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

March 2014

The INL is a
U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance

Idaho National Laboratory

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

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

March 2014

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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

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

INL/EXT-14-31642

March 2014

Approved by:

Shannon Bragg-Sitton Project Manager	3/28/14 Date
Richard D. Boardman Approving Manager	3/28/14 Date

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-CO_2 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.

CONTENTS

FIGURES

TABLES

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.

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

AFR-100 Product	Product Description
Reactor Conditions	
Thermal Energy Rating	250 MW_t
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 MW_e Net AC or DC Generated by Rankine or Supercritical carbon dioxide Brayton power cycle with thermal efficiency > 40%

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-CO_2) 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 $\dot{Q}_H$ and $\dot{Q}_L$ represent the heat flow from the high temperature source and the low temperature sink, respectively:

$$\dot{W} = \dot{Q}_H - \dot{Q}_L \tag{2}$$

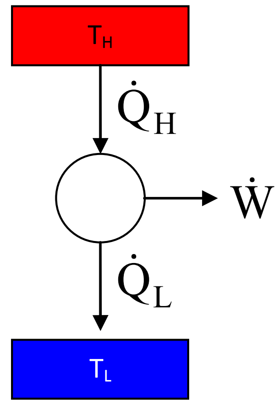


Figure 1. Heat engine between hot source and cold sink.

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:

$$\eta_{th} = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H} \tag{3}$$

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:

$$\eta_{Carnot} = \frac{T_H - T_L}{T_H} \tag{4}$$

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.

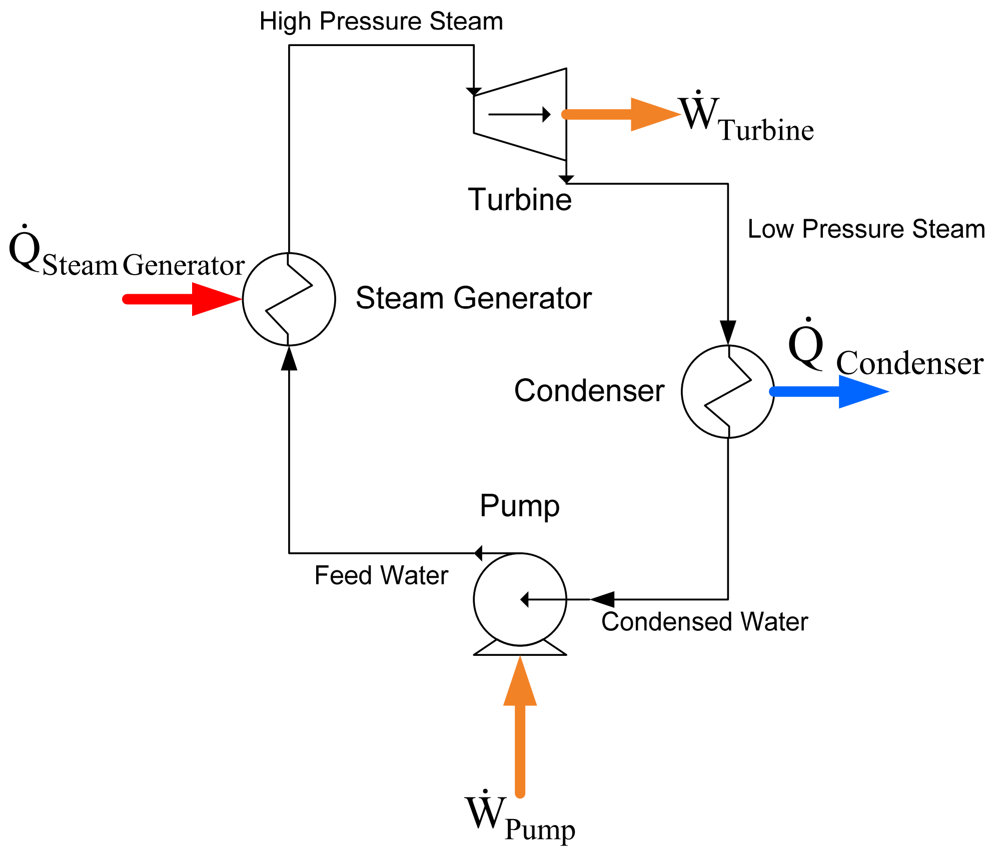


Figure 2. Basic Rankine steam cycle.

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:

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

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:

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

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.

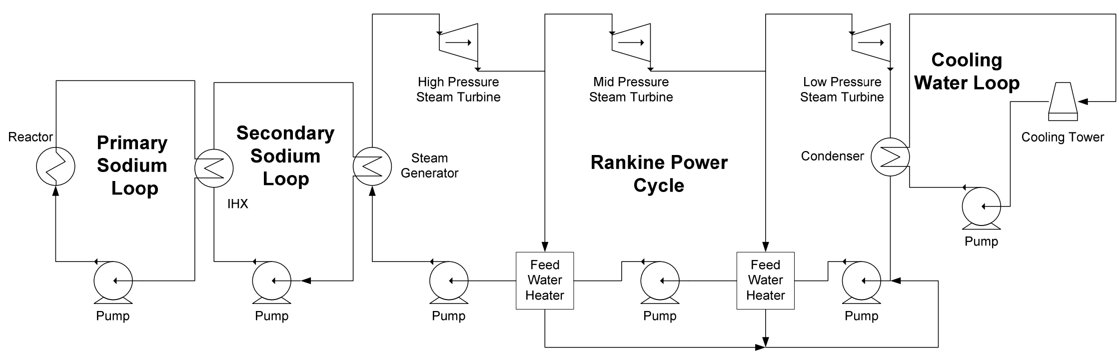


Figure 3. Rankine steam cycle with feed water heaters.

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.

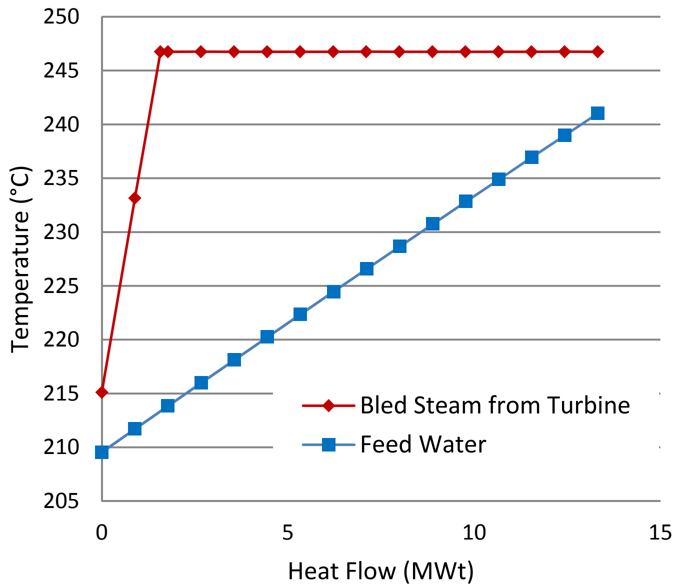


Figure 4. Typical temperature profile for an optimized feed water heater.

2.1.3 Supercritical Carbon Dioxide Modified Brayton Gas Cycle (S-CO_2)

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).

$$\eta_{th} = \frac{\dot{W}_{Turbine} - \dot{W}_{Compressor}}{\dot{Q}_{Gas\,Heater}} \tag{7}$$

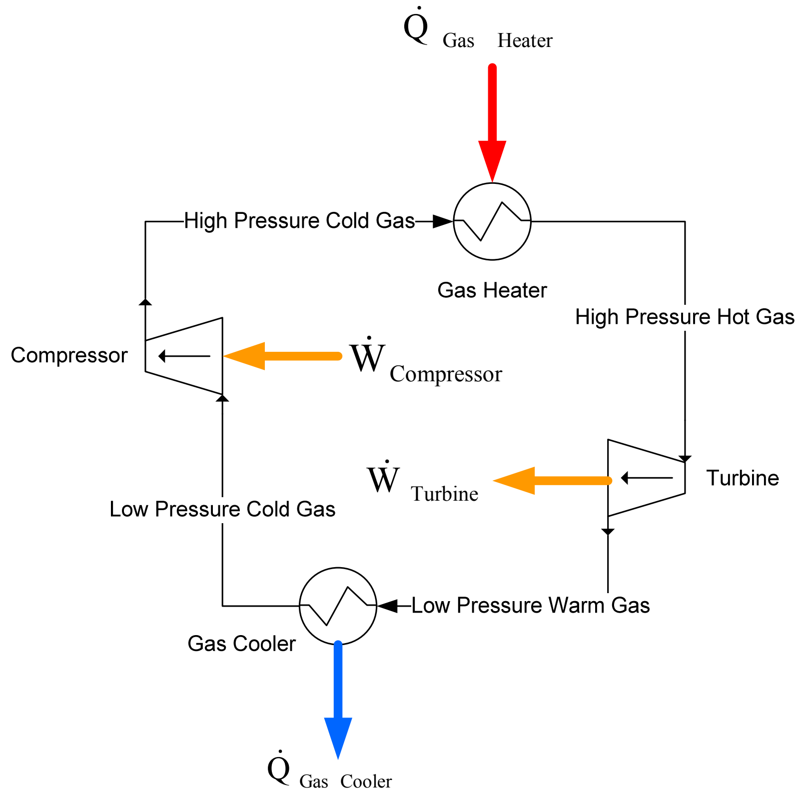


Figure 5. Simple Brayton cycle.

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 CO_2. 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-CO_2 cycle as shown in Figure 6 is described by Eq.8.

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

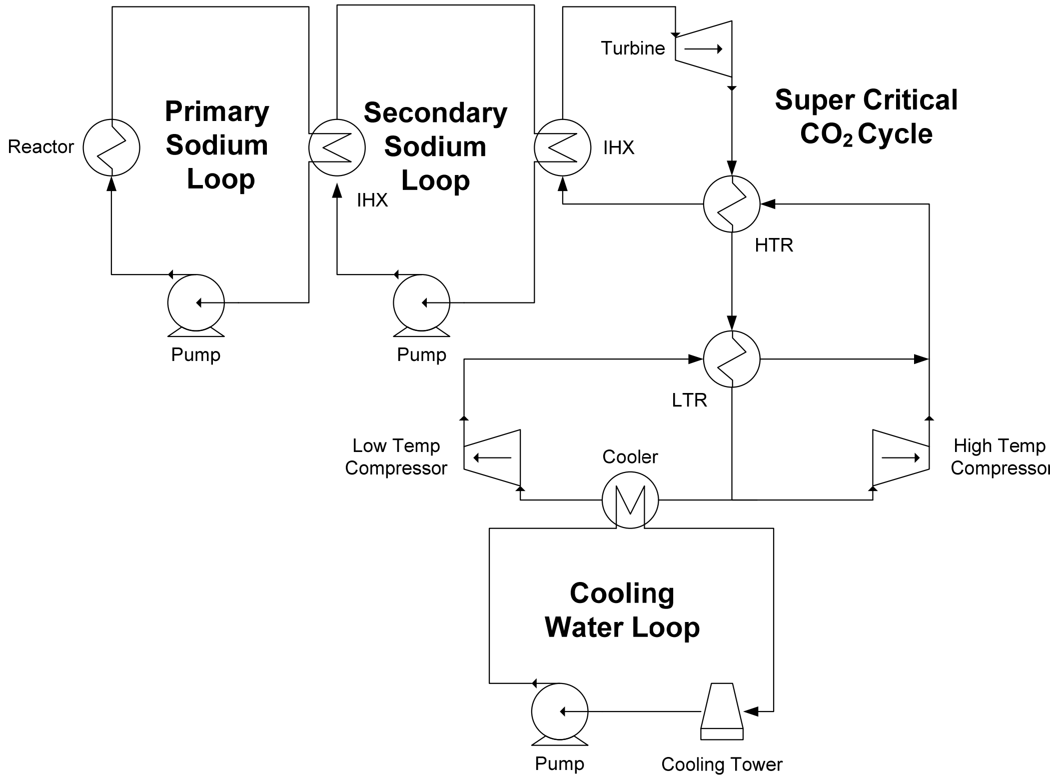


Figure 6. Supercritical CO_2 cycle.

The S-CO_2 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 CO_2 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 CO_2 temperatures. The process model developed for this study is based on the Argonne National Laboratory modelling work of the S-CO_2 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-CO_2 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.

