8:				0.4000
62	C9	C9:			Temperature	1073 K
63		Echnology Inc. Asp BATTELLE ENERGY ALLIANCE	en HYSYS Vers	ion 7.3 (25.0.0.7336)		Page 28 of 33 * Specified by user.

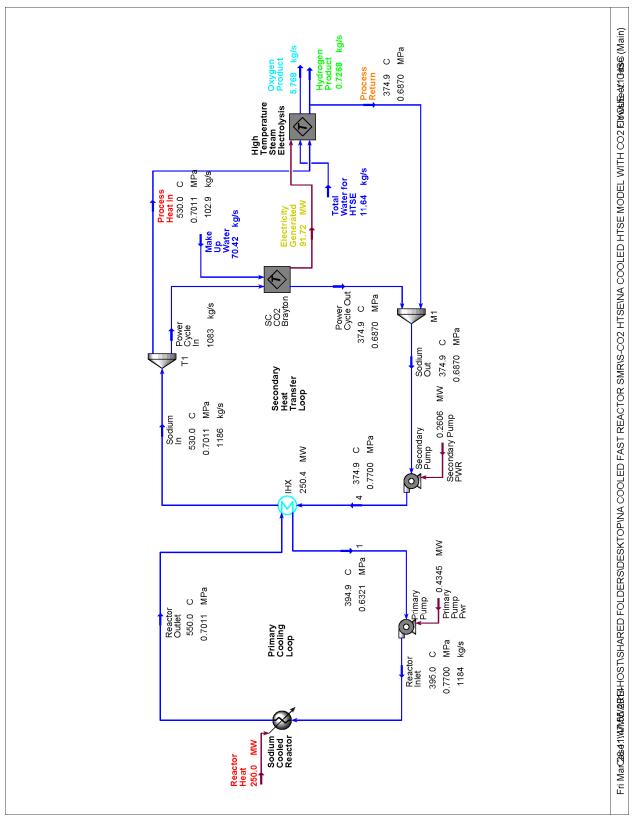
1	\sim				Case Name: NA	COOLED HTSE W SUB CRITICAL RA	ANKINE V1.HSC				
2 3		enentech	BATTELLE ENERG Burlington, MA	Y ALLIANCE	Unit Set: AFF	2					
4	d	spentech	USA		Date/Time: Fri N	Mar 28 11:35:17 2014					
5 6					Date/Time.	Date/Time: Fri Mar 28 11:35:17 2014					
7		Spr	readsheet:	Temp Av	erage ASR (@TPL4 (continued	¹ Units Set: Electrolysis_				
8							.1				
9 10					PARAMETERS						
11				E							
12				EX	portable Variables						
13	Cell	î	Visible Name		Variable Descriptio	i	Value				
14 15	D9 C10	D9: C10:				 Temperature	0.4000 1073 K				
16	D10	D10:					0.4000				
17	C11	C11:				Temperature	1073 K				
18	D11	D11:					0.4000				
19	C12	C12:				Temperature	1073 K				
20 21	D12	D12:					0.4000				
21	C13 D13	C13: D13:				Temperature	1073 K 0.4000				
23	C14	C14:				Temperature	1073 K				
24	D14	D14:					0.4000				
25	C15	C15:				Temperature	1073 K				
26	D15	D15:					0.4000				
27	C16	C16:				Temperature	1073 K				
28	D16	D16:				 	0.4000				
30	C17 D17	C17: D17:				Temperature	1073 K 0.4000				
31	C18	C18:				Temperature	1073 K				
32	D18	D18:					0.4000				
33	C19	C19:				Temperature	1073 K				
34	D19	D19:					0.4000				
35	A4	A4:				Temperature	1073 K				
36 37	A5 A6	A5: A6:				Temperature Temperature	1073 K 1073 K				
38	A7	A7:				Temperature	1073 K				
39	A8	A8:				Temperature	1073 K				
40	A9	A9:				Temperature	1073 K				
41	A10	A10:				Temperature	1073 K				
42	A11	A11:				Temperature	1073 K				
43 44	A12 A13	A12: A13:				Temperature Temperature	1073 K 1073 K				
44	A14	A13:				Temperature	1073 K				
46	A15	A15:				Temperature	1073 K				
47	A16	A16:				Temperature	1073 K				
48	A17	A17:				Temperature	1073 K				
49	A18	A18:				Temperature	1073 K				
50 51	A19 A20	A19: A20:				Temperature	1073 K 40.00				
52	E3	E3:				Temperature	1073 K				
53	E4	E4:				Temperature	1073 K				
54	E5	E5:				Temperature	1073 K				
55	E6	E6:				Temperature	1073 K				
56	E7	E7:				Temperature	1073 K				
57 58	E8 E9	E8: E9:				Temperature	1073 K				
59	E9 E10	E9: E10:				Temperature Temperature	1073 K 1073 K				
60	E11	E11:		1		Temperature	1073 K				
61	E12	E12:				Temperature	1073 K				
62	E13	E13:				Temperature	1073 K				
63		Technology Inc.	V NULLINGE	Aspen HYS	SYS Version 7.3 (25.0	.0.7336)	Page 29 of 33				
	ucensed to	BATTELLE ENERG	Y ALLIANCE				* Specified by user.				

Burdington, MA Und Set AFF Image: I	1	\sim		Case Name: NA COOLED HTSE	W SUB CRITICAL RANKI	NE V1.HSC	
Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Endowins 0 PARAMETERS Endowins Endowins Endowins 10 F14 E14	2 3		BATTELLE ENERGY ALLIANCE Burlington, MA	Unit Set: AFR			
Control Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average ASR @TPL4 (continued) Units Str Dechnopsis Image: Spreadsheet: Temp Average Asr Asr Spreadsheet: Temp Average Asr Asr Asr Asr	4	a		Dete (Time) Eri May 20, 11/25/17	2014		
Spreadsheet: Temp Average ASR @TPL4 (continued) Units Set Electrolysics 9 FARAMETERS FARAMETERS 10 Call Exportable Variables 11 Exportable Variables 10 12 Elit File 10 13 File File 10 14 Elit Temperature 10 15 File File	5			Date/Time. Pri Mar 26 11.35.17	2014		
B PARAMETERS II Exportable Variables II Exportable Variables III Cell Variable Description Variable Type IT FIG FIG Cell Tergenzame O0000 K FIG FIG Cell Tergenzame O0000 K FIG FIG FIG Cell Tergenzame Odd000 FIG FIG Cell - Odd000 FIG FIG Cell Cell - Odd000 FIG FIG Cell - - Odd000			Spreadsheet: Temp Av		continued'	Inits Set: Electrolysis	
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22 F7 F7 F7 e							
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27 F12 F12 F12 F13 F							
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22 F14 F14: 0.4000 30 B20 B20 19.20 31 User Variables 32 FORMULAS 33 FORMULAS 34 4.3 +f 18 35 Cell Formula Result 36 A.4 +f 18 1073 K 38 A.6 a.4 +f 18 1073 K 39 A.7 colspan="2">a.8 +f 18 1073 K 39 A.7 +f 18 1073 K 4.3 +f 18 1073 K 4.3 +f 18 1073 K 4.3 +f 18 1073 K 4.3 +f 18 1073 K 4.3 +f 18 1073 K 4.10 +f 18 1073 K 4.10 +f 18 1073 K 4.10 +f 18 <td cols<="" th=""><th></th><th></th><th></th><th></th><th></th><th></th></td>	<th></th> <th></th> <th></th> <th></th> <th></th> <th></th>						
30 B20 B20:							
User Variables FORMULAS Solution of the second							
Jacobi Strate FORMULAS 33 FORMULAS 34 Formula Result 35 Cell In73 k 36 A4 FA3+F16 1073 k 37 A5 FA4+F16 1073 k 38 A6 FA5+F16 1073 k 39 A7 FA8+F16 1073 k 41 A9 FA8+F16 1073 k 42 A10 FA9+F16 1073 k 43 A11 FA10+F16 1073 k 44 A12 FA11+F16 1073 k 44 A12 FA11+F16 1073 k 45 A13 FA12+F16 1073 k 46 A14 FA15+F16 1073 k 47 A15 FA14+F16 1073 k 48 A16 FA15+F16 1073 k 49 A16 FA15+F16 1073 k 51 A18+F16 1073 k 04000 52 A20 #4(64+86+86+810+812+814+816+							
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34 Formula Result 35 Cell Formula 1073 K 36 A4 =A3+F16 1073 K 37 A5 =A4+F16 1073 K 38 A6 =A5+F18 1073 K 38 A7 =A6+F16 1073 K 40 A8 =A7+F16 1073 K 41 A9 =A6+F16 1073 K 42 A10 =A9+F16 1073 K 43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A16 =A15+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 51 A19 =A16+F16 1073 K				FORMULAS			
35 A4 =A3+F18 1073 K 37 A5 =A4+F16 1073 K 38 A6 =A5+F18 1073 K 38 A7 =A6+F18 1073 K 40 A8 =A7+F18 1073 K 41 A9 =A6+F18 1073 K 42 A10 =A3+F18 1073 K 43 A9 =A6+F18 1073 K 44 A9 =A6+F18 1073 K 45 A11 =A10+F18 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A16 =A15+F16 1073 K 48 A16 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A16+F16 1073 K 52 A20 =M(E468+B8+B10+B12B+D1+D2+D5+D7+D19+D1+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @m(E15==A3,F15,1/13*F16*(B3+A20+B20+F15)//(E15-A3)) 0.4000		Cell		Formula		Result	
37 A5 =A4+F18 1073 K 38 A6 =A5+F18 1073 K 39 A7 =A6+F18 1073 K 39 A7 =A6+F18 1073 K 40 A8 =A7+F18 1073 K 41 A9 =A8+F18 1073 K 42 A10 =A9+F16 1073 K 43 A11 =A10+F18 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F18 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F18 1073 K 48 A16 =A14+F18 1073 K 49 A16 =A14+F18 1073 K 49 A17 =A18+F18 1073 K 50 A18 =A17+F18 1073 K 51 A19 =A17+F18 1073 K 52 A20 =416+F18 1073 K 51 A19 =A18+F18 1073 K 52 A20 =416+F18 A10+F16(930/A)*0.00003973+(E1							
33 A7 =A8+F18 1073 K 40 A8 =A7+F16 1073 K 41 A9 =A8+F18 1073 K 42 A10 =A9+F16 1073 K 43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 45 A12 =A11+F16 1073 K 46 A12 =A11+F16 1073 K 47 A15 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(64+B6+B8+B10+B12+B14+B18+D19+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F8+F8+F10+F12+F14) 40.00 53 B12 @EXP(10300/A910.0003973+(E1-0.463) 0.4000 54 B3 @EXP(10300/A910.0003973+(E1-0.463) 0.4000 55 B5 @EXP(10300/A910.00003973+(E1	37						
40 A8 =A7+F16 1073 K 41 A9 =A8+F16 1073 K 42 A10 =A9+F16 1073 K 43 A11 =A10+F16 1073 K 43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A14+F16 1073 K 49 A17 =A16+F16 1073 K 49 A18 =A17+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4/64+86+88+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 52 B3 @EXP(10300/A3'0.00003973+(B1-0.463) 0.4000 54 @EXP(10300/A3'0.00003973+(B1-0	38	A6	=A5+F16			1073 K	
41 A9 =A8+F16 1073 K 42 A10 =A9+F18 1073 K 43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A12+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B18+D1+D9+D5+D7+D9+D11+D19+D1+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @inf(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3/10.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A9/10.00003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A9/10.00003973+(B1-0.463) 0.4000 <th>39</th> <th>A7</th> <th>=A6+F16</th> <th></th> <th></th> <th>1073 K</th>	39	A7	=A6+F16			1073 K	
42 A10 =A9 #F 16 1073 K 43 A11 =A10 +F 18 1073 K 44 A12 =A11 +F 16 1073 K 45 A13 =A12 +F 18 1073 K 46 A14 =A13 +F 16 1073 K 47 A15 =A14 +F 16 1073 K 48 A16 =A14 +F 18 1073 K 49 A17 =A16 +F 18 1073 K 49 A17 =A16 +F 18 1073 K 50 A18 =A17 +F 16 1073 K 51 A19 =A18 +F 18 1073 K 52 A20 =4*(84+86+88+B10+B12+B14+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @m(f(15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 59 B8	40	A8	=A7+F16			1073 K	
43 A11 =A10+F16 1073 K 44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A14+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+B6H0+B12+B14+B16+B18+D1+D3+D6+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @ift(E15==A3,F16;(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(E1-0.463) 0.4000 55 B4 @EXP(10300/A5)*0.00003973+(E1-0.463) 0.4000 56 B5 @EXP(10300/A6)*0.00003973+(E1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.00003973+(E1-0.463) 0.4000 58 B7 @EXP(10300/A6)*0.00003973+(E1-0.463) 0.4000 59 B8<	41	A9	=A8+F16			1073 K	
44 A12 =A11+F16 1073 K 45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @tf(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A4)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 59 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000	42	A10	=A9+F16			1073 K	
45 A13 =A12+F16 1073 K 46 A14 =A13+F16 1073 K 47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @tt(E15===A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A10)*0.00003973+(B1-0.463) 0.4000 59 B10 @EXP(10300/A10)*0.00003973+(B1-0.463) 0.4000 50 B11 @EXP(10300/A10)*0.00003973+(B1		A11	=A10+F16			1073 K	
46 A14 =A13+F16 1073 K 47 A15 =A14+F18 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A18+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+E8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 4000 52 A20 =4*(B4+B6+E8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 4000 53 B2 @(fc[15===A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 58 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 59 B87 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 50		A12	=A11+F16			1073 K	
47 A15 =A14+F16 1073 K 48 A16 =A15+F16 1073 K 49 A17 =A16+F16 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A17+F16 1073 K 52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B19+D1+D3+D5+D7+D9+D11+D13+D15+D17+D18+F2+F4+F6+F8+F10+F12+F14) 40.00 52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B19+D1+D3+D5+D7+D9+D11+D13+D15+D17+D18+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @#(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 59 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000							
4 A16 =A15+F18 1073 K 49 A17 =A16+F18 1073 K 49 A17 =A16+F18 1073 K 50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B6+B8+B10+B12+B14+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @if(E15==A3,F15,(13*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 58 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A10)*0.00003973+(B1-0.463) 0.4000 59 B10 @EXP(10300/A10)*0.00003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A10)*0.00003973+(B1-0.463) 0.4000 61 B10 @EX							
A17 =A18+F16 1073 K 50 A18 =A17+F18 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(64+86+88+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 59 B7 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 50 B10 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 51 B10 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 52 <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>							
50 A18 =A17+F16 1073 K 51 A19 =A18+F16 1073 K 52 A20 =4*(64+66+88+E10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @(f(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.00003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 59 B7 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 50 B9 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 50 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 51 B10 @EXP(10300/A1)*0.00003973+(B1-0.463)	48						
51 A19 =A18+F16 1073 K 52 A20 =4*(B4+B8+B8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D18+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @tf(E15==x3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A5)*0.00003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A5)*0.00003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A5)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A5)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 59 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 50 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 51 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 52 B11 @EXP(10300/A11)*0.00003973+(B1-0.463) 0.4000 53 B10 @EXP(10300/A11)*0.00003973+(B1-0.463) 0.4000 54 B11	49						
52 A20 =4*(B4+B6+B8+B10+B12+B14+B16+B18+D1+D3+D5+D7+D9+D11+D13+D15+D17+D19+F2+F4+F6+F8+F10+F12+F14) 40.00 53 B2 @if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A0)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
53 B2 @if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3)) 0.4000 54 B3 @EXP(10300/A3)*0.00003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.00003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A4)*0.00003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 58 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 59 B9 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
54 B3 @EXP(10300/A3)*0.0003973+(B1-0.463) 0.4000 55 B4 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 58 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33					+F8+F10+F12+F14)		
55 B4 @EXP(10300/A4)*0.0003973+(B1-0.463) 0.4000 56 B5 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A5)*0.00003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33)			
56 B5 @EXP(10300/A5)*0.0003973+(B1-0.463) 0.4000 57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A6)*0.00003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
57 B6 @EXP(10300/A6)*0.0003973+(B1-0.463) 0.4000 58 B7 @EXP(10300/A7)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A8)*0.00003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A8)*0.00003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A1)*0.00003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A1)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
58 B7 @EXP(10300/A7)*0.0003973+(B1-0.463) 0.4000 59 B8 @EXP(10300/A8)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A8)*0.0003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
59 B8 @EXP(10300/A8)*0.0003973+(B1-0.463) 0.4000 60 B9 @EXP(10300/A9)*0.0003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
60 B9 @EXP(10300/A9)*0.0003973+(B1-0.463) 0.4000 61 B10 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 62 B11 @EXP(10300/A10)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
61 B10 @EXP(10300/A10)*0.0003973*(B1-0.463) 0.4000 62 B11 @EXP(10300/A11)*0.0003973*(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
62 B11 @EXP(10300/A11)*0.0003973+(B1-0.463) 0.4000 63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
63 Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 30 of 33							
				SYS Version 7.3 (25.0.0.7336)			
	للتس			2.2.101010111.0(20.0.0.7000)		* Specified by user.	