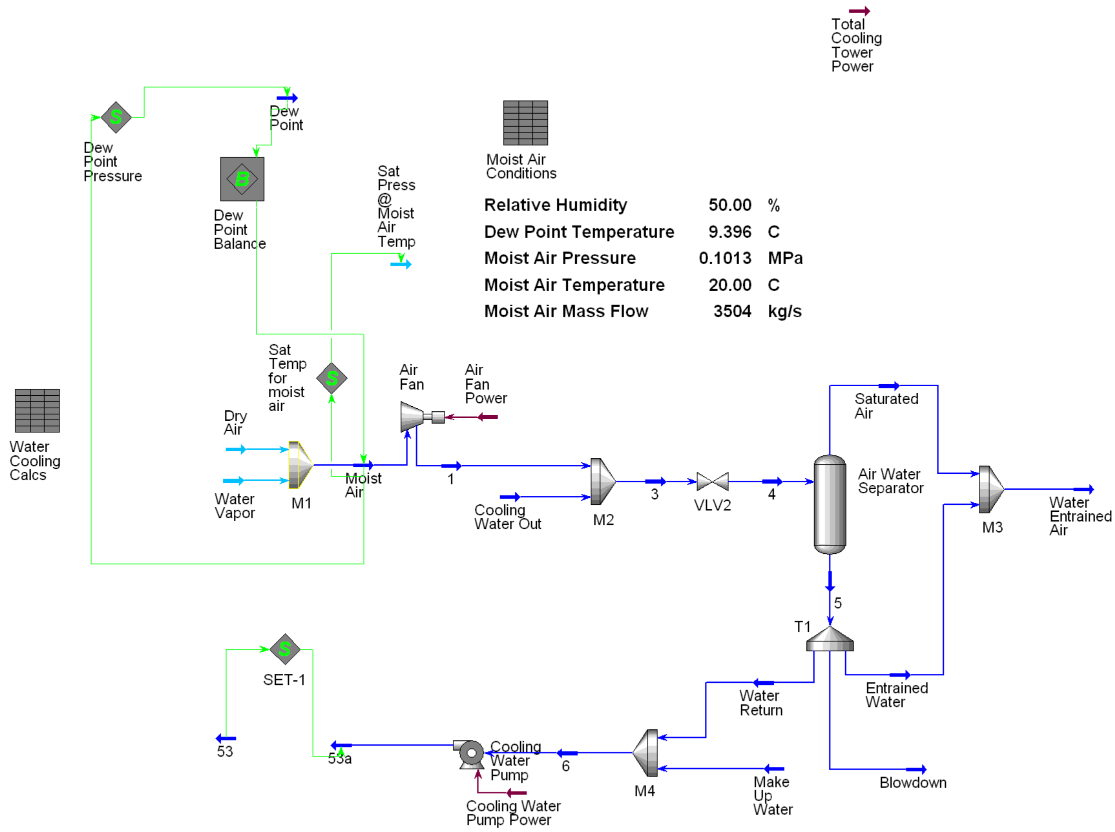


Figure 7. Water cooling tower process flow diagram.

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-CO_2 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-CO_2 cycle is constrained by both the reactor outlet and inlet temperatures. Another analysis was performed in which the inlet temperature into the CO_2 side of the IHX was allowed to increase, while keeping the IHX outlet CO_2 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 CO_2 side as a function of the CO_2 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. The temperature 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.

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

	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

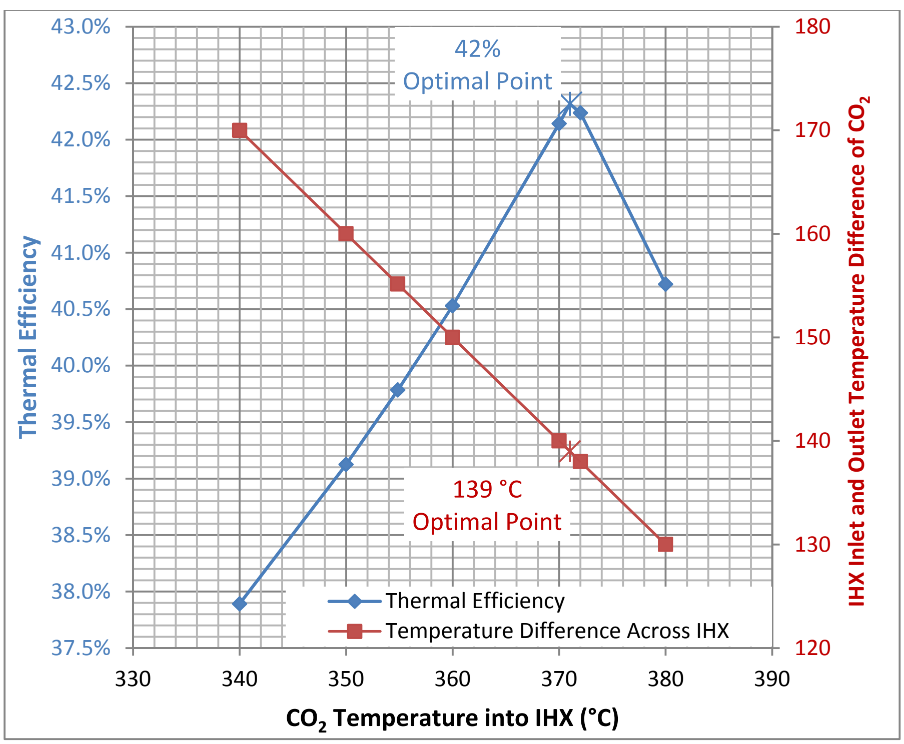


Figure 8. Thermal efficiency of S-CO_2 cycle as a function of IHX temperature difference of inlet and outlet CO_2

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.

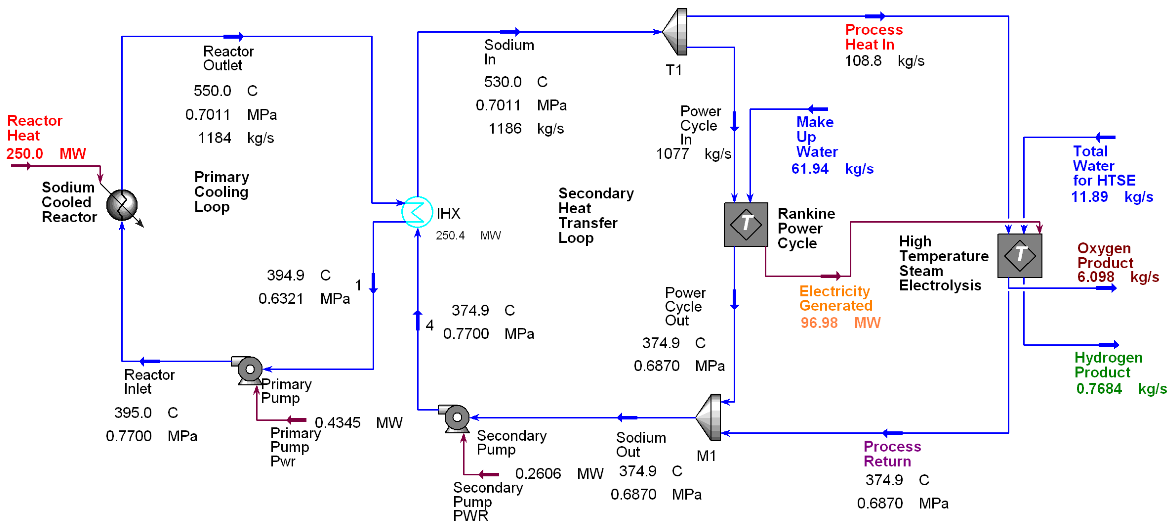


Figure 9. Process flow diagram of AFR-100/HTSE Integration

Table 3. HTSE electrolysis cell parameters

	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

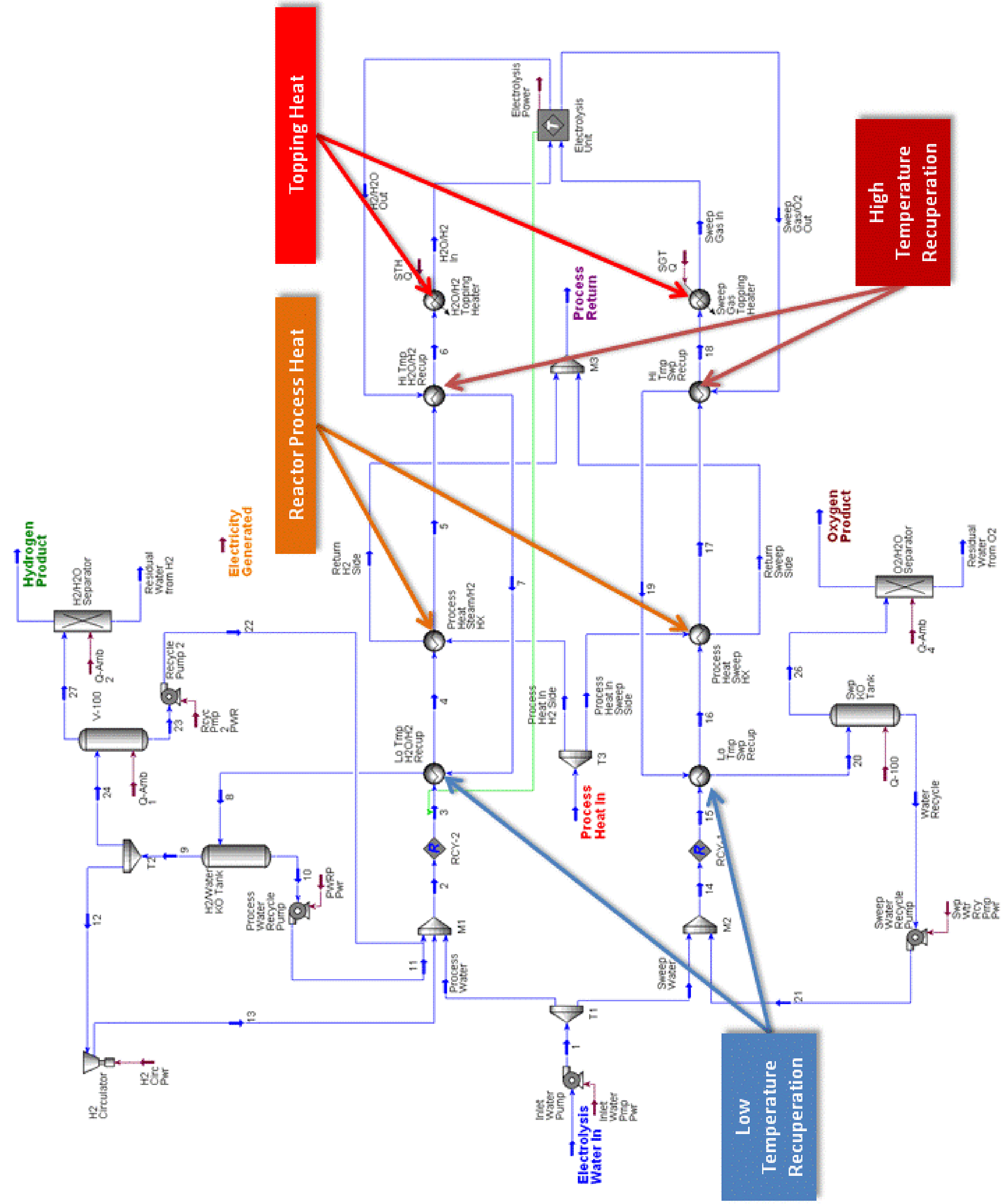


Figure 10. HTSE heat integration process flow diagram.

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 ~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.

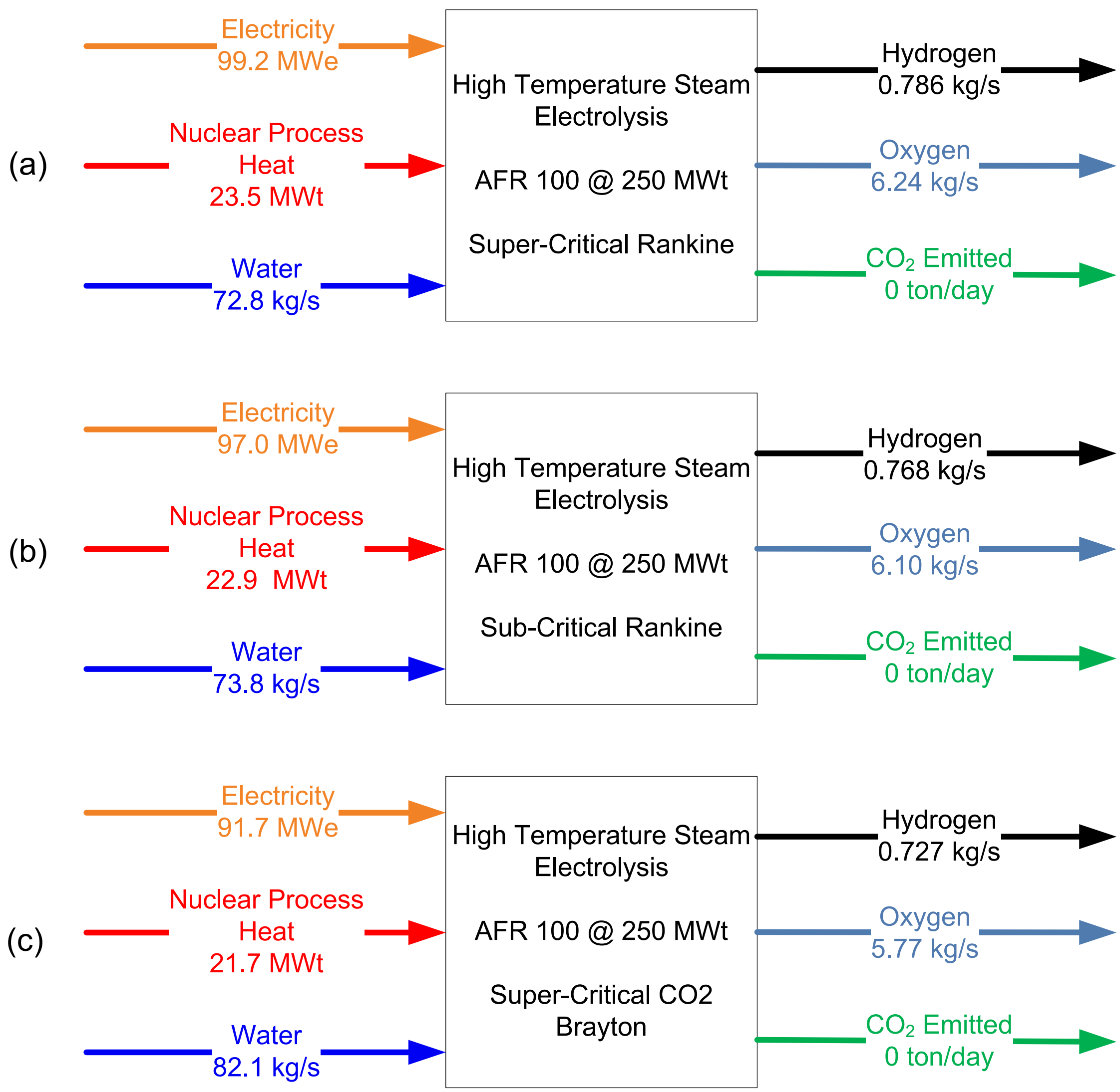


Figure 11. General energy and product flows for AFR-100 integration with HTSE using the analyzed power conversion cycles: (a) Supercritical Rankine, (b) Subcritical Rankine and (c) Supercritical CO_2 Brayton.