1	_		Case Name: NA COOLED HTSE W SUB CRITICAL RANK	KINE V1.HSC
2	(1)	BATTELLE ENERGY ALLIANCE Burlington, MA	Unit Set: AFR	
4	d	spentech ^{Burlington, MA} USA	Date/Time: Fri Mar 28 11:35:17 2014	
5 6			Daterrine. Primar 2011.35.17 2014	
7		Spreadsheet: Temp Av	verage ASR @TPL4 (continued)	Units Set: Electrolysis_
8 9				
10			FORMULAS	
11	Cell		Formula	Result
12	B12	@EXP(10300/A12)*0.00003973+(B1-0.463)		0.4000
13	B13 B14	@EXP(10300/A13)*0.00003973+(B1-0.463) @EXP(10300/A14)*0.00003973+(B1-0.463)		0.4000
15	B14 B15	@EXP(10300/A15)*0.00003973+(B1-0.463)		0.4000
16	B16	@EXP(10300/A16)*0.00003973+(B1-0.463)		0.4000
17	B17	@EXP(10300/A17)*0.00003973+(B1-0.463)		0.4000
18	B18	@EXP(10300/A18)*0.00003973+(B1-0.463)		0.4000
19	B19	@EXP(10300/A19)*0.00003973+(B1-0.463)		0.4000
20	B20	=2*(B5+B7+B9+B11+B13+B15+B17+B19+D2+D4+D6+D8	+D10+D12+D14+D16+D18+F1+F3+F5+F7+F9+F11+F13)	19.20
21	C1	=A19+F16		1073 K
22	C2	=C1+F16		1073 K
23	C3	=C2+F16		1073 K
24	C4	=C3+F16		1073 K
25 26	C5 C6	=C4+F16 =C5+F16		1073 K
26	C6 C7			1073 K
28	C8	=C6+F16 =C7+F16		1073 K 1073 K
29	C9	=C8+F16		1073 K
30	C10	=C9+F16		1073 K
31	C11	=C10+F16		1073 K
32	C12	=C11+F16		1073 K
33	C13	=C12+F16		1073 K
34	C14	=C13+F16		1073 K
35	C15	=C14+F18		1073 K
36	C16	=C15+F16		1073 K
37	C17	=C16+F16		1073 K
38	C18	=C17+F16		1073 K
39	C19	=C18+F16		1073 K
40 41	D1	@EXP(10300/C1)*0.00003973+(B1-0.463)		0.4000
41	D2 D3	@EXP(10300/C2)*0.00003973+(B1-0.463) @EXP(10300/C3)*0.00003973+(B1-0.463)		0.4000
43	D3	@EXP(10300/C4)*0.00003973+(B1-0.463)		0.4000
44	D5	@EXP(10300/C5)*0.00003973+(B1-0.463)		0.4000
45	D6	@EXP(10300/C6)*0.00003973+(B1-0.463)		0.4000
46	D7	@EXP(10300/C7)*0.00003973+(B1-0.463)		0.4000
47	D8	@EXP(10300/C8)*0.00003973+(B1-0.463)		0.4000
48	D9	@EXP(10300/C9)*0.00003973+(B1-0.463)		0.4000
49	D10	@EXP(10300/C10)*0.00003973+(B1-0.463)		0.4000
50	D11	@EXP(10300/C11)*0.00003973+(B1-0.463)		0.4000
51	D12	@EXP(10300/C12)*0.00003973+(B1-0.463)		0.4000
52 53	D13	@EXP(10300/C13)*0.00003973+(B1-0.463)		0.4000
53 54	D14 D15	@EXP(10300/C14)*0.00003973+(B1-0.463) @EXP(10300/C15)*0.00003973+(B1-0.463)		0.4000
55	D15	@EXP(10300/C16)*0.00003973+(B1-0.463)		0.4000
56	D17	@EXP(10300/C17)*0.00003973+(B1-0.463)		0.4000
57	D18	@EXP(10300/C18)*0.00003973+(B1-0.463)		0.4000
58	D19	@EXP(10300/C19)*0.00003973+(B1-0.463)		0.4000
59	E1	=C19+F16		1073 K
60	E2	=E1+F16		1073 K
61	E3	=E2+F16		1073 K
62	E4	=E3+F16		1073 K
63			SYS Version 7.3 (25.0.0.7336)	Page 31 of 33
	Licensed to:	BATTELLE ENERGY ALLIANCE		* Specified by user.

1	\sim			Case Name:	NA COOLED HTSE W S	UB CRITICAL R	ANKINE V1.HSC	
3		spentech Burlington, M	NERGY ALLIANCE A	Unit Set:	AFR			
4	<u> </u>	USA USA		Date/Time:	Fri Mar 28 11:35:17 2014			
5 6								
7 8		Spreadshe	et: Temp Av	verage A	SR @TPL4 (co	ontinued	Units Set:	Electrolysis_
9					<u></u>			
10 11	Cell	1		FOR MULA	3			esult
12	E5	=E4+F16		ormula			1073 K	esuit
13	E6	=E5+F16					1073 K	
14	E7	=E6+F16					1073 K	
15	E8	=E7+F16					1073 K	
16	E9	=E8+F16					1073 K	
17	E10	=E9+F16					1073 K	
18 19	E11 E12	=E10+F16 =E11+F16					1073 K 1073 K	
20	E12 E13	=E12+F16					1073 K	
21	E14	=E13+F16					1073 K	
22	F1	@EXP(10300/E1)*0.00003973+(I	B1-0.463)				0.4000	
23	F2	@EXP(10300/E2)*0.00003973+(I	31-0.463)				0.4000	
24	F3	@EXP(10300/E3)*0.00003973+(I					0.4000	
25	F4	@EXP(10300/E4)*0.00003973+(I					0.4000	
26	F5	@EXP(10300/E5)*0.00003973+(I					0.4000	
27 28	F6	@EXP(10300/E6)*0.00003973+(I					0.4000	
20	F7 F8	@EXP(10300/E7)*0.00003973+(I @EXP(10300/E8)*0.00003973+(I					0.4000	
30	F9	@EXP(10300/E9)*0.00003973+(I					0.4000	
31	F10	@EXP(10300/E10)*0.00003973+					0.4000	
32	F11	@EXP(10300/E11)*0.00003973+					0.4000	
33	F12	@EXP(10300/E12)*0.00003973+	(B1-0.463)				0.4000	
34	F13	@EXP(10300/E13)*0.00003973+					0.4000	
35	F14	@EXP(10300/E14)*0.00003973+					0.4000	
36 37	F15 F16	@EXP(10300/E15)*0.00003973+ =(E15-A3)/50	(B1-0.463)				0.4000 0.0000 K	
38	1 10	-(210/43)/30		A	-4		0.0000 K	
39				Spreadshe				
40 41	1	A	В	0.0770.*	<u> </u>	1701/ *	D	0.4000 *
41	2	ASR @ 1100 K * Temp Average ASR *		0.2776 *		073 K * 073 K *		0.4000 *
43	3	1073 K*		0.4000 *		073 K *		0.4000 *
44	4	1073 K*		0.4000 *		173 K *		0.4000 *
45	5	1073 K *		0.4000 *	1	173 K *		0.4000 *
46	6	1073 K *		0.4000 *		173 K *		0.4000 *
47	7	1073 K*		0.4000 *		173 K *		0.4000 *
48	8	1073 K*		0.4000 *		073 K *		0.4000 *
49 50	9 10	1073 K * 1073 K *		0.4000 *		073 K * 073 K *		0.4000 *
51	10	1073 K*		0.4000 *)73 K *		0.4000 *
52	12	1073 K*		0.4000 *		073 K *		0.4000 *
53	13	1073 K*		0.4000 *		073 K *		0.4000 *
54	14	1073 K *		0.4000 *	1	073 K *		0.4000 *
55	15	1073 K *		0.4000 *		073 K *		0.4000 *
56	16	1073 K *		0.4000 *		073 K *		0.4000 *
57	17	1073 K*		0.4000 *		173 K *		0.4000 *
50	18 19	1073 K * 1073 K *		0.4000 *)73 K *)73 K *		0.4000 * 0.4000 *
60 60	20	40.00 *		19.20 *	I	aran		0.4000 -
61		E	F	, 3,20				
62	1			0.4000 *				
63		Technology Inc.	Aspen HYS	SYS Version 7.	3 (25.0.0.7336)			e 32 of 33
	Licensed to	: BATTELLE ENERGY ALLIANCE					* Specifi	ed by user.