Table 4. Hydrogen production summary.

	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

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.

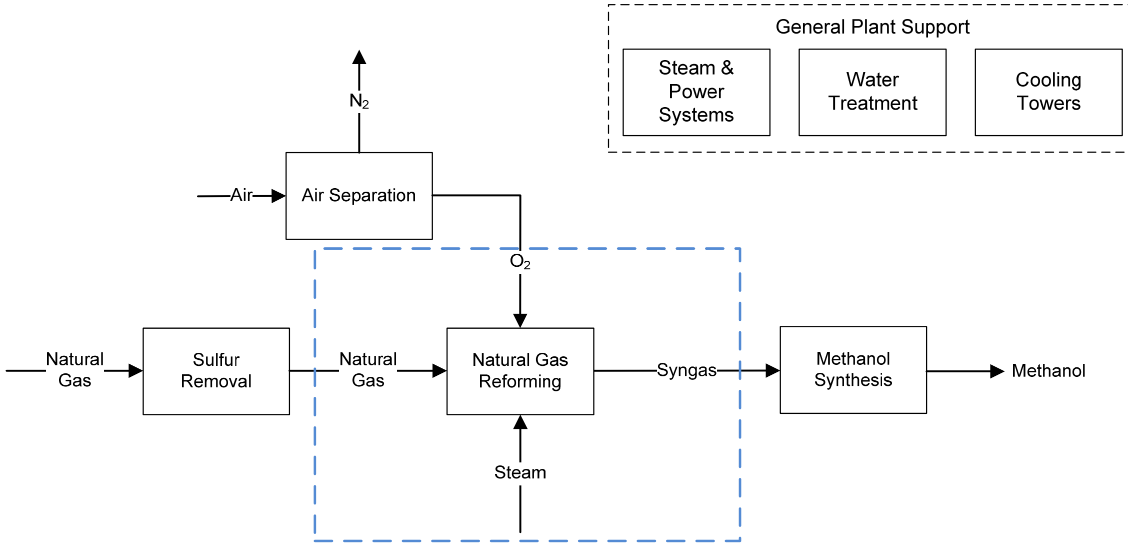


Figure 12. Steps for converting natural gas to methanol. The center section of the diagram (outlined in blue) is further described in Figure 13.

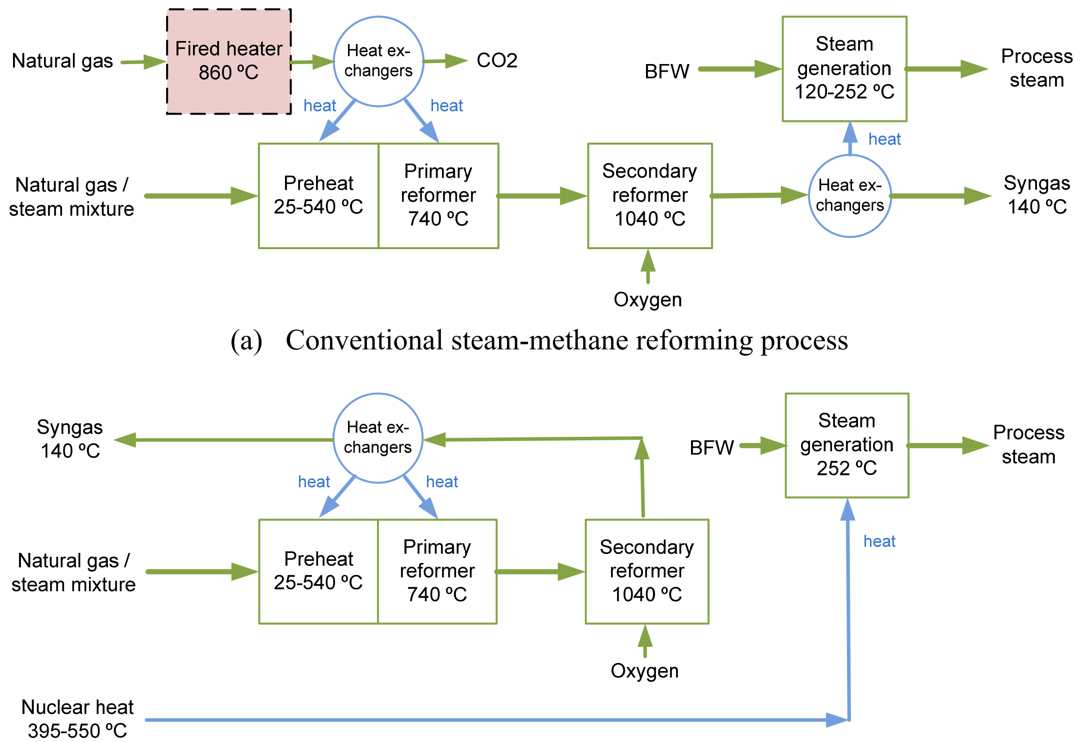
A synthesis gas mixture (or syngas) is adjusted to achieve a molar ratio (M) of 2.10, as calculated by the following expression:

$$M = (H_2\text{-}CO_2)/(CO + CO_2).$$

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 cost-benefit 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 sodium-cooled 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 market-requested 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 inflation-adjusting 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.

Table 5. Standard 15-year MACRS depreciation schedule.

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

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).

Table 6. Assumed Economic Input Parameters used in Financial Analysis

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 (nuclear and chemical)	90%

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.

Table 8. Capital cost estimates for chemical plant components.

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**

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 Generation 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.

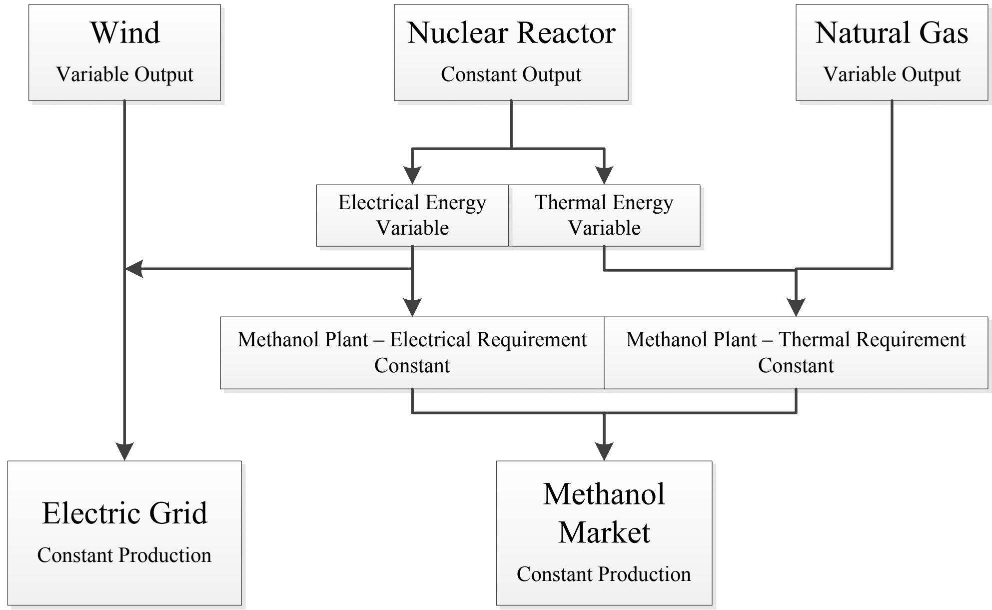


Figure 14. MIMO nuclear hybrid energy system depicting wind energy and methanol production integration.

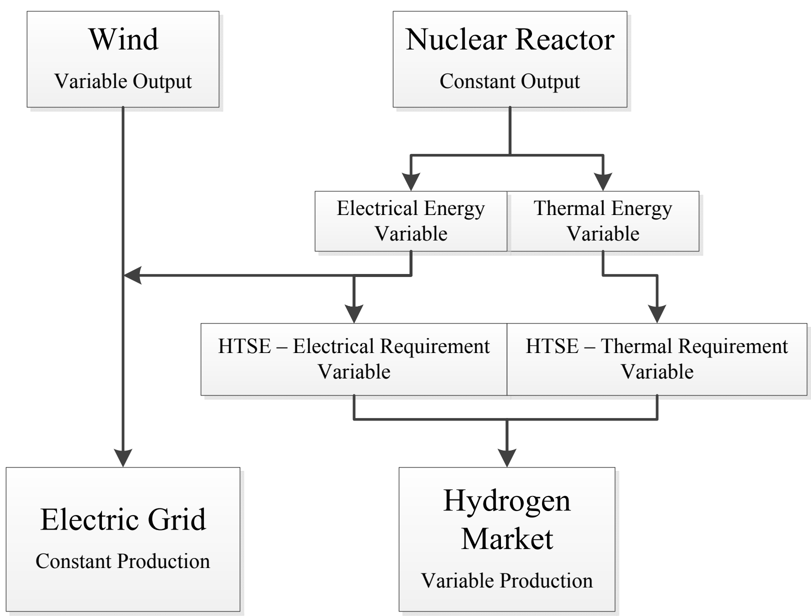


Figure 15. MIMO nuclear hybrid energy system depicting wind energy and hydrogen production integration.

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.

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.

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 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 presented in Section 2.2 of the current report. "Derived" corresponds to the AFR/HTSE plant size used for 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.

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

Case #	**Integrated Subsystems Note: All configurations include the AFR-100 and Electricity Production**			**Subsystems Included in Capital Cost**	**Subsystems Included in Revenue**	**Price of Electricity (¢/kW-h)**	**Calculated IRR (%)**
	Wind	HTSE	Methanol				
1a*	--	--	--	N	N	12	4.9
1b*	--	--	--	N	N	12	0.37
2a	--	--	--	N	N	8	-1.68
2b	--	--	--	N	N	10	2.04
2c	--	--	--	N	N	12	4.9
2d	--	--	--	N	N	14	7.31
2e	--	--	--	N	N	16	9.47
3a‡	--	--	--	N	N	12	4.9
3b‡	--	--	--	N	N	12	8.10
3c‡	--	--	--	N	N	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	M	M	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

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.

¢Cases 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.

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

Case #	Price of Electricity (¢/kW-h)	Subsystems Included in Revenue (MWe)		Subsystems Included in Capital Cost (Yes or No)		Calculated CO_2 Production (MT/day)	Calculated IRR (%)
		Nuclear	Wind	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

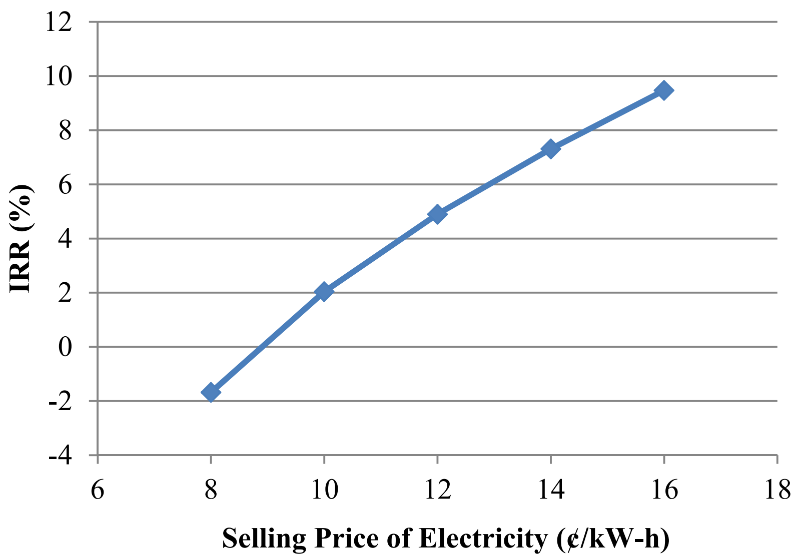


Figure 16. Results from Case 2 evaluations, indicating the variation in the IRR as a function of electricity price for Single-Input/Single-Output cases (nuclear to electricity only).

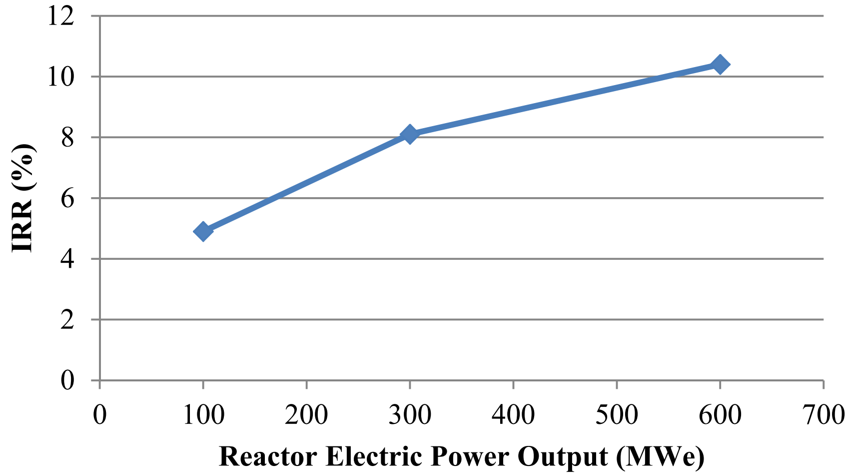


Figure 17. Results from Case 3 evaluations, demonstrating the increased IRR for larger single-unit nuclear plants (note that these results do not translate directly to the build of multiple lower power units to achieve the same total electric power).

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 (¢/kW-h)	Subsystems Included in Revenue			Subsystems Included in Capital Cost			Calculated CO_2 Production (MT/day)	Calculated IRR (%)
		N (MWe)	W (MWe)	M (MT/day)	N	W	M		
4a	12	70	30	0	Yes	Yes	No	433	4.92

N = Nuclear, W = Wind, M = Methanol

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.

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

Case #	Price of Electricity (¢/kW-h)	Subsystems Included in Revenue			Subsystems Included in Capital Cost (Yes or No)			Calculated CO_2 Production (MT/day)	Calculated IRR (%)
		N (MWe)	W (MWe)	M (MT/day)	N	W	M		
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

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.

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.

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 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 (¢/kW-h)**	**Revenue Contribution through Production**			**Capital Cost Contribution (Yes or No)**			**Calculated CO_2 Production (MT/day**	**Calculated IRR (%)**
		N (MWe)	**W (MWe)**	**H (MT/day)**	**N**	**W**	**H**		
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

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.

	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 reactor 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

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-CO_2 at 40.2%
- The Rankine cycles have the lowest pressure at the condenser (7.4 kPa), which will necessitate large equipment. The S-CO_2 system will, in general, have higher pressures throughout the cycle, reducing the physical equipment size.
- The S-CO_2 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 CO_2 emissions relative to standard methanol production methods. HTSE offsets CO_2 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 gas-fired burners to supplement nuclear-generated heat, and

d) Turn-down capability of the SMR in circumstances where the chemical plant is off-line 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 CO_2 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

Aspen Technology Inc. (1995). *Aspen HYSYS V7.3* . Aspen Technology Inc.

Boardman, C. (n.d.). Economic Assessment of S-PRISM Including Development and Generating Costs. *Proceedings of 9th International Conference on Nuclear Engineering (ICONE-9).* Nice, France: ICONE.

Bragg-Sitton, S., Boardman, R., McKellar, M., Garcia, H., Wood, R., Sabharwall, P., et al. (2013). *Value Proposition for Load-Following Small Modular Reactor Hybrid Energy Systems, INL/EXT-13-29298.* Idaho Falls: Idaho National Laboratory.

Chang, Y., Finck, P., Grandy, C., & Sienicki, J. (2006). *Advanced Burner Test Reactor Preconceptual Design Report, ANL-ABR-1 (ANL-AFCI-173).* Argonne: Argonne National Laboratory, Nuclear Engineering Division.

Delene, J., Williams, K., & Shapiro, B. (1988). *A Reference Data Base for Nuclear and Coal-fired Powerplant Power Generation Cost Analysis, Rep. no. DOE/NE-0095.* Washington D.C.: Department of Energy.

Dostal, V., Driscoll, M. J., & Hejzlar, P. (2004). *A Supercritical Carbon Dioxide Cycel for Next Generation Nuclear Reactors, MIT-ANP-TR-100200.* Cambridge: Massachusetts Institute of Technology.

Gandrik, A. (2011). *HTGR Cost Model Estimating Tool, Report number INL/MIS-11-23534.* Idaho Falls: Idaho National Laboratory.

Gandrik, A. M. (2012). *HTGR Application Economic Model User's Manual, INL/EXT-11-24143.* Idaho Falls: Idaho National Laboratory.

GIF. (2007). *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems, GIF/EMWG/2007/004, Rev. 4.2.* Generation-IV International Forum.

IPCC. (2012). *IPCC, Special Report of the Intergovernmental Panel on Climate Control, Renewable Energy Strategies and Climate Change Mitigation.* ISBN 978 1 107 02340 6.

Kim, T., Grandy, C., & Hill, R. N. (2012). A 100 MWe Advanced Sodium-Cooled Fast Reactor Core Concept. *PHYSOR 2012-Advances in Reactor Physics-Linking Research, Industry, and Education.* Knoxville: American Nuclear Society.

Krull, P., Roll, J., & Varrin, R. D. (March 2013). *HTSE Plant Cost Model for the INL HTSE Optimization Study, Dominion Engineering Report R-6828-00-01.*

Lee, N., Gribik, A., Maio, V., McKellar, M., Patterson, M., & Wood, R. (2010). *Integration of High Temperature Gas-Cooled Reactors into Industrial Process Applications, Revision 2, INL/EXT09-16942.* Idaho Falls: Idaho National Laboratory.

NETL. (Nov. 2008). *DOE/NETL-2009/1346, Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels.* NETL.

NGNP. (July 2009). *NGNP Hydrogen Technology Down-Selection: Results of the Independent Review Team (IRT) Evaluation, R-6917-00-01.* Idaho Falls: NGNP.

O'Brien, J. (2008). Thermodynamic Considerations for Thermal Splitting Processes and High Temperature Electrolysis, IMECE2008-68880. *Proceedings of the 2008 International Mechanical Engineering Congress and Exposition.* Boston: American Society of Mechanical Engineers.

Perry, R., & Green, D. (2008). *Perry's Chemical Engieer's Handbook (8th Edition).* New York: McGraw Hill.

Peters, M. S., & Timmerhaus, K. D. (1991). *, Plant Design and Economics for Chemical Engineers, 4th Edition.* McGraw-Hill.

Sienicki, J. (2011). Alternative Cycles for Power Converters. *48th Annual Technical Meeting of Society of Engineering Sciences.* Northwestern University: Argonne National Laboratory.

TEV-666. (May 2010). *TEV-666, Nuclear-Integrated Ammonia Production Analysis, Technical Evaluation Study, Rev 1.* Idaho Falls: Idaho National Laboratory.

TEV-693. (May 2010). *TEV-693, Nuclear-Integrated Hydrogen Production Analysis, Technical Evaluation Study, Rev 1.* Idaho Falls: Idaho National Laboratory.

TEV-953. (Sept. 2010). *HTGR-Integrated Hydrogen Production vis Steam Methane Reforming (SMR) Process Analysis.* Idaho Falls: Idaho National Laboratory.

TEV-954. (Sept. 2010). *HTGR-Integrated Hydrogen Production via Steam Methane Reforming (SMR) Economic Analysis.* Idaho Falls: Idaho National Laboratory.

The Babcock & Wilcox Company. (2005). *Steam: its generation and use, Edition: 41.* Barberton, Ohio: The Babcock & Wilcox Company.

U.S. Energy Information Administration. (n.d.). *www.eia.gov*. From U.S. Energy Information Administration Annual Energy Outlook 2013, Release Dates; April 15-May2, 2013: http://www.eia.gov/forcasts/aeo/images/figure_88

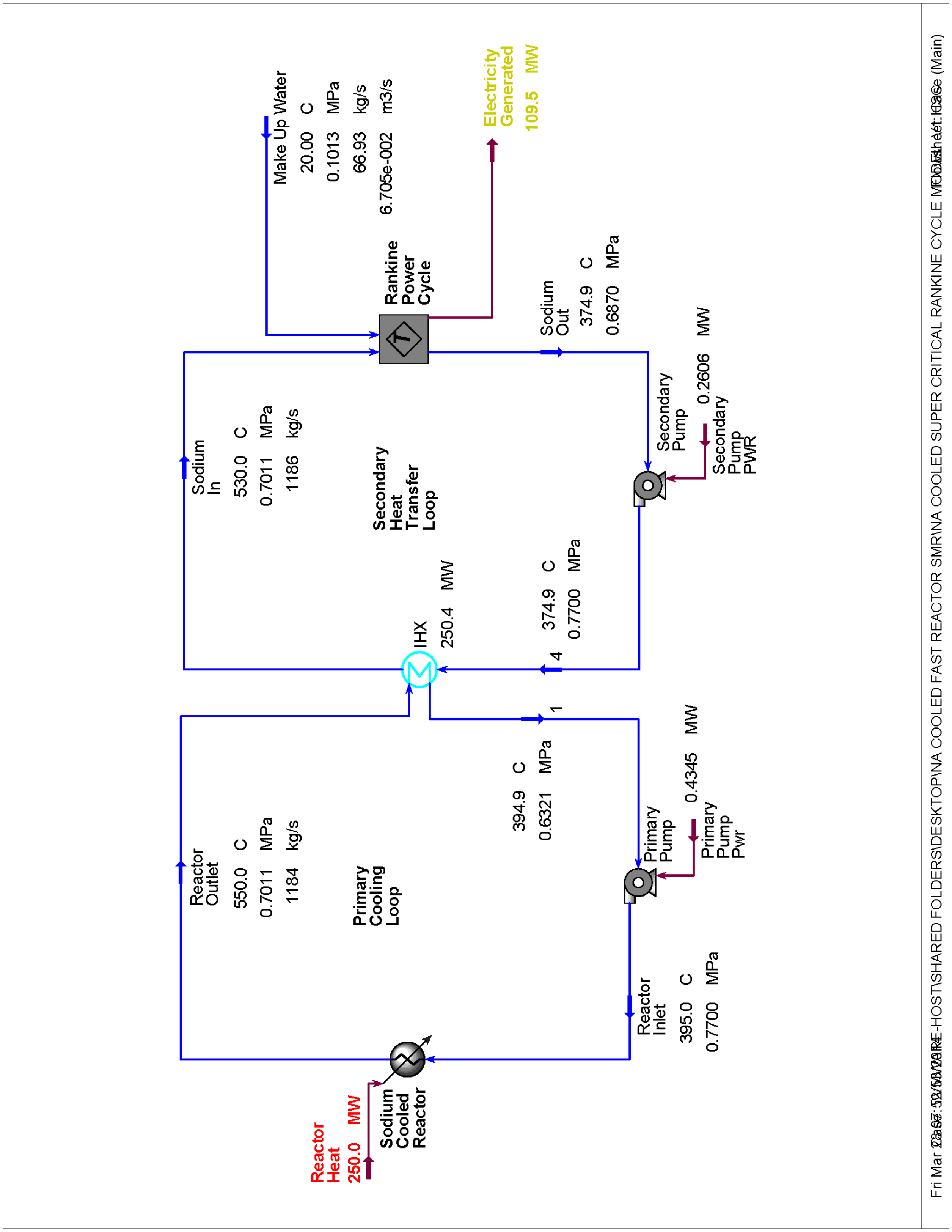
Yang, C., & Ogden, J. (2008). *Determining the Lowest-Cost Hydrogen Delivery Mode.* Institute of Transportation Studies, Department of Environmental Science and Policy, Univerisity of California, Davis.

Zhai, H., & Rubin, E. S. (2010). Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage. *Energy Policy 38*, 5653-5660.

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



BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
	Unit Set:	AFR
	Date/Time:	Fri Mar 28 09:55:16 2014

Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	1186	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	4544	4544	4537	4537	4537
Heat Flow	(MW)	818.8	568.3	849.9	599.9	599.5
Name		Sodium Out	Make Up Water			
Vapour Fraction		0.0000	0.0000			
Temperature	(C)	374.9	20.00			
Pressure	(MPa)	0.6870	0.1013			
Molar Flow	(kgmole/h)	1.857e+005	1.338e+004			
Mass Flow	(kg/s)	1186	66.93			
Liquid Volume Flow	(m3/h)	4544	241.4			
Heat Flow	(MW)	568.1	-1060			

Compositions

Fluid Pkg: All

Name	Sodium In	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***
Name	Sodium Out	Make Up Water			
Comp Mole Frac (H2O)	***	1.0000			
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	***			
Comp Mole Frac (Air)	***	***			

Energy Streams

Fluid Pkg: All

Name		Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWF	
Heat Flow	(MW)	250.0 *	109.5	0.4345	0.2606	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
Rankine Power Cycle	Standard Sub-Flowsheet	Sodium In Make Up Water	Sodium Out Electricity Generated	No	2500 *
Efficiency Calcs	Spreadsheet			No	500.0 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Case (Main) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Spreadsheet: Efficiency Calcs

Units Set: NuScale1

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A1	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
A4	Energy Stream: Electricity Generated	Power	109.5 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A2	A2:		---	<empty>
A3	A3: Heat to Rankine Cycle	Heat to Rankine Cycle	Energy	<empty>
A5	A5: Power Cycle Efficiency	Power Cycle Efficiency	Percent	<empty>
A6	A6: Reactor Heat to HTSE	Reactor Heat to HTSE	Energy	<empty>
B1	B1:		Mass Flow	<empty>
B2	B2:		Mass Heating Value	<empty>
B3	B3: Hydrogen Production Efficiency	Hydrogen Production Efficiency	Percent	<empty>
C1	C1:		Molar Enthalpy	<empty>
C2	C2:		Molar Enthalpy	<empty>
C3	C3:		Molar Flow	<empty>
C4	C4:		---	<empty>

User Variables

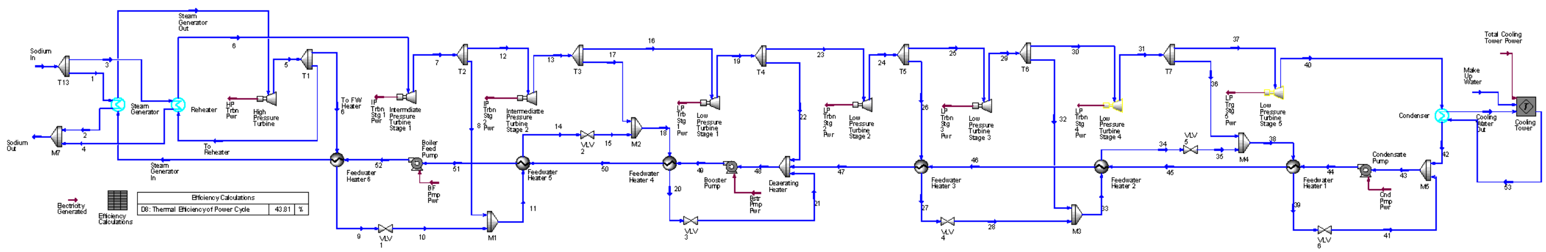
FORMULAS

Cell	Formula	Result
A3	=A1*A2	<empty>
A5	=A4/A3*100	<empty>
A6	=A1-A3	<empty>
B3	=(B1*B2/1000)/A1*100	<empty>
C4	=C3*(C2-C1)/3600000	<empty>

Spreadsheet

	A	B	C	D
1	250.0 MW *	<empty> *	<empty> *	
2	<empty> *	<empty> *	<empty> *	
3	<empty> *	<empty> *	<empty> *	
4	109.5 MW *		<empty> *	
5	<empty> *			
6	<empty> *			
7				
8				
9				
10				

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.