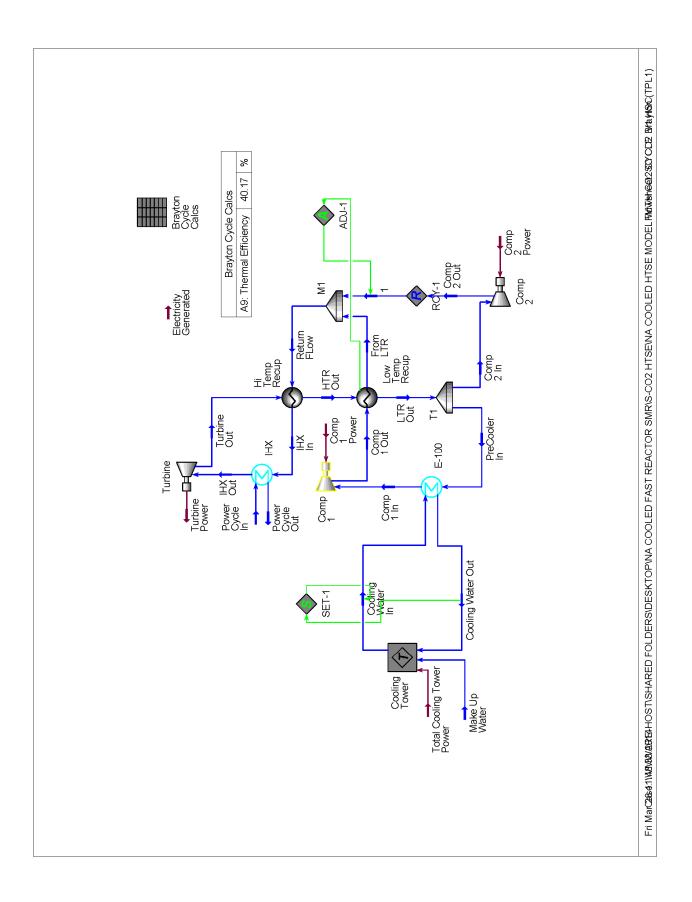
1	(Case Name:	NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC	
2 3 4 5	(1	BATTELLE ENERGY ALLIANCE aspentech Burlington, MA USA	Unit Set:	AFR	
4		USA	Date/Time:	Fri Mar 28 11:35:17 2014	
6					
7 8		Spreadsheet: Temp	Average A	SR @TPL4 (continued) Units Set: Electroly	sis_
9			Spreadshee	et	
10 11	2	1073 K *	0.4000 *		
12	3	1073 K*	0.4000 *		
12 13 14	4	1073 K *	0.4000 *		
14 15	5 6	1073 K * 1073 K *	0.4000 * 0.4000 *		
15 16	7	1073 K *	0.4000 *		
17	8	1073 K *	0.4000 *		
18	9	1073 K*	0.4000 *		
19 20 21 22 23 24 25 26 27	10 11	1073 K * 1073 K *	0.4000 *		
21	12	1073 K*	0.4000 *		
22	13	1073 K *	0.4000 *		
23	14	1073 K*	0.4000 *		
24	15 16	1073 K * delta T *	0.4000 * 0.0000 K *		
26	17	uena i	0.0000 K		
27	18				
28 29	19				
29	20				
31					
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30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51					
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54 55 56 57 58 59 60 61					
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59 60					
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63		en Technology Inc. Aspen ed to: BATTELLE ENERGY ALLIANCE	HYSYS Version 7.3	3 (25.0.0.7336) Page 33 of 3 * Specified by user.	3



6.6 Supercritical CO₂ Brayton HTSE

1				Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC						
2	aspentech	Burlington,	E ENERGY ALLIANCE , MA	Unit Set:	AFR					
4 5	- aspenteen	USA		Date/Time:	Fri Mar 28 11:57:05 201	4				
6										
7	Wo	rkbook:	: Case (Mai	n)						
9				Material Stream		Fluid Pk	a: All			
10	Name		Lindreson Draduat	Oxygen Product	Total Water for HTSE	Sodium In	-			
12	Vapour Fraction		Hydrogen Product 1 0000	Oxygen Product 1.0000	0.0000	0.0000	Process Heat In 0.0000			
13	Temperature	(C)	54.44	54.44	21.11	530.0	530.0			
14	Pressure	(MPa)	6.901	6.901	0.1013	0.7011	0.7011			
15	Molar Flow	(kgmole/h)	1298	648.9	2325	1.857e+005	1.612e+004			
16	Mass Flow	(kg/s)	0.7268	5.768	11.64	1186	102.9			
17	Liquid Volume Flow	(m3/h)	37.46	18.25	41.98	4544	394.3			
18	Heat Flow	(MVV)	0.3069	6.293e-002	-184.3	818.8	71.05			
19	Name		Process Return	4	Reactor Outlet	Reactor Inlet	1			
20	Vapour Fraction		0.0000	0.0000	0.0000	0.000	0.0000			
21	Temperature	(C)	374.9	374.9	550.0 *	395.0	394.9 *			
22	Pressure	(MPa)	0.6870	0.7700 *	0.7011	0.7700 *	0.6321			
23	Molar Flow	(kgmole/h)	1.612e+004	1.857e+005	1.854e+005	1.854e+005	1.854e+005			
24	Mass Flow	(kg/s)	102.9	1186	1184	1184	1184			
25	Liquid Volume Flow	(m3/h)	394.3	4544	4537	4537	4537			
26	Heat Flow	(M <i>\</i> V)	49.30	568.3	849.9	599.9	599.5			
27	Name		Sodium Out	Power Cycle In	Power Cycle Out	Make Up Water				
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000				
29	Temperature	(C)	374.9	530.0	374.9	20.00				
30	Pressure	(MPa)	0.6870	0.7011	0.6870	0.1013				
31	Molar Flow	(kgmole/h)	1.857e+005	1.696e+005	1.696e+005	1.407e+004				
32	Mass Flow	(kg/s)	1186	1083	1083	70.42				
33	Liquid Volume Flow	(m3/h)	4544	4149	4149	254.0				
34	Heat Flow	(MVV)	568.1	747.7	518.8	-1116				
35 36				Compositions	;	Fluid Pk	g: All			
37	Name		Hydrogen Product	Oxygen Product	Total Water for HTSE	Sodium In	Process Heat In			
38	Comp Mole Frac (H2O)		0.0000	0.0000		***				
39			0.0000	0.0000	1.0000	***	***			
40	Comp Mole Frac (Nitroger	1)	0.0000	0.0000	1.0000	***	***			
41										
41	Comp Mole Frac (Nitrogen)	0.0000 0.0000 1.0000	0.0000	*** ***	***	***			
42	Comp Mole Frac (Nitrogen Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO2))	0.0000 0.0000 1.0000 0.0000	0.0000 1.0000 0.0000 0.0000	***	*** *** *** ***	*** *** ***			
42 43	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO2) Comp Mole Frac (CO)) en)	0.0000 0.0000 1.0000 0.0000 0.0000	0.0000 1.0000 0.0000 0.0000 0.0000	*** *** *** ***	*** *** *** ***	*** *** *** ***			
42 43 44	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium)) en)	0.0000 0.0000 1.0000 0.0000 0.0000	0.0000 1.0000 0.0000 0.0000 0.0000	*** *** *** *** ***	*** *** *** *** 1.0000	***			
42 43 44	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO2) Comp Mole Frac (CO Comp Mole Frac (Sodium, Comp Mole Frac (Air)) en)	0.0000 0.0000 1.0000 0.0000 0.0000 *** ***	0.0000 1.0000 0.0000 0.0000 0.0000 *** ***	· · · · · · · · · · · · · · · · · · ·	*** *** *** 1.0000 ***	*** *** *** 1.0000 ***			
42 43 44 45	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	reactor Outlet	**** **** **** 1.0000 **** Reactor Inlet	*** *** *** 1.0000 ***			
42 43 44 45 46 47	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O)) en))	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 *** 4 ***	Reactor Outlet	**** **** 1.0000 *** Reactor Inlet ***	**** **** **** 1.0000 **** 1			
42 43 44 45	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (CQ) Comp Mole Frac (CQ) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger) en)) 	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	reactor Outlet	**** **** **** 1.0000 **** Reactor Inlet	*** *** *** 1.0000 ***			
42 43 44 45 46 47 48 49	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen)) en)) 	0.0000 0.0000 0.0000 0.0000 **** Process Return ***	0.0000 1.0000 0.0000 0.0000 *** *** 4 ***	Reactor Outlet	**** **** 1.0000 **** Reactor Inlet	*** *** *** 1.0000 *** 1 ***			
42 43 44 45 46 47 48 49 50	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Hydroge) en)) 	0.0000 0.0000 1.0000 0.0000 **** Process Return **** ****	0.0000 1.0000 0.0000 0.0000 *** *** 4 *** ***	**** **** **** Reactor Outlet **** **** **** **** **** **** ****	**** **** 1.000 Reactor Inlet ****	*** *** *** 1.0000 *** 1 ***			
42 43 44 45 46 47 48 49 50 51	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Ozygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Sodium, Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Coxygen Comp Mole Frac (Coxygen Comp Mole Frac (CO2)) en)) 	0.0000 0.0000 1.0000 0.0000 **** Process Return **** ****	0.0000 1.0000 0.0000 0.0000 *** 4 4 ***	****	**** **** **** **** **** **** ****	**** **** **** 1.0000 **** 1 **** ****			