Fri Mar 23 08:15:57 2018 Case: \\VMWARE-HOST\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.CSC Flowsheet: Rankine Power Cycle (TPL1)

Workbook: Rankine Power Cycle (TPL1)

Streams

Fluid Pkg: All

Name		Steam Generator Out	To Reheater @TPL1	To FW Heater 6 @TPL	6 @TPL1	9 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	510.0	354.9	354.9	510.0	276.0
Pressure	(MPa)	24.00	8.510	8.510	8.340	8.340
Molar Flow	(kgmole/h)	2.168e+004	2.018e+004	1505	2.018e+004	1505
Mass Flow	(kg/s)	108.5	101.0	7.530	101.0	7.530
Std Ideal Liq Vol Flow	(m3/h)	391.4	364.2	27.16	364.2	27.16
Heat Flow	(MW)	-1379	-1306	-97.41	-1263	-110.8
Molar Enthalpy	(kJ/kgmole)	-2.289e+005	-2.330e+005	-2.330e+005	-2.253e+005	-2.650e+005
Name		**52 @TPL1**	**Steam Generator In @**	**51 @TPL1**	**8 @TPL1**	**12 @TPL1**
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
Temperature	(C)	270.5	295.3	263.1	442.4	442.4
Pressure	(MPa)	24.99 *	24.49	4.936	5.390	5.390
Molar Flow	(kgmole/h)	2.168e+004	2.168e+004	2.168e+004	1400	1.878e+004
Mass Flow	(kg/s)	108.5	108.5 *	108.5	7.007	93.96
Std Ideal Liq Vol Flow	(m3/h)	391.4	391.4	391.4	25.28	338.9
Heat Flow	(MW)	-1599	-1586	-1603	-88.51	-1187
Molar Enthalpy	(kJ/kgmole)	-2.655e+005	-2.633e+005	-2.662e+005	-2.276e+005	-2.276e+005
Name		**11 @TPL1**	**16 @TPL1**	**18 @TPL1**	**23 @TPL1**	**22 @TPL1**
Vapour Fraction		0.6439	1.0000	0.3688	1.0000	1.0000
Temperature	(C)	268.7	363.6	235.4	272.6	272.6
Pressure	(MPa)	5.390	3.080	3.080	1.365	1.365
Molar Flow	(kgmole/h)	2905	1.747e+004	4208	1.626e+004	1213
Mass Flow	(kg/s)	14.54	87.44	21.06	81.37	6.068
Std Ideal Liq Vol Flow	(m3/h)	52.44	315.4	75.96	293.5	21.89
Heat Flow	(MW)	-199.3	-1117	-300.1	-1053	-78.55
Molar Enthalpy	(kJ/kgmole)	-2.469e+005	-2.302e+005	-2.567e+005	-2.332e+005	-2.332e+005
Name		**49 @TPL1**	**14 @TPL1**	**20 @TPL1**	**47 @TPL1**	**48 @TPL1**
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	194.5	235.2	200.1	155.2	193.6
Pressure	(MPa)	5.140 *	5.390	3.018	1.365	1.365
Molar Flow	(kgmole/h)	2.168e+004	2905	4208	1.626e+004	2.168e+004
Mass Flow	(kg/s)	108.5	14.54	21.06	81.37	108.5
Std Ideal Liq Vol Flow	(m3/h)	391.4	52.44	75.96	293.5	391.4
Heat Flow	(MW)	-1638	-216.7	-317.4	-1242	-1638
Molar Enthalpy	(kJ/kgmole)	-2.719e+005	-2.686e+005	-2.715e+005	-2.751e+005	-2.720e+005
Name		**21 @TPL1**	**25 @TPL1**	**26 @TPL1**	**27 @TPL1**	**30 @TPL1**
Vapour Fraction		0.0145	1.0000	1.0000	0.0000	0.9923
Temperature	(C)	193.9	196.4	196.4	123.1	123.1
Pressure	(MPa)	1.365	0.6210	0.6210	0.6086	0.2190
Molar Flow	(kgmole/h)	4208	1.513e+004	1129	1129	1.408e+004
Mass Flow	(kg/s)	21.06	75.73	5.647	5.647	70.47
Std Ideal Liq Vol Flow	(m3/h)	75.96	273.2	20.37	20.37	254.2
Heat Flow	(MW)	-317.4	-990.8	-73.89	-87.01	-932.3
Molar Enthalpy	(kJ/kgmole)	-2.715e+005	-2.357e+005	-2.357e+005	-2.776e+005	-2.383e+005

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1
Vapour Fraction		0.9923	0.9420	0.0000	0.0000	0.0000
Temperature	(C)	123.1	84.51	84.50	45.89	40.33
Pressure	(MPa)	0.2190	5.670e-002	0.2146	5.557e-002	1.450 *
Molar Flow	(kgmole/h)	1050	1.310e+004	2179	3156	1.626e+004
Mass Flow	(kg/s)	5.255	65.58	10.90	15.79	81.37
Std Ideal Liq Vol Flow	(m3/h)	18.96	236.6	39.33	56.97	293.5
Heat Flow	(MW)	-69.53	-879.2	-169.8	-248.5	-1282
Molar Enthalpy	(kJ/kgmole)	-2.383e+005	-2.415e+005	-2.805e+005	-2.834e+005	-2.838e+005
Name		40 @TPL1	38 @TPL1	42 @TPL1	33 @TPL1	41 @TPL1
Vapour Fraction		0.8839	0.2917	0.0000	0.4783	0.0100
Temperature	(C)	40.51	84.51	38.80	123.1	40.13
Pressure	(MPa)	7.584e-003 *	5.670e-002	7.433e-003	0.2190	7.433e-003
Molar Flow	(kgmole/h)	1.310e+004	3156	1.310e+004	2179	3156
Mass Flow	(kg/s)	65.58	15.79	65.58	10.90	15.79
Std Ideal Liq Vol Flow	(m3/h)	236.6	56.97	236.6	39.33	56.97
Heat Flow	(MW)	-893.8	-235.3	-1034	-156.5	-248.5
Molar Enthalpy	(kJ/kgmole)	-2.455e+005	-2.684e+005	-2.839e+005	-2.587e+005	-2.834e+005
Name		1 @TPL1	3 @TPL1	2 @TPL1	4 @TPL1	Sodium In @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
Molar Flow	(kgmole/h)	1.534e+005	3.229e+004	1.534e+005	3.229e+004	1.857e+005
Mass Flow	(kg/s)	979.7	206.2	979.7	206.2	1186
Std Ideal Liq Vol Flow	(m3/h)	3754	790.0	3754	790.0	4544
Heat Flow	(MW)	676.4	142.4	469.3	98.78	818.8
Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004
Name		Sodium Out @TPL1	5 @TPL1	10 @TPL1	7 @TPL1	13 @TPL1
Vapour Fraction		0.0000	1.0000	0.0226	1.0000	1.0000
Temperature	(C)	374.9	354.9	268.7	442.4	363.6
Pressure	(MPa)	0.6870	8.510 *	5.390	5.390 *	3.080 *
Molar Flow	(kgmole/h)	1.857e+005	2.168e+004	1505	2.018e+004	1.878e+004
Mass Flow	(kg/s)	1186	108.5	7.530	101.0	93.96
Std Ideal Liq Vol Flow	(m3/h)	4544	391.4	27.16	364.2	338.9
Heat Flow	(MW)	568.1	-1404	-110.8	-1275	-1201
Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.330e+005	-2.650e+005	-2.276e+005	-2.302e+005
Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45 @TPL1
Vapour Fraction		1.0000	1.0000	0.9923	0.9420	0.0000
Temperature	(C)	272.6	196.4	123.1	84.51	78.94
Pressure	(MPa)	1.365	0.6210 *	0.2190 *	5.670e-002 *	1.421
Molar Flow	(kgmole/h)	1.747e+004	1.626e+004	1.513e+004	1.408e+004	1.626e+004
Mass Flow	(kg/s)	87.44	81.37	75.73	70.47	81.37
Std Ideal Liq Vol Flow	(m3/h)	315.4	293.5	273.2	254.2	293.5
Heat Flow	(MW)	-1132	-1065	-1002	-944.8	-1269
Molar Enthalpy	(kJ/kgmole)	-2.332e+005	-2.357e+005	-2.383e+005	-2.415e+005	-2.809e+005

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 09:55:16 2014

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28 @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	117.5	229.7	363.6	235.3	123.1
Pressure	(MPa)	1.393	5.037	3.080	3.080	0.2190
Molar Flow	(kgmole/h)	1.626e+004	2.168e+004	1303	2905	1129
Mass Flow	(kg/s)	81.37	108.5	6.521	14.54	5.647
Std Ideal Liq Vol Flow	(m3/h)	293.5	391.4	23.52	52.44	20.37
Heat Flow	(MW)	-1256	-1620	-83.33	-216.7	-87.01
Molar Enthalpy	(kJ/kgmole)	-2.780e+005	-2.691e+005	-2.302e+005	-2.686e+005	-2.776e+005

Name		36 @TPL1	35 @TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
Vapour Fraction		0.9420	0.0000	0.0001	---	---
Temperature	(C)	84.51	84.50	40.13	---	---
Pressure	(MPa)	5.670e-002	5.670e-002	7.433e-003	---	---
Molar Flow	(kgmole/h)	977.3	2179	1.626e+004	---	---
Mass Flow	(kg/s)	4.891	10.90	81.37	---	---
Std Ideal Liq Vol Flow	(m3/h)	17.64	39.33	293.5	---	---
Heat Flow	(MW)	-65.57	-169.8	-1282	24.72	12.81
Molar Enthalpy	(kJ/kgmole)	-2.415e+005	-2.805e+005	-2.838e+005	---	---

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 @T
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	13.84	14.49	0.6251	11.30	11.11
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---

Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated @
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	12.44	14.59	3.663	0.1577	109.5
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---

Name		Cooling Water Out @T	53 @TPL1	Make Up Water @TPL	Total Cooling Tower P	
Vapour Fraction		0.0000	0.0000	0.0000	---	
Temperature	(C)	34.96	25.00	20.00	---	
Pressure	(MPa)	0.1015	0.1035	0.1013	---	
Molar Flow	(kgmole/h)	6.507e+005	6.507e+005	1.338e+004	---	
Mass Flow	(kg/s)	3256	3256	66.93	---	
Std Ideal Liq Vol Flow	(m3/h)	1.175e+004	1.175e+004	241.4	---	
Heat Flow	(MW)	-5.160e+004	-5.174e+004	-1060	0.6353	
Molar Enthalpy	(kJ/kgmole)	-2.854e+005	-2.862e+005	-2.854e+005	---	

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Expanders

Fluid Pkg: All

Name		High Pressure Turbine	Intermdiate Pressure T	Intermediatte Pressure	Low Pressure Turbine	Low Pressure Turbine
Power	(MW)	24.72	12.81	13.84	14.49	11.30
Capacity (act feed vol flow) (ACT_m3/h)		4717	1.475e+004	1.951e+004	2.846e+004	5.178e+004
Feed Pressure	(MPa)	24.00	8.340	5.390	3.080	1.365
Product Pressure	(MPa)	8.510 *	5.390 *	3.080 *	1.365	0.6210 *
Product Temperature	(C)	354.9	442.4	363.6	272.6	196.4
Adiabatic Efficiency		85 *	90 *	90 *	80 *	80 *
Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
Power	(MW)	11.11	12.44	14.59		
Capacity (act feed vol flow) (ACT_m3/h)		9.176e+004	2.048e+005	6.407e+005		
Feed Pressure	(MPa)	0.6210	0.2190	5.670e-002		
Product Pressure	(MPa)	0.2190 *	5.670e-002 *	7.584e-003 *		
Product Temperature	(C)	123.1	84.51	40.51		
Adiabatic Efficiency		75 *	80 *	80 *		

Pumps

Fluid Pkg: All

Name		Boiler Feed Pump @T	Booster Pump @TPL1	Condensate Pump @T		
Power	(MW)	3.663	0.6251	0.1577		
Capacity(Actual Vol. Flow)	(m3/h)	501.5	447.9	715.3		
Feed Pressure	(MPa)	4.936	1.365	7.433e-003		
Product Pressure	(MPa)	24.99 *	5.140 *	1.450 *		
Product Temperature	(C)	270.5	194.5	40.33		
Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		

Heat Exchangers

Fluid Pkg: All

Name		Feedwater Heater 6 @	Feedwater Heater 5 @	Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
Duty	(MW)	13.35	17.46	17.29	13.12	13.22
Tube Side Feed Mass Flow	(kg/s)	108.5	108.5	108.5	81.37	81.37
Shell Side Feed Mass Flow	(kg/s)	7.530	14.54	21.06	5.647	10.90
Tube Inlet Temperature	(C)	270.5	229.7	194.5	117.5	78.94
Tube Outlet Temperature	(C)	295.3	263.1	229.7	155.2	117.5
Shell Inlet Temperature	(C)	354.9	268.7	235.4	196.4	123.1
Shell Outlet Temperature	(C)	276.0	235.2	200.1	123.1	84.50
LMTD	(C)	15.08	15.75	15.48	18.00	17.06
Minimum Approach	(C)	5.556	5.555	5.556	5.556	5.556
UA	(kJ/C-h)	3.187e+006	3.992e+006	4.020e+006	2.625e+006	2.789e+006
Name		Feedwater Heater 1 @	Steam Generator @TF	Reheater @TPL1	Condenser @TPL1	
Duty	(MW)	13.14	207.1	43.59	139.9	
Tube Side Feed Mass Flow	(kg/s)	81.37	979.7	206.2	3256	
Shell Side Feed Mass Flow	(kg/s)	15.79	108.5 *	101.0	65.58	
Tube Inlet Temperature	(C)	40.33	530.0	530.0	25.00	
Tube Outlet Temperature	(C)	78.94	374.9	374.9 *	34.96	
Shell Inlet Temperature	(C)	84.51	295.3	354.9	40.51	
Shell Outlet Temperature	(C)	45.89	510.0	510.0	38.80	
LMTD	(C)	16.39	57.33	23.77	9.554	
Minimum Approach	(C)	5.556	20.00	20.00	5.556	
UA	(kJ/C-h)	2.885e+006	1.300e+007	6.603e+006	5.269e+007	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
High Pressure Turbine @TPL	Expander	Steam Generator Out @TPL1	5 @TPL1 HP Trbn Pwr @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Intermdiate Pressure Turbine	Expander	6 @TPL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *
Intermediatte Pressure Turbin	Expander	12 @TPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 1	Expander	16 @TPL1	19 @TPL1 LP Trb Stg 1 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 2	Expander	23 @TPL1	24 @TPL1 LP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 3	Expander	25 @TPL1	29 @TPL1 LP Trbn Stg 3 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 4	Expander	30 @TPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 5	Expander	37 @TPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *
Feedwater Heater 6 @TPL1	Heat Exchanger	52 @TPL1 To FW Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *
Feedwater Heater 5 @TPL1	Heat Exchanger	50 @TPL1 11 @TPL1	51 @TPL1 14 @TPL1	No	500.0 *
Feedwater Heater 4 @TPL1	Heat Exchanger	49 @TPL1 18 @TPL1	50 @TPL1 20 @TPL1	No	500.0 *
Feedwater Heater 3 @TPL1	Heat Exchanger	46 @TPL1 26 @TPL1	47 @TPL1 27 @TPL1	No	500.0 *
Feedwater Heater 2 @TPL1	Heat Exchanger	45 @TPL1 33 @TPL1	46 @TPL1 34 @TPL1	No	500.0 *
Feedwater Heater 1 @TPL1	Heat Exchanger	44 @TPL1 38 @TPL1	45 @TPL1 39 @TPL1	No	500.0 *
Steam Generator @TPL1	Heat Exchanger	1 @TPL1 Steam Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *
Reheater @TPL1	Heat Exchanger	3 @TPL1 To Reheater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *
Condenser @TPL1	Heat Exchanger	53 @TPL1 40 @TPL1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *
Boiler Feed Pump @TPL1	Pump	51 @TPL1 BF Pmp Pwr @TPL1	52 @TPL1	No	500.0 *
Booster Pump @TPL1	Pump	48 @TPL1 Bstr Pmp Pwr @TPL1	49 @TPL1	No	500.0 *
Condensate Pump @TPL1	Pump	43 @TPL1 Cnd Pmp Pwr @TPL1	44 @TPL1	No	500.0 *
M1 @TPL1	Mixer	10 @TPL1 8 @TPL1	11 @TPL1	No	500.0 *
M2 @TPL1	Mixer	17 @TPL1 15 @TPL1	18 @TPL1	No	500.0 *
Deaerating Heater @TPL1	Mixer	47 @TPL1 21 @TPL1 22 @TPL1	48 @TPL1	No	500.0 *
M4 @TPL1	Mixer	36 @TPL1 35 @TPL1	38 @TPL1	No	500.0 *
M3 @TPL1	Mixer	32 @TPL1 28 @TPL1	33 @TPL1	No	500.0 *
M5 @TPL1	Mixer	41 @TPL1 42 @TPL1	43 @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M7 @TPL1	Mixer	2 @TPL1 4 @TPL1	Sodium Out @TPL1	No	500.0 *
VLV 3 @TPL1	Valve	20 @TPL1	21 @TPL1	No	500.0 *
VLV 4 @TPL1	Valve	27 @TPL1	28 @TPL1	No	500.0 *
VLV 5 @TPL1	Valve	34 @TPL1	35 @TPL1	No	500.0 *
VLV 1 @TPL1	Valve	9 @TPL1	10 @TPL1	No	500.0 *
VLV 2 @TPL1	Valve	14 @TPL1	15 @TPL1	No	500.0 *
VLV 6 @TPL1	Valve	39 @TPL1	41 @TPL1	No	500.0 *
SG tb dP @TPL1	Set			No	500.0 *
SG sh dP @TPL1	Set			No	500.0 *
FW6 tb dP @TPL1	Set			No	500.0 *
FW6 sh dP @TPL1	Set			No	500.0 *
FW4 tb dP @TPL1	Set			No	500.0 *
FW5 tb dP @TPL1	Set			No	500.0 *
FW5 sh dP @TPL1	Set			No	500.0 *
FW4 sh dP @TPL1	Set			No	500.0 *
Cnd sh dP @TPL1	Set			No	500.0 *
FW1 tb dP @TPL1	Set			No	500.0 *
FW1 sh dP @TPL1	Set			No	500.0 *
FW2 tb dP @TPL1	Set			No	500.0 *
FW2 sh dP @TPL1	Set			No	500.0 *
FW3 tb dP @TPL1	Set			No	500.0 *
FW3 sh dP @TPL1	Set			No	500.0 *
Rht tb dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Cnd Tb dP @TPL1	Set			No	500.0 *
SET-3 @TPL1	Set			No	500.0 *
SET-4 @TPL1	Set			No	500.0 *
SET-5 @TPL1	Set			No	500.0 *
SET-6 @TPL1	Set			No	500.0 *
SET-7 @TPL1	Set			No	500.0 *
SET-8 @TPL1	Set			No	500.0 *
T1 @TPL1	Tee	5 @TPL1	To FW Heater 6 @TPL1 To Reheater @TPL1	No	500.0 *
T2 @TPL1	Tee	7 @TPL1	8 @TPL1 12 @TPL1	No	500.0 *
T3 @TPL1	Tee	13 @TPL1	17 @TPL1 16 @TPL1	No	500.0 *
T4 @TPL1	Tee	19 @TPL1	22 @TPL1 23 @TPL1	No	500.0 *
T5 @TPL1	Tee	24 @TPL1	26 @TPL1 25 @TPL1	No	500.0 *
T6 @TPL1	Tee	29 @TPL1	32 @TPL1 30 @TPL1	No	500.0 *
T7 @TPL1	Tee	31 @TPL1	36 @TPL1 37 @TPL1	No	500.0 *
T13 @TPL1	Tee	Sodium In @TPL1	3 @TPL1 1 @TPL1	No	500.0 *
Efficiency Calculations @TPL	Spreadsheet			No	500.0 *
Cooling Tower @TPL1	Standard Sub-Flowsheet	Cooling Water Out @TPL1 Make Up Water @TPL1	53 @TPL1	No	2500 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Cooling Tower @TPL1	Standard Sub-Flowsheet	Total Cooling Tower Power @		No	2500 *

Spreadsheet: Efficiency Calculations @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
B1	Energy Stream: HP Trbn Pwr @TPL1	Power	24.72 MW
B2	Energy Stream: IP Trbn Stg 1 Pwr @TPL1	Power	12.81 MW
B3	Energy Stream: IP Trbn Stg 2 Pwr @TPL1	Power	13.84 MW
B4	Energy Stream: LP Trb Stg 1 Pwr @TPL1	Power	14.49 MW
B5	Energy Stream: LP Trbn Stg 2 Pwr @TPL1	Power	11.30 MW
B6	Energy Stream: LP Trbn Stg 3 Pwr @TPL1	Power	11.11 MW
B7	Energy Stream: LP Trbn Stg 4 Pwr @TPL1	Power	12.44 MW
B8	Energy Stream: LP Trg Stg 5 Pwr @TPL1	Power	14.59 MW
B9	Energy Stream: Cnd Pmp Pwr @TPL1	Power	0.1577 MW
B10	Energy Stream: Bstr Pmp Pwr @TPL1	Power	0.6251 MW
D1	Energy Stream: BF Pmp Pwr @TPL1	Power	3.663 MW
D2	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
D3	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
D4	Energy Stream: Total Cooling Tower Powe	Power	0.6353 MW
D5	Energy Stream: Reactor Heat	Heat Flow	250.0 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
D7	Electricity Generated @TPL1	Power	109.5 MW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
D6	D6: Total Turbine Power	Total Turbine Power	Power	115.3 MW
D7	D7: Power	Power	Power	109.5 MW
D8	D8: Thermal Efficiency of Power Cycle	Thermal Efficiency of Power Cycle	Percent	43.81

User Variables

FORMULAS

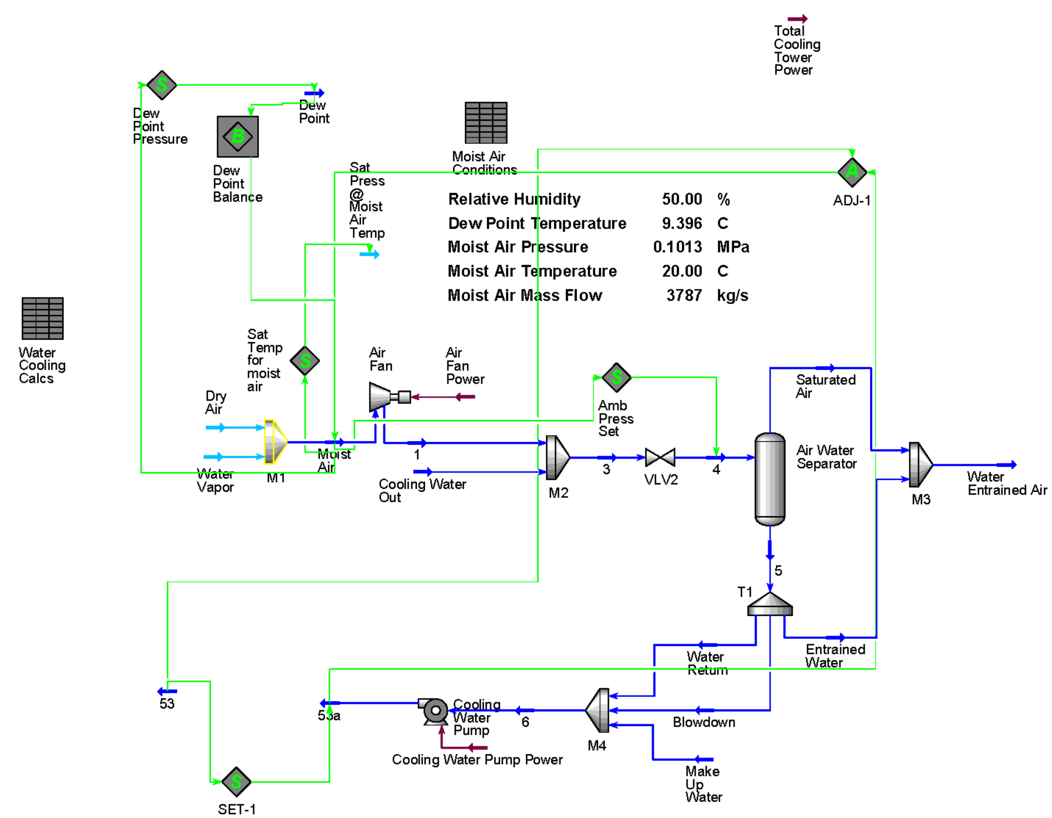
Cell	Formula	Result
D6	=B1+B2+B3+B4+B5+B6+B7+B8	115.3 MW
D7	=D6-B9-B10-D1-D2-D3-D4	109.5 MW
D8	=D7/D5*100	43.81

Spreadsheet

	A	B	C	D
1	HP Trb Pwr *	24.72 MW *	BF Pmp Pwr *	3.663 MW *
2	IP Trb Stg 1 Pwr *	12.81 MW *	Primary Pump Power *	0.4345 MW *
3	IP Trb Stg 2 Pwr *	13.84 MW *	Secondary Pump Power *	0.2606 MW *
4	LP Trb Stg 1 Pwr *	14.49 MW *	Cooling Tower Power *	0.6353 MW *
5	LP Trb Stg 2 Pwr *	11.30 MW *	Reactor Heat *	250.0 MW *
6	LP Trb Stg 3 Pwr *	11.11 MW *	Total Turbine Power *	115.3 MW *
7	LP Trb Stg 4 Pwr *	12.44 MW *	Electricity Generated *	109.5 MW *
8	LP Trb Stg 5 Pwr *	14.59 MW *	Thermal Efficiency of Power Cycle *	43.81 *
9	Cnd Pmp Pwr *	0.1577 MW *		<empty> *
10	Bstr Pmp Pwr *	0.6251 MW *		<empty> *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.