42 43 44 45 46 47 48 49 50	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (O2) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CXygen) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 **** Process Return *** **** ****	0.0000 1.0000 0.0000 0.0000 	****	****	1 *** 1.0000 *** *** *** *** ***			
42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Ozygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Sodium, Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (Coxygen Comp Mole Frac (Coxygen Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 *** Process Return *** Process Return ***	0.0000 1.0000 0.0000 0.0000 	***	*** ***	1 *** 1 *** *** *** *** *** ***			
42 43 44 45 46 47 48 49 50 51 52 53	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** **** 1.0000 **** 1 **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 53	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** 1.0000 **** 1 **** **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** **** 1.0000 **** 1 **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** **** 1.0000 **** 1 **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** 1.0000 **** 1 **** **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** 1.0000 **** 1 **** **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)) en)))) n))) en)	0.0000 0.0000 0.0000 0.0000 	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** 1.0000 **** 1 **** **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (CQ) Comp Mole Frac (CQ) Comp Mole Frac (CO) Comp Mole Frac (CO) Comp Mole Frac (Sodium) Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CQ) Comp Mole Frac (CQ) Comp Mole Frac (CQ) Comp Mole Frac (CQ) Comp Mole Frac (CAir)) en)) n)) en))	0.0000 0.0000 1.0000 0.0000 *** Process Return *** *** *** 1.0000 ***	0.0000 1.0000 0.0000 0.0000 *** 4 *** 4 *** *** 1.0000 *	****	**** **** **** **** **** **** ****	**** **** **** 1.0000 **** 1 **** **** *			
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Nitroger Comp Mole Frac (Oxygen Comp Mole Frac (Oxygen Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co3) Comp Mole Frac (Air) Name Comp Mole Frac (H2O) Comp Mole Frac (Nitroger Comp Mole Frac (Nitroger Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2))	0.0000 0.0000 1.0000 0.0000 *** Process Return *** *** *** 1.0000 ***	0.0000 1.0000 0.0000 0.0000 	****	**** **** **** **** **** **** ****	**** **** 1.0000 **** 1 **** **** **** *			

1					Case Name:	NA COOLED HTSE MO	DDEL WITH	CO2 CYCLE '	V1.HSC
2	aspentech	BATTELLE	E ENERGY ALLIANC , MA	CE	Unit Set:	AFR			
4	aspenteen	USA			Date/Time:	Fri Mar 28 11:57:05 201	14		
5									
7 8	Work	book	: Case (M	lain	ı) (continue	ed)			
9				Cor	mpositions (conti	inued)		Fluid Pkg:	All
10 11	Name		Sodium Out		Power Cycle In	Power Cycle Out	Make Up		
12	Comp Mole Frac (H2O)			***	+twei Cycle III	Fower Cycle Out	i wake op	1.0000	
13	Comp Mole Frac (Nitrogen)			***	***	***		***	
14	Comp Mole Frac (Oxygen)		-	***	***	***		***	
15	Comp Mole Frac (Hydrogen)		-	***	***	***		***	
16	Comp Mole Frac (CO2)			***	***	***		***	
17	Comp Mole Frac (CO)			***	***	***		***	
18 19	Comp Mole Frac (Sodium)		1.00	UU ***	1.0000	1.0000		***	
20	Comp Mole Frac (Air)						1		
21					Energy Stream	5		Fluid Pkg:	All
22	Name		Reactor Heat		Electricity Generated	Primary Pump Pwr	Secondar	y Pump PWF	
23	Heat Flow	(MVV)	250).0 *	91.72	0.4345		0.2606	
24 25									
26	Operation Name Operation Type				Feeds	Products		Ignored	Calc Level
27 28	Sodium Cooled Reactor	Heater			actor Inlet	Reactor Outlet		No	500.0 *
20				-	actor Heat	Hydrogen Product			
30	High Temperature Steam Elec	Standard	Sub-Flowsheet	Process Heat In Total Water for HTSE		Oxygen Product		No	2500 *
31	riigh remperatore occum Lieb	otanadia	Capitionalicer	Electricity Generated		Process Return		140	2000
32				i	wer Cycle In	Power Cycle Out			
33	SC CO2 Brayton	Standard	Sub-Flowsheet	Mal	ke Up Water	Electricity Generate	ed	No	2500 *
34	Efficiency Calcs	Spreadsh	eet					No	500.0 *
35	IHX	Heat Excl	nanger		actor Outlet	1 Cardium In		No	500.0 *
36 37				4		Sodium In Reactor Inlet			
38	Primary Pump	Pump		Primary Pump Pwr				No	500.0 *
39	Secondary Pump	Pump		i —	dium Out	4		No	500.0 *
40	occontrariy r amp	1 amp		Secondary Pump PWR		Dawar Quala In		140	000.0
41 42	T1	Tee		Soc	dium In	Power Cycle In		No	500.0 *
42				Pov	wer Cycle Out	Process Heat In Sodium Out			
44	M1	Mixer			icess Return			No	500.0 *
45									
46									
47 48									
48									
50									
51									
52									
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55									
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60									
61									
62				_					
63	Aspen Technology Inc.	ALLIANOE	Asp	en H'	YSYS Version 7.3 (2	25.0.0.7336)			Page 2 of 28
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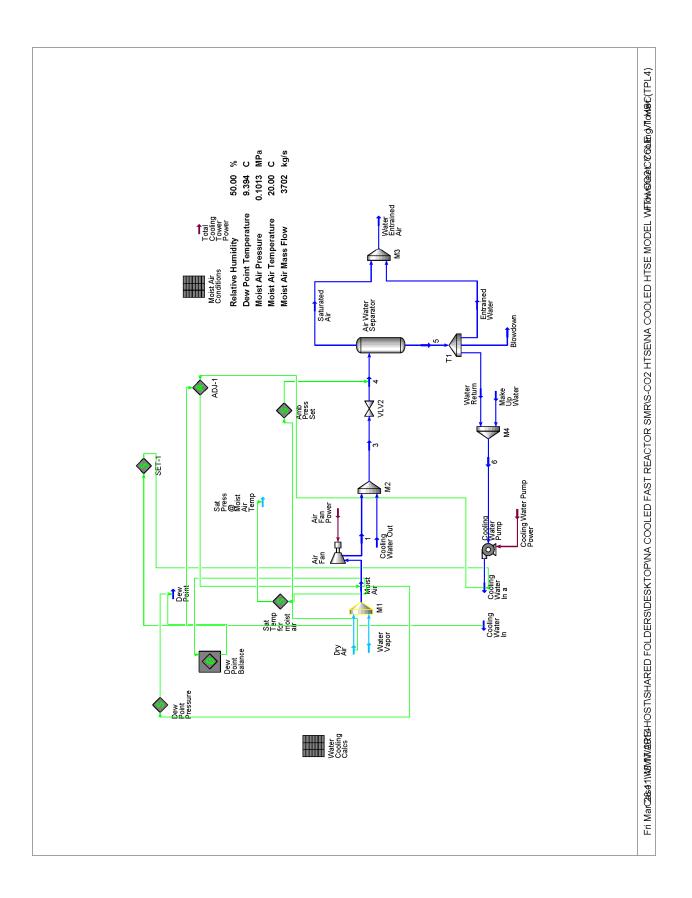


1				Case Name:	NA COOLED HTSE MC	DEL WITH CO2 CYCLE	V1.HSC	
3	aspontach		ENERGY ALLIANCE	Unit Set:	AFR			
4	aspentech	USA		Date/Time:	Fri Mar 28 11:57:05 201	4		
5 6								
7 8	Wo	rkbook:	SC CO2 B	rayton (TPL	1)			
9 10				Material Stream	s	Fluid Pkg: All		
11	Name		Power Cycle In @TPL	Power Cycle Out @TF	IHX Out @TPL1	IHX In @TPL1	Turbine Out@TPL1	
12	Vapour Fraction		0.0000	0.0000	1.0000	1.0000	1.0000	
13	Temperature	(C)	530.0	374.9	510.0	354.9	403.8	
14	Pressure	(MPa)	0.7011	0.6870	19.60	20.00	7.866 *	
15	Molar Flow	(kgmole/h)	1.696e+005	1.696e+005	9.818e+004	9.818e+004	9.818e+004	
16	Mass Flow	(kg/s)	1083	1083	1200	1200	1200	
17	Liquid Volume Flow	(m3/h)	4149	4149	5236	5236	5236	
18	Heat Flow	(MVV)	747.7	518.8	-1.017e+004	-1.040e+004	-1.031e+004	
19	Name		HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1	
20 21	Vapour Fraction		1.0000	1.0000	1.0000	0.0000	0.0000	
21	Temperature	(C) (MDe)	139.3	133.7	74.28	30.56	68.74	
22	Pressure Molar Flow	(MPa) (kgmole/h)	7.709 9.818e+004	20.41 9.818e+004	7.555 9.818e+004	7.404 6.816e+004	20.83 6.816e+004	