Fri Mar 28 ... Case: ... \VMWARE-HOST\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC ... Flowsheet: Cooling Tower (TPL2)

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 09:55:16 2014

Workbook: Cooling Tower (TPL2)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Vapour Fraction		0.0000	0.0000	---	---	1.0000
Temperature	(C)	34.96	25.00 *	---	---	20.00 *
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
Molar Flow	(kgmole/h)	6.507e+005	6.507e+005	4.692e+005	5459	4.746e+005
Mass Flow	(kg/s)	3256	3256	3760	27.32	3787 *
Liquid Volume Flow	(m3/h)	1.175e+004	1.175e+004	1.565e+004	98.54	1.575e+004
Heat Flow	(MW)	-5.160e+004	-5.174e+004	---	---	-387.2
Name		Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Vapour Fraction		1.0000 *	1.0000	0.4304	1.0000 *	0.4304
Temperature	(C)	20.00	20.16	25.11	9.396	25.10
Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013
Molar Flow	(kgmole/h)	---	4.746e+005	1.125e+006	4.746e+005	1.125e+006
Mass Flow	(kg/s)	---	3787	7044	3787	7044
Liquid Volume Flow	(m3/h)	---	1.575e+004	2.749e+004	1.575e+004	2.749e+004
Heat Flow	(MW)	---	-386.5	-5.198e+004	-428.0	-5.198e+004
Name		Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.10	25.10	25.10	25.10	25.10
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	4.843e+005	6.410e+005	650.7	3031	6.374e+005
Mass Flow	(kg/s)	3836	3208	3.256	15.17	3190
Liquid Volume Flow	(m3/h)	1.592e+004	1.157e+004	11.75	54.71	1.151e+004
Heat Flow	(MW)	-1019	-5.097e+004	-51.74	-241.0	-5.067e+004
Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Vapour Fraction		0.9987	0.0000	0.0000	0.0000	
Temperature	(C)	25.10	20.00 *	25.00	25.00	
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1035	
Molar Flow	(kgmole/h)	4.850e+005	1.338e+004	6.538e+005	6.538e+005	
Mass Flow	(kg/s)	3839	66.93	3272	3272	
Liquid Volume Flow	(m3/h)	1.593e+004	241.4	1.180e+004	1.180e+004	
Heat Flow	(MW)	-1071	-1065	-5.198e+004	-5.198e+004	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Name	Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Comp Mole Frac (H2O)	1.0000 *	0.0115	0.5831	0.0115	0.5831
Comp Mole Frac (Nitrogen)	***	0.7809	0.3294	0.7809	0.3294
Comp Mole Frac (Oxygen)	***	0.2076	0.0875	0.2076	0.0875
Comp Mole Frac (Hydrogen)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	0.0000	0.0000	0.0000	0.0000

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Cooling Tower (TPL2) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Comp Mole Frac (H2O)	0.0313	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (Nitrogen)	0.7653	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.2034	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000	0.0000	0.0000	0.0000

Name	Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Comp Mole Frac (H2O)	0.0326	1.0000 *	1.0000	1.0000	
Comp Mole Frac (Nitrogen)	0.7643	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Oxygen)	0.2032	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000	0.0000	

Energy Streams

Fluid Pkg: All

Name	Air Fan Power @TPL2	Cooling Water Pump P	Total Cooling Tower P		
Heat Flow (MW)	0.6259	9.430e-003	0.6353		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL2	Mixer	Dry Air @TPL2 Water Vapor @TPL2	Moist Air @TPL2	No	500.0 *
M2 @TPL2	Mixer	1 @TPL2 Cooling Water Out @TPL2	3 @TPL2	No	500.0 *
M3 @TPL2	Mixer	Saturated Air @TPL2 Entrained Water @TPL2	Water Entrained Air @TPL2	No	500.0 *
M4 @TPL2	Mixer	Water Return @TPL2 Blowdown @TPL2 Make Up Water @TPL2	6 @TPL2	No	500.0 *
Moist Air Conditions @TPL2	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL2	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL2	Set			No	500.0 *
Dew Point Pressure @TPL2	Set			No	500.0 *
Amb Press Set @TPL2	Set			No	500.0 *
SET-1 @TPL2	Set			No	500.0 *
Air Fan @TPL2	Compressor	Moist Air @TPL2 Air Fan Power @TPL2	1 @TPL2	No	500.0 *
VLV2 @TPL2	Valve	3 @TPL2	4 @TPL2	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Adjust: ADJ-1 @TPL2

Adjusted Variable		Measured Variable	
OBJECT	VARIABLE	OBJECT	VARIABLE
Moist Air	Mass Flow	53a	Temperature

Solving Parameters

Source for Target Value:	Value from Object	Object:	53 @TPL2	Offset:	0.0000 C *
Solving Method:	Secant	Tolerance:	1.000e-003 C *	Maximum Iterations:	1000 *
Step Size:	10.00 kg/s *	Maximum:	---	Minimum:	---

User Variables

Set: Amb Press Set @TPL2

Target

OBJECT	VARIABLE
4	Pressure

Source

OBJECT	VARIABLE
Moist Air	Pressure

Equation Parameters

MULTIPLIER	OFFSET
1.000	0.0000 kPa

User Variables

NOTES

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 09:55:16 2014

Balance: Dew Point Balance @TPL2

CONNECTIONS

INLET STREAMS	OUTLET STREAMS
Dew Point @TPL2	Moist Air @TPL2

PARAMETERS

Not a general balance - no ratios required

User Variables

CONDITIONS

Name		Dew Point @TPL2	Moist Air @TPL2		
Vapour		1.0000 *	1.0000		
Temperature	(C)	9.3960	20.0000 *		
Pressure	(MPa)	0.1013	0.1013 *		
Molar Flow	(kgmole/h)	474622.3797	474622.3797		
Mass Flow	(kg/s)	3787.1761	3787.1761 *		
Std Ideal Liq Vol Flow	(m3/h)	15745.5782	15745.5782		
Molar Enthalpy	(kJ/kgmole)	-3246	-2937		
Molar Entropy	(kJ/kgmole-C)	150.9	152.0		
Heat Flow	(MW)	-4.2798e+02	-3.8716e+02		

PROPERTIES

Name		Dew Point @TPL2	Moist Air @TPL2			
Molecular Weight		28.73	28.73			
Molar Density	(kgmole/m3)	4.317e-002	4.160e-002			
Mass Density	(kg/m3)	1.240	1.195			
Act. Volume Flow	(m3/h)	1.099e+007	1.141e+007			
Mass Enthalpy	(kJ/kg)	-113.0	-102.2			
Mass Entropy	(kJ/kg-C)	5.253	5.290			
Heat Capacity	(kJ/kgmole-C)	29.16	29.22			
Mass Heat Capacity	(kJ/kg-C)	1.015	1.017			
LHV Vol Basis (Std)	(MJ/m3)	0.0000	0.0000			
HHV Vol Basis (Std)	(MJ/m3)	471.7	471.7			
HHV Mass Basis (Std)	(kJ/kg)	16.42	16.42			
CO2 Loading		---	---			
CO2 Apparent Mole Conc.	(kgmole/m3)	---	---			
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	---			
LHV Mass Basis (Std)	(kJ/kg)	---	---			
Phase Fraction [Vol. Basis]		1.000	1.000			
Phase Fraction [Mass Basis]		1.000	1.000			
Phase Fraction [Act. Vol. Basis]		1.000	1.000			
Partial Pressure of CO2	(MPa)	0.0000	0.0000			
Cost Based on Flow	(Cost/s)	0.0000	0.0000			
Act. Gas Flow	(ACT_m3/h)	1.099e+007	1.141e+007			
Avg. Liq. Density	(kgmole/m3)	30.14	30.14			
Specific Heat	(kJ/kgmole-C)	29.16	29.22			
Std. Gas Flow	(STD_m3/h)	1.122e+007	1.122e+007			
Std. Ideal Liq. Mass Density	(kg/m3)	865.9	865.9			
Act. Liq. Flow	(m3/s)	0.0000	---			
Z Factor		---	0.9992			
Watson K		6.042	6.042			
User Property		---	---			

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Balance: Dew Point Balance @TPL2 (continued)

PROPERTIES

Name		Dew Point @TPL2	Moist Air @TPL2			
Partial Pressure of H2S	(MPa)	0.0000	0.0000			
Cp/(Cp - R)		1.399	1.398			
Cp/Cv		1.403	1.401			
Heat of Vap.	(kJ/kgmole)	3770	3770			
Kinematic Viscosity	(cSt)	14.44	15.42			
Liq. Mass Density (Std. Cond)	(kg/m3)	1.216	1.216			
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.121e+007	1.121e+007			
Liquid Fraction		0.0000	0.0000			
Molar Volume	(m3/kgmole)	23.16	24.04			
Mass Heat of Vap.	(kJ/kg)	131.2	131.2			
Phase Fraction [Molar Basis]		1.0000	1.0000			
Surface Tension	(dyne/cm)	---	---			
Thermal Conductivity	(W/m-K)	2.471e-002	2.548e-002			
Viscosity	(cP)	1.790e-002	1.842e-002			
Cv (Semi-Ideal)	(kJ/kgmole-C)	20.85	20.91			
Mass Cv (Semi-Ideal)	(kJ/kg-C)	0.7258	0.7279			
Cv	(kJ/kgmole-C)	20.79	20.86			
Mass Cv	(kJ/kg-C)	0.7238	0.7261			
Cv (Ent. Method)	(kJ/kgmole-C)	---	---			
Mass Cv (Ent. Method)	(kJ/kg-C)	---	---			
Cp/Cv (Ent. Method)		---	---			
Reid VP at 37.8 C	(MPa)	---	---			
True VP at 37.8 C	(MPa)	---	---			
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.121e+007	1.121e+007			
Viscosity Index		-6.592	-5.996			

COMPOSITION

Name	Dew Point @TPL2	Moist Air @TPL2		
Hydrogen	0.0000	0.0000		
H2O	0.0115	0.0115		
Oxygen	0.2076	0.2076		
Nitrogen	0.7809	0.7809		
CO2	0.0000	0.0000		
CO	0.0000	0.0000		
Air	0.0000	0.0000		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Set: Dew Point Pressure @TPL2

Target

OBJECT	VARIABLE
Dew Point	Pressure

Source

OBJECT	VARIABLE
Moist Air	Pressure

Equation Parameters

MULTIPLIER	OFFSET
1.000	0.0000 kPa

User Variables

NOTES

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC Unit Set: AFR Date/Time: Fri Mar 28 09:55:16 2014

Spreadsheet: Moist Air Conditions @TPL2

Units Set: NGNP1

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
B2	Material Stream:	Sat Press @ Moist Air Ter	Pressure	2.339e-003 MPa
B4	Material Stream:	Moist Air @TPL2	Pressure	0.1013 MPa
B6	Pure Component:	H2O	Molecular Weight	18.02
B7	Pure Component:	Air	Molecular Weight	28.95
B9	Material Stream:	Moist Air @TPL2	Mass Flow	3787 kg/s
D1	Material Stream:	Moist Air @TPL2	Temperature	20.00 C
D2	Material Stream:	Dew Point @TPL2	Temperature	9.396 C

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
B10	Dry Air @TPL2	Mass Flow	3760 kg/s

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B1	B1: Relative Humidity	Relative Humidity	Percent	50.00
B3	B3: Water Vapor Pressure	Water Vapor Pressure	Pressure	1.169e-003 MPa
B5	B5: Air Pressure	Air Pressure	Pressure	0.1002 MPa
B8	B8: Humidity Ratio	Humidity Ratio	---	7.266e-003
B10	B10: Mass Flow	Mass Flow	Mass Flow	3760 kg/s

User Variables

FORMULAS

Cell	Formula	Result
B3	=B1/100*B2	1.169e-003 MPa
B5	=B4-B3	0.1002 MPa
B8	=B6*B3/(B7*B5)	7.266e-003
B10	=B9/(1+B8)	3760 kg/s

Spreadsheet

	A	B	C	D
1	Relative Humidity *	50.00 *	Moist Air Temperature *	20.00 C *
2	ter Vapor Sat Pres @ Moist Air Temp *	2.339e-003 MPa *	Dew Point Temperature *	9.396 C *
3	Water Vapor Pressure *	1.169e-003 MPa *		
4	Moist Air Pressure *	0.1013 MPa *		
5	Air Pressure *	0.1002 MPa *		
6	Molecular Weight of Water *	18.02 *		
7	Molecular Weight of Air *	28.95 *		
8	Humidity Ratio *	7.266e-003 *		
9	Moist Air Mass Flow *	3787 kg/s *		
10	Dry Air Mass Flow *	3760 kg/s *		

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC Unit Set: AFR Date/Time: Fri Mar 28 09:55:16 2014

Set: Sat Temp for moist air @TPL2

Target

OBJECT	VARIABLE
Sat Press @ Moist Air Temp	Temperature

Source

OBJECT	VARIABLE
Moist Air	Temperature

Equation Parameters

MULTIPLIER	OFFSET
1.000	0.0000 C

User Variables

NOTES

Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.