23	Mass Flow		9.0100+004 1200	9.0100+004 1200	1200	833.2	833.2	
24	Liquid Volume Flow	(kg/s) (m3/h)	5236	5236	5236	3635	3635	
26	Heat Flow	(ms/n) (MVV)	-1.067e+004	-1.076e+004	-1.077e+004	-7610	-7590	
27	Name	(101 0 0)	From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1 @TPL1	
28	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000	
29	Temperature	(C)	120.2	74.28	74.28	168.3	168.4 *	
30	Pressure	(C) (MPa)	20.41	7.555	7.555	20.41 *	20.41 *	
31	Molar Flow	(kgmole/h)	6.816e+004	6.816e+004	3.002e+004	3.002e+004	3.002e+004 *	
32	Mass Flow	(kg/s)	833.2	833.2	367.0	367.0	367.0	
33	Liquid Volume Flow	(m3/h)	3635	3635	1601	1601	1601	
34	Heat Flow	(MVV)	-7490	-7475	-3293	-3270	-3270	
35	Name	(Cooling Water Out @1	Cooling Water In @TF	Make Up Water @TPL			
36	Vapour Fraction		0.0000	0.0000	0.0000			
37	Temperature	(C)	28.69	25.00 *	20.00			
38	Pressure	(MPa)	0.1015	0.1035	0.1013			
39	Molar Flow	(kgmole/h)	1.705e+006	1.705e+006	1.407e+004			
40	Mass Flow	(kg/s)	8532	8532	70.42			
41	Liquid Volume Flow	(m3/h)	3.078e+004	3.078e+004	254.0			
42	Heat Flow	(MVV)	-1.354e+005	-1.355e+005	-1120			
43 44				Compositions		Fluid Pk	g: All	
45	Name		Power Cycle In @TPL	Power Cycle Out @TF	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1	
46	Comp Mole Frac (H2O)		***	***	***	***	***	
47	Comp Mole Frac (Nitrogen))	***	***	***	***	***	
48	Comp Mole Frac (Oxygen)		***	***	***	***	***	
49	Comp Mole Frac (Hydroger	n)	***	***	***	***	***	
50	Comp Mole Frac (CO2)		***	***	1.0000 *	1.0000	1.0000	
51	Comp Mole Frac (CO)		***	***	***	***	***	
52	Comp Mole Frac (Sodium)		1.0000	1.0000	***	***	***	
53	Comp Mole Frac (Air)		***	***	***	***	***	
54	Name		HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1	
55	Comp Mole Frac (H2O)		***	***	***	***	***	
56	Comp Mole Frac (Nitrogen))	***	***	***	***	***	
57	Comp Mole Frac (Oxygen)		***	***	***	***	***	
58	Comp Mole Frac (Hydroger	า)	***	***	***	***	***	
59	Comp Mole Frac (CO2)		1.0000	1.0000	1.0000	1.0000	1.0000	
60	Comp Mole Frac (CO)		***	***	***	***	***	
61	Comp Mole Frac (Sodium)		***	***	***	***	***	
62	Comp Mole Frac (Air)		***	***	***	***	***	
63	Aspen Technology Inc		Aspen H	YSYS Version 7.3 (25.0.0.7336)		Page 3 of 28	
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1					Case Name:	NA COOLED HTSE MC	DEL WITH	CO2 CYCLE	V1.HSC
2		BATTELLE Burlington,	ENERGY ALLIANC	E	Unit Set:	AFR			
4	aspentech	USA					4		
5 6					Date/Time:	Fri Mar 28 11:57:05 201	4		
7	Work	book:	SC CO2	Bra	vton (TPL	1) (continue	d)		
8					,	.,(,		
9 10				Com	positions (conti	nued)	Fluid Pkg: All		
11	Name		From LTR @TPL1	P	reCooler In @TPL1	Comp 2 In @TPL1	Comp 2 (Out@TPL1	1 @TPL1
12	Comp Mole Frac (H2O)		*	**	***	***		***	***
13	Comp Mole Frac (Nitrogen)		*		***	***		***	***
14	Comp Mole Frac (Oxygen)		*		***	***		***	***
15	Comp Mole Frac (Hydrogen) Comp Mole Frac (CO2)		1.000		1.0000	1.0000		1.0000	1.0000 *
17	Comp Mole Frac (CO2)		*		***	***		***	***
18			*	**	***	***		***	***
19	19 Comp Mole Frac (Air)		*	**	***	***		***	***
20			Cooling Water Out	_	ooling Water In @TF	Make Up Water @TPL			
21	Comp Mole Frac (H2O)		1.000	- 1	1.0000	1.0000			
22	Comp Mole Frac (Nitrogen)		0.000		0.0000	0.0000			
23 24	Comp Mole Frac (Oxygen)		0.000		0.0000	0.0000			
25	Comp Mole Frac (Hydrogen) Comp Mole Frac (CO2)		0.000		0.0000	0.0000			
26	Comp Mole Frac (CO)		0.000		0.0000	0.0000			
27	Comp Mole Frac (Sodium)		*	**	***	***			
28	Comp Mole Frac (Air)		*	**	***	***			
29					Energy Streams			Fluid Pkg	: All
30									
31	Name Heat Flow	(14)40	Turbine Power @1 136		omp 1 Power @TPL 20.87	Comp 2 Power @TPL 22.88	Electricity	y Generated (91.72	Total Cooling Tower P 0.6364
33	Heat FIUW	(MVV)	130	.0		22.00		81.72	0.0304
34					Unit Ops				
35	Operation Name	Ope	ration Type		Feeds	Products		Ignored	Calc Level
36	IHX @TPL1	Heat Exch	anger		r Cycle In @TPL1	Power Cycle Out @	TPL1	No	500.0 *
37					@TPL1	IHX Out @TPL1			
38	Hi Temp Recup @TPL1	Heat Exch	anger		n FLow @TPL1	IHX In @TPL1		No	500.0 *
35 40					ne Out@TPL1 1 Out@TPL1	HTR Out @TPL1 From LTR @TPL1			
41	Low Temp Recup @TPL1	Heat Exch	anger		Dut@TPL1	LTR Out @TPL1		No	500.0 *
42	5 400 OTD 4				ng Water In @TPL1	Cooling Water Out	@TPL1		500.0.1
43	E-100 @TPL1	Heat Exch	anger	PreCo	oler In @TPL1	Comp 1 In @TPL1		No	500.0 *
44	IHX tb dP @TPL1	Set						No	500.0 *
45	IHX sh dP @TPL1	Set						No	500.0 *
46 47	HTR tb dP @TPL1 HTR sh dP @TPL1	Set Set						No No	500.0 * 500.0 *
48	LTR sh dP @TPL1	Set						No	500.0 *
49	LTR tb dP @TPL1	Set						No	500.0 *
50	Pre Cooler tb dP @TPL1	Set						No	500.0 *
51	Pre Cooler sh dP @TPL1	Set						No	500.0 *
52	SET-1@TPL1	Set						No	500.0 *
53 64	Turbine @TPL1	Expander		IHX C	ut@TPL1	Turbine Out @TPL		No	500.0 *
J4						Turbine Power @TI	1		
55									
55 56									
56									
56 57 58 59									
56 57 58 59 60									
56 57 58 60 61									
56 57 58 59 60	Aspen Technology Inc.		Asn	an HVG	SYS Version 7.3 (2	25.0.0.7336			Page 4 of 28

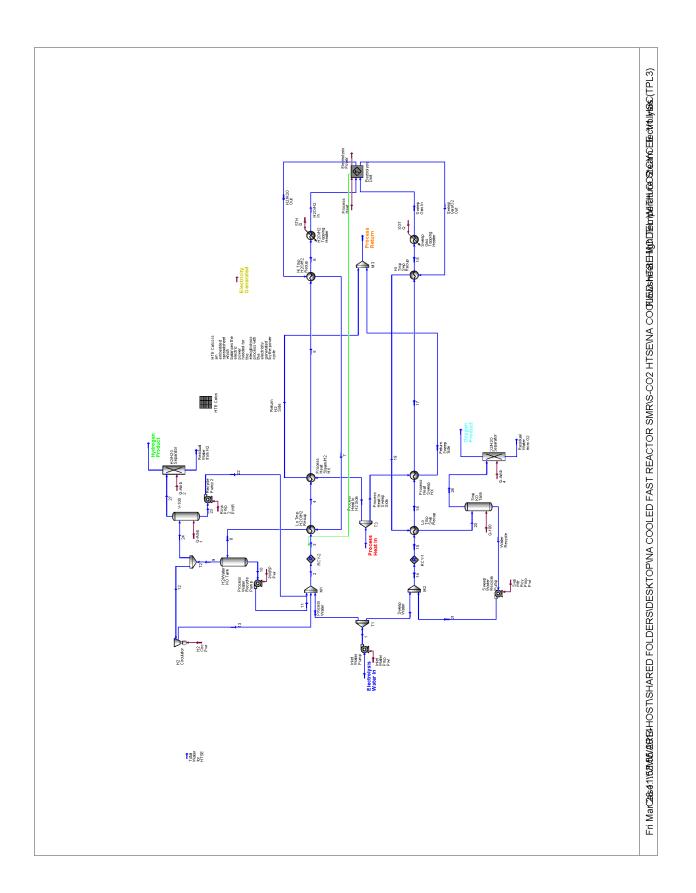
1		BATTELLE ENERGY ALLIANCE		Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC					
2 3 4	entech	Burlington, M		-	Unit Set:	AF	R		
4 5		USA			Date/Time:	Fr	i Mar 28 11:57:05 2014		
6		da a - I-	60.000	D			(
7 8	VVOrk	(DOOK:	SC CO2	Bray	yton (TPI	L1)	(continued)		
9 10				Uni	it Ops (contin	nued	l)		
11	Operation Name	Opera	ation Type		Feeds		Products	Ignored	Calc Level
12 13									
14									
15 16									
17			-						
18 19									
20									
21 22									
23									
24 25									
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27 28									
22 23 24 25 26 27 28 29 30 31 32									
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59 60									
61									
62 63	Aspon Tochnology In-		۸		YS Version 7.3	(25	0 0 7336)		Dago 5 of 20
03	Aspen Technology Inc. Licensed to: BATTELLE ENERGY		ASPE	11113	TO VEISION 7.3	ι <u></u> 20.	0.0.1330	*	Page 5 of 28 Specified by user.

1	~			Case Name:	Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC					
3		aspentech Burlington, M	NERGY ALLIANCE A	Unit Set:	Unit Set: AFR					
4 5		USA		Date/Time:	Date/Time: Fri Mar 28 11:57:05 2014					
6										
7 8		Spreadshe	et: Brayt	on Cycle C	alcs @TPL1		Units Set: NuScale2			
9				CONNECTI	ONS					
10 11										
12										
13 14	Cel A1		Power@TPL1	Power	Variable Description		Value 136.8 MVV			
15	A2			Power			20.87 MVV			
16	A3			Power			22.88 MVV			
17	A4			Power			0.6364 MVV			
18	A5	Energy Stream: Primary F	Pump Pwr I	Power			0.4345 MVV			
19	A6	Energy Stream: Seconda	ry Pump PWR	Power			0.2606 MVV			
20	A8	Energy Stream: Reactor I	Heat I	Heat Flow			250.0 MVV			
21	A10	Tee: T1		Flow Ratio (Flow Ratio	_1)		0.9132			
22 23			Expor	ted Variables' F	ormula Results					
24	Cel				Variable Description		Value			
25	A7	Electricity Generated @TPL1		Power			91.72 MW			
26 27				PARAMETI	ERS					
28 29				Exportable Va	riables					
30	Cel	Visible Name	Variable	Description	Variable Type	Value				
31	A7	A7: Power		Power			91.72 MW			
32	A9	A9: Thermal Efficiency	-	Thermal Efficiency	Percent	40.17				
33 34				User Varial	bles					
35 36				FORMUL	AS					
37	Cel			Formula			Result			
38	A7	=A1-A2-A3-A4-A5-A6					91.72 MVV			
39	A9	=A7/(A8*A10)*100					40.17			
40 41				Spreadsh	eet					
42		А		В	С		D			
43	1	136.8 MVV *								
44	2	20.87 MVV *								
45	3	22.88 MVV *								
46	4	0.6364 MVV *								
47	5	0.4345 MVV *								
48 49	6 7	0.2606 MVV * 91.72 MVV *								
50	8	250.0 MVV *								
51	9	40.17 *								
52	10	0.9132 *								
53				I						
54										
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58										
55 56 57 58 59 60										
60										
61										
62										
63		en Technology Inc.	Asper	1 HYSYS Version 7	7.3 (25.0.0.7336)		Page 6 of 28			
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1	Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC									
2			E ENERGY ALLIANCE	Linit Set						
4	Caspentech	USA	. 100							
5				Date/Time:	Fri Mar 28 11:57:05 201	4				
6	Mo	rkhook								
8	Workbook: Cooling Tower (TPL4)									
9				Material Stream	IS	Fluid Pk	j: All			
10 11	Name		Cooling Water Out @]	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air			
12	Vapour Fraction		0.0000	0.0000			1.0000 *			
13	Temperature	(C)	28.69	25.00			20.00			
14	Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	2.339e-003			
15	Molar Flow	(kgmole/h)	1.705e+006	1.705e+006	4.586e+005	5336				
16	Mass Flow	(kg/s)	8532	8532	3675	26.70				
17	Liquid Volume Flow	(m3/h)	3.078e+004	3.078e+004	1.530e+004	96.33				
18	Heat Flow	(MVV)	-1.354e+005	-1.355e+005						
19	Name		1 @TPL4	3 @TPL4	Dew Point @TPL4	4@TPL4	Saturated Air @TPL4			
20	Vapour Fraction		1.0000	0.2183	1.0000 *	0.2183	1.0000			
21	Temperature	(C)	20.16	25.05	9.394	25.04	25.04			
22	Pressure	(MPa)	0.1015	0.1015	0.1013	0.1013	0.1013			
23	Molar Flow	(kgmole/h)	4.640e+005	2.169e+006	4.640e+005	2.169e+006	4.734e+005			
24	Mass Flow	(kg/s)	3702	1.223e+004	3702	1.223e+004	3749			
25	Liquid Volume Flow	(m3/h)	1.539e+004	4.617e+004	1.539e+004	4.617e+004	1.556e+004			
26	Heat Flow	(MVV)	-377.8	-1.358e+005	-418.4	-1.358e+005	-992.5			
27	Name		5 @TPL4	Entrained Water @TP	Blowdown @TPL4	Water Return @TPL4	Water Entrained Air @			
28	Vapour Fraction		0.0000	0.0000	0.0000	0.000	0.9964			
29	Temperature	(C)	25.04	25.04	25.04	25.04	25.04			
30	Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013			
31	Molar Flow	(kgmole/h)	1.695e+006	1705	2951	1.691e+006	4.751e+005			
32	Mass Flow	(kg/s)	8484	8.532	14.77	8461	3758			
33	Liquid Volume Flow	(m3/h)	3.061e+004	30.78	53.28	3.052e+004	1.559e+004			
34	Heat Flow	(MVV)	-1.348e+005	-135.5	-234.6	-1.344e+005	-1128			
35	Name		Make Up Water @TPL	Cooling Water In a @1	6 @TPL4	Moist Air @TPL4				
36 37	Vapour Fraction	(0)	0.0000 20.00 *	0.0000 25.00	0.0000 25.00	1.0000				
38	Temperature Pressure	(C)		0.1035	0.1013	20.00 * 0.1013 *				
39	Molar Flow	(MPa) (kgmole/h)	0.1013 1.407e+004	1.705e+006	1.705e+006	4.640e+005				
40	Mass Flow	(kg/lole/h) (kg/s)	70.42	8532	8532	3702 *				
40	Liquid Volume Flow	(r.g/s) (m3/h)	254.0	3.078e+004	3.078e+004	1.539e+004				
42	Heat Flow	(MVV)	-1120	-1.355e+005	-1.355e+005	-378.5				
43	Troat Thom	(mrry	1120							
44				Compositions		Fluid Pkg	g: All			
45	Name		Cooling Water Out @1	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air			
46	Comp Mole Frac (H2O)		1.0000	1.0000 *	0.0000 *	1.0000 *	1.0000 *			
47	Comp Mole Frac (Nitrogen)	1	0.0000	0.0000 *	0.7900 *	* 0.000.0	***			
48	Comp Mole Frac (Oxygen)		0.0000	0.0000 *	0.2100 *	* 0.000.0	***			
49	Comp Mole Frac (Hydroger	ר)	0.0000	0.0000 *	0.0000 *	* 0.000.0	***			
50	Comp Mole Frac (CO2)		0.0000	0.0000 *	0.0000 *	* 0.0000	***			
51	Comp Mole Frac (CO)		0.0000	0.0000 *	0.0000 *	0.0000 *	***			
52	Comp Mole Frac (Sodium)									
53	Comp Mole Frac (Air)		1 @TDI 4	1.0TDI 4	***	4 @ TDI 4	Contract Alia @TDL4			
54 55	Name Comp Mole Erac (H2O)		1 @TPL4 0.0115	3 @TPL4 0.7885	Dew Point @TPL4 0.0115	4@TPL4 0.7885	Saturated Air @TPL4 0.0312			
55 56	Comp Mole Frac (H2O) Comp Mole Frac (Nitrogen)		0.7809	0.7885	0.7809	0.7885	0.7654			
57	Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		0.2076	0.0444	0.7809	0.0444	0.2035			
58	Comp Mole Frac (Oxyger) Comp Mole Frac (Hydroger	2)	0.0000	0.0444	0.2078	0.0444	0.2035			
59	Comp Mole Frac (Hydrogen Comp Mole Frac (CO2)	9	0.0000	0.0000	0.0000	0.0000	0.0000			
60	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000			
61	Comp Mole Frac (CO)		***	***	***	***	***			
62	Comp Mole Frac (Soulari) Comp Mole Frac (Air)		***	***	***	***	***			
63	Aspen Technology Inc.		Aspen F	YSYS Version 7.3 ()	25.0.0.7336		Page 7 of 28			
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1					Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC						
2 3	(E ENERGY ALLIANCE								
3	aspentech	Burlington, USA	MA		Unit Set:	AFR					
5			Date/Time: Fri Mar 28 11:57:05			Fri Mar 28 11:57:05 201	114				
6				-							
7	VVork	book:	Cooling	Iov	ver (TPL4)	(continued)				
9				Cam	positions (conti	nuod)		Fluid Pkg	r All		
10	N				· · ·						
11	Name Comp Mole Frac (H2O)		5 @TPL4 1.00	- 1	ntrained Water @TP 1.0000	Blowdown @TPL4 1.0000	vvater Re	turn @TPL4 1.0000	Water Entrained Air @ 0.0347		
13	Comp Mole Frac (Nitrogen)		0.00		0.0000	0.0000		0.0000	0.7626		
14	Comp Mole Frac (Oxygen)		0.00	00	0.0000	0.0000		0.0000	0.2027		
15	Comp Mole Frac (Hydrogen)		0.00	00	0.0000	0.0000		0.0000	0.0000		
16	Comp Mole Frac (CO2)		0.00	00	0.0000	0.0000		0.0000	0.0000		
17	Comp Mole Frac (CO)		0.00		0.0000	0.0000		0.0000	0.000		
18	Comp Mole Frac (Sodium)			**	***	***		***	***		
19	Comp Mole Frac (Air)			**	***	***		***	***		
20 21	Name		Make Up Water @		ooling Water In a @T	6 @TPL4	Moist Air				
21	Comp Mole Frac (H2O)		1.00		1.0000	1.0000		0.0115			
22	Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		0.00		0.0000	0.0000		0.7809			
24	Comp Mole Frac (Oxygen)		0.00		0.0000	0.0000		0.0000			
25	Comp Mole Frac (CO2)		0.00		0.0000	0.0000		0.0000			
26	Comp Mole Frac (CO)		0.00		0.0000	0.0000		0.0000			
27	Comp Mole Frac (Sodium)		-	**	***	***		***			
28	Comp Mole Frac (Air)		1	**	***	***		***			
29					Energy Streams Fluid Pkg:						
30									j: All		
31	Name		Air Fan Power @		ooling Water Pump F	Total Cooling Tower P					
32	Heat Flow	(MVV)	0.61	18	2.459e-002	0.6364					
34					Unit Ops						
35	Operation Name	Ope	ration Type		Feeds	Products		Ignored	Calc Level		
36	M1 @TPL4	Mixer		Dry Ai	r@TPL4	Moist Air @TPL4		No	500.0 *		
37	witten en	MILAGI			Vapor @TPL4			140			
38	M2 @TPL4	Mixer		1@T		3 @TPL4		No	500.0 *		
39	-				ng Water Out @TPL4	Attack Takes is a d. 0.					
40	M3 @TPL4	Mixer			ated Air @TPL4 ned Water @TPL4	Water Entrained Air @TPL		No	500.0 *		
41					Return @TPL4	6 @TPL4		No			
43	M4 @TPL4	Mixer			Up Water @TPL4	0001121			500.0 *		
44	Moist Air Conditions @TPL4	Spreadshe	eet		<u> </u>			No	500.0 *		
45	Water Cooling Calcs @TPL4	Spreadshe	et					No	500.0 *		
46	Sat Temp for moist air @TPL4	Set						No	500.0 *		
47	Dew Point Pressure @TPL4	Set						No	500.0 *		
48	Amb Press Set @TPL4	Set						No	500.0 *		
49 50						+					
50						_					
52						1					
53											
54											
55											
56											
57											
58 59											
59 60											
							I				
61 62											
61	Aspen Technology Inc.		Asp	en HYS	SYS Version 7.3 (2	25.0.0.7336)			Page 8 of 28 * Specified by user.		



1				Case Name:	Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC					
2 3	aspentech	Burlington,	ENERGY ALLIANCE MA	Unit Set:	AFR					
4		USA		Date/Time:	Fri Mar 28 11:57:05 201	4				
5	5									
7	Wo	rkbook:	High Temp	perature Ste	am Electrol	ysis (TPL3)				
9 10				Material Stream	s	Fluid Pkg: All				
11	Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3			
12	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000			
13	Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6			
14	Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042			
15	Molar Flow	(kgmole/h)	3245	3245	1299	650.1	3245			
16 17	Mass Flow	(kg/s)	11.91	6.144	9.023	3.255	6.144			
17	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	69.11 -128.3	83.13 -43.10	29.99 -33.90	-38.51	83.13 -51.75			
19	Name	(101 V V)	-128.3 6 @TPL3	5@TPL3	-33.80 18 @TPL3	19 @TPL3	17@TPL3			
20	Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000			
21	Temperature	(C)	757.2	510.0 *	794.4	641.3	510.0 *			
22	Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482			
23	Molar Flow	(kgmole/h)	3245	3245	650.1	1299	650.1			
24	Mass Flow	(kg/s)	11.91	11.91	3.255	9.023	3.255			
25	Liquid Volume Flow	(m3/h)	69.11	69.11	11.74	29.99	11.74			
26	Heat Flow	(MVV)	-129.9	-138.5	-38.56	-36.13	-40.79			
27	Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3			
28	Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.6276			
29	Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5			
30	Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634			
31	Molar Flow	(kgmole/h)	1.442e+004	1.442e+004	1692	1692	3245			
32	Mass Flow	(kg/s)	92.11	92.11	10.80	10.80	11.91			
33	Liquid Volume Flow	(m3/h)	352.9	352.9	41.39	41.39	69.11			
34 35	Heat Flow Name	(M <i>\</i> V)	63.59 20 @TPL3	44.12 26 @TPL3	7.459 Water Recycle @TPL3	5.175 Sweep Water @TPL3	-158.0 21@TPL3			
36	Vapour Fraction		0.8417	1.0000	0.0000	0.0000	21@1FL3			
37	Temperature	(C)	222.7	100.0 *	100.0	21.77	100.1			
38	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790			
39	Molar Flow	(kgmole/h)	1299	662.6	636.4	13.64	636.4			
40	Mass Flow	(kg/s)	9.023	5.836	3.187	6.826e-002	3.187			
41	Liquid Volume Flow	(m3/h)	29.99	18.50	11.49	0.2462	11.49			
42	Heat Flow	(MW)	-43.64	-0.5882	-49.50	-1.085	-49.50			
43	Name		14 @TPL3	15@TPL3	16 @TPL3	8 @TPL3	9 @TPL3			
44	Vapour Fraction		0.0000	0.0000	0.9076	0.7769	1.0000			
45	Temperature	(C)	98.49	98.46 *	290.8	158.5	158.5			
46	Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901			
47	Molar Flow	(kgmole/h)	650.1	650.1	650.1	3245	2521			
48 49	Mass Flow Liquid Volume Flow	(kg/s)	3.255	3.255 *	3.255	6.144	2.524			
49 50	Liquid Volume Flow Heat Flow	(m3/h) (MVV)	-50.58	-50.58	11.74 _43.07		70.05			
51	Name	(m v v)	-50.56 10 @TPL3	-50.58 12@TPL3	24 @TPL3	13 @TPL3	-14.10 11@TPL3			
52	Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000			
53	Temperature	(C)	158.5	158.5	158.5	178.6	158.6			
54	Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790			
55	Molar Flow	(kgmole/h)	724.0	1080	1441	1080	724.0			
56	Mass Flow	(kg/s)	3.620	1.082	1.443	1.082	3.620			
57	Liquid Volume Flow	(m3/h)	13.08	30.01	40.04	30.01	13.08			
58	Heat Flow	(MVV)	-55.35	-6.065	-8.091	-5.886	-55.34			
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