Set: SET-1 @TPL2

Target

OBJECT	VARIABLE
53a	Pressure

Source

OBJECT	VARIABLE
53	Pressure

Equation Parameters

MULTIPLIER	OFFSET
1.000	0.0000 kPa

User Variables

NOTES

Case Name:	NA COOLED SUPER CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 09:55:16 2014

Spreadsheet: Water Cooling Calcs @TPL2

Units Set: NGNP1

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
B1	Material Stream:	Cooling Water Out @TPL2	Mass Flow	3256 kg/s
B5	Material Stream:	Moist Air @TPL2	Actual Volume Flow	3169 m3/s
B3	Material Stream:	Saturated Air @TPL2	Master Comp Mass Flow (H2O)	75.8339 kg/s
B7	Material Stream:	Water Return @TPL2	Mass Flow	3190 kg/s
D1	Energy Stream:	Cooling Water Pump Powe	Power	9.430 kW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
B2	Entrained Water @TPL2	Mass Flow	3.256 kg/s
B6	Air Fan Power @TPL2	Power	625.9 kW
B4	Blowdown @TPL2	Mass Flow	15.17 kg/s
B8	Make Up Water @TPL2	Mass Flow	66.93 kg/s
D2	Total Cooling Tower Power @TPL2	Power	635.3 kW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B2	B2: Mass Flow	Mass Flow	Mass Flow	3.256 kg/s
B6	B6: Power	Power	Power	625.9 kW
B4	B4: Mass Flow	Mass Flow	Mass Flow	15.17 kg/s
B8	B8: Mass Flow	Mass Flow	Mass Flow	66.93 kg/s
B9	B9:		---	<empty>
D2	D2: Power	Power	Power	635.3 kW
D7	D7:		---	<empty>

User Variables

FORMULAS

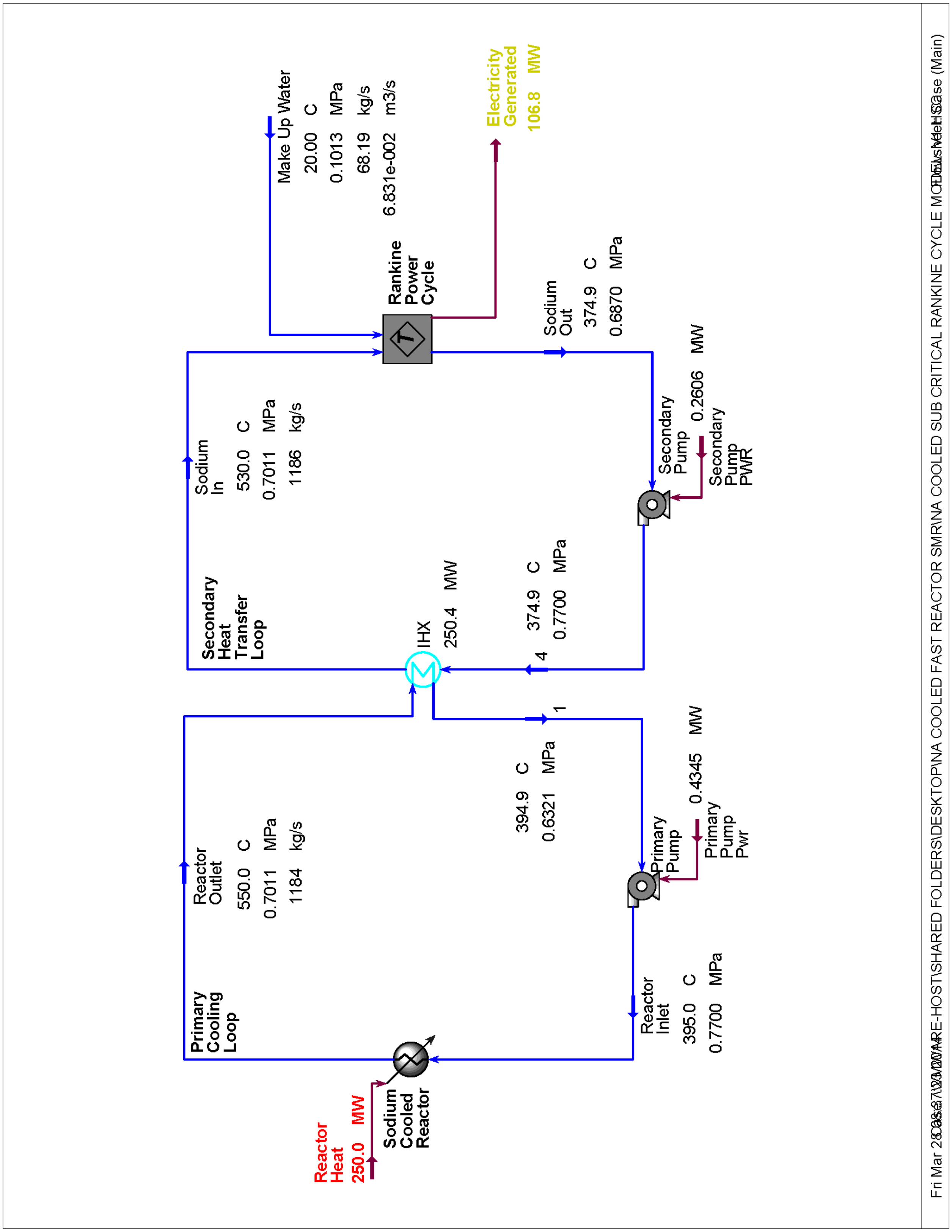
Cell	Formula	Result
B2	=.001*B1	3.256 kg/s
B4	=.20*B3	15.17 kg/s
B6	=B5/5.063	625.9 kW
B8	=B1-B7	66.93 kg/s
D2	=D1+B6	635.3 kW

Spreadsheet

	A	B	C	D
1	Cooling Water Mass Flow *	3256 kg/s *	Cooling Water Pump Power *	9.430 kW *
2	Entrained Water Mass Flow *	3.256 kg/s *	Total Cooling Tower Power *	635.3 kW *
3	Evaporated Water Mass Flow *	75.8339 kg/s *		
4	Blowdown Mass Flow *	15.17 kg/s *		
5	Moist Air Volume Flow *	3169 m3/s *		
6	Fan Power *	625.9 kW *		
7	Water Return Flow *	3190 kg/s *		<empty> *
8	Make Up Water Flow *	66.93 kg/s *		
9		<empty> *		
10		<empty> *		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

6.2 Subcritical Rankine Power Cycle Model



BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC Unit Set: AFR Date/Time: Fri Mar 28 10:00:36 2014

Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	1186	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	4544	4544	4537	4537	4537
Heat Flow	(MW)	818.8	568.3	849.9	599.9	599.5
Name		Sodium Out	Make Up Water			
Vapour Fraction		0.0000	0.0000			
Temperature	(C)	374.9	20.00			
Pressure	(MPa)	0.6870	0.1013			
Molar Flow	(kgmole/h)	1.857e+005	1.363e+004			
Mass Flow	(kg/s)	1186	68.19			
Liquid Volume Flow	(m3/h)	4544	246.0			
Heat Flow	(MW)	568.1	-1080			

Compositions

Fluid Pkg: All

Name	Sodium In	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***
Name	Sodium Out	Make Up Water			
Comp Mole Frac (H2O)	***	1.0000			
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	***			
Comp Mole Frac (Air)	***	***			

Energy Streams

Fluid Pkg: All

Name		Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWR	
Heat Flow	(MW)	250.0 *	106.8	0.4345	0.2606	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
Rankine Power Cycle	Standard Sub-Flowsheet	Sodium In Make Up Water	Sodium Out Electricity Generated	No	2500 *
Efficiency Calcs	Spreadsheet			No	500.0 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Case (Main) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Efficiency Calcs

Units Set: NuScale1

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A1	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
A4	Energy Stream: Electricity Generated	Power	106.8 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A2	A2:		---	<empty>
A5	A5: Power Cycle Efficiency	Power Cycle Efficiency	Percent	<empty>
A6	A6: Reactor Heat to HTSE	Reactor Heat to HTSE	Energy	<empty>
B1	B1:		Mass Flow	<empty>
B2	B2:		Mass Heating Value	<empty>
B3	B3: Hydrogen Production Efficiency	Hydrogen Production Efficiency	Percent	<empty>
C1	C1:		Molar Enthalpy	<empty>
C2	C2:		Molar Enthalpy	<empty>
C3	C3:		Molar Flow	<empty>
C4	C4:		---	<empty>
A3	A3: Heat to Rankine Cycle	Heat to Rankine Cycle	Energy	<empty>

User Variables

FORMULAS

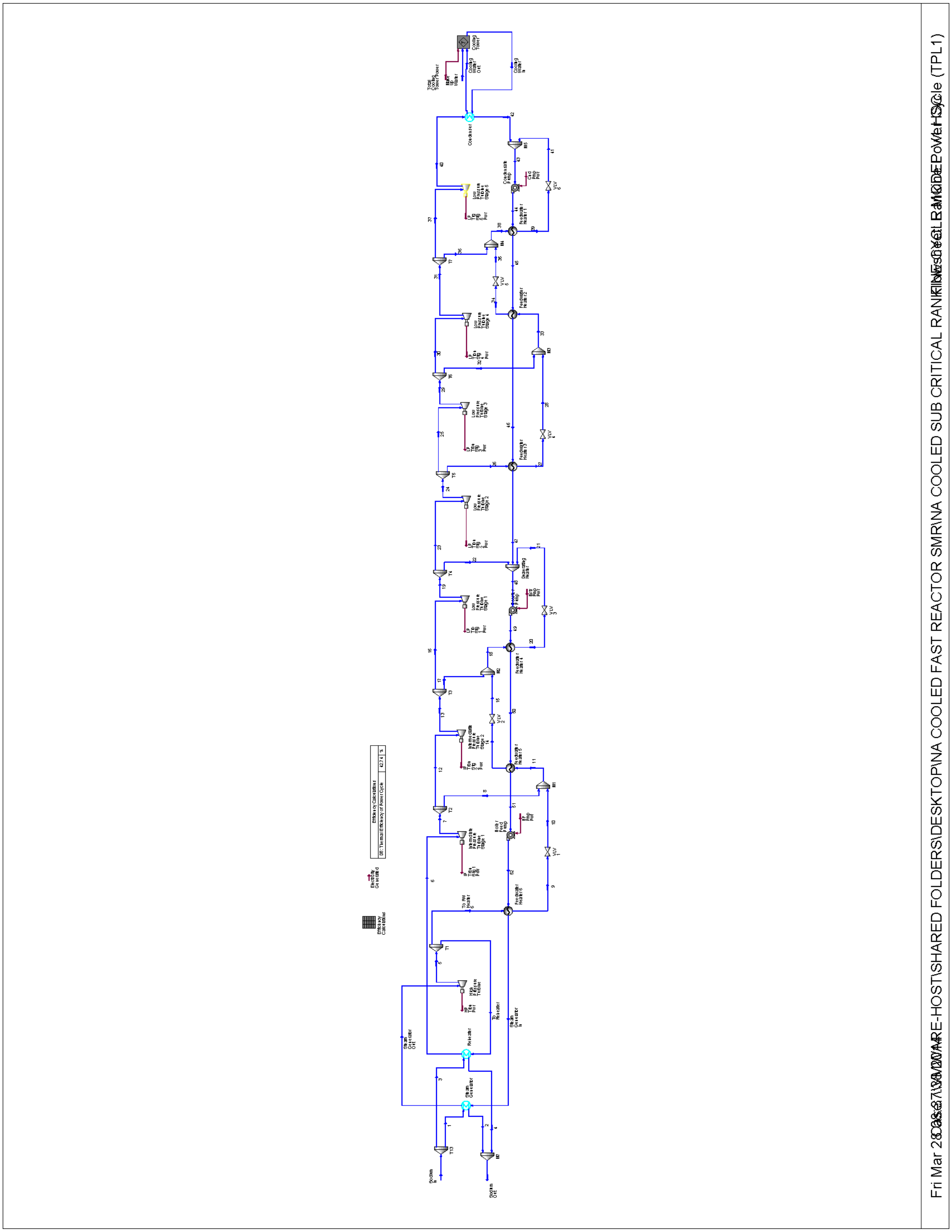
Cell	Formula	Result
A3	=A1*A2	<empty>
A5	=A4/A3*100	<empty>
A6	=A1-A3	<empty>
B3	=(B1*B2/1000)/A1*100	<empty>
C4	=C3*(C2-C1)/3600000	<empty>

Spreadsheet

	A	B	C	D
1	250.0 MW *	<empty> *	<empty> *	
2	<empty> *	<empty> *	<empty> *	
3	<empty> *	<empty> *	<empty> *	
4	106.8 MW *		<empty> *	
5	<empty> *			
6	<empty> *			
7				
8				
9				
10				

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.



BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name: NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set: AFR
Date/Time: Fri Mar 28 10:00:36 2014

Workbook: Rankine Power Cycle (TPL1)

Streams

Fluid Pkg: All

Name		Steam Generator Out	To Reheater @TPL1	To FW Heater 6 @TPI	6 @TPL1	9 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	510.0	354.8	354.8	510.0	251.1
Pressure	(MPa)	17.00	5.850	5.850	5.733	5.733
Molar Flow	(kgmole/h)	2.008e+004	1.888e+004	1207	1.888e+004	1207
Mass Flow	(kg/s)	100.5	94.46	6.040	94.46	6.040
Std Ideal Liq Vol Flow	(m3/h)	362.5	340.7	21.79	340.7	21.79
Heat Flow	(MW)	-1268	-1215	-77.70	-1178	-89.59
Molar Enthalpy	(kJ/kgmole)	-2.272e+005	-2.318e+005	-2.318e+005	-2.247e+005	-2.672e+005

Name		52 @TPL1	Steam Generator In @	51 @TPL1	8 @TPL1	12 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
Temperature	(C)	245.6	270.4	241.0	445.6	445.6
Pressure	(MPa)	17.70 *	17.35	3.409	3.760	3.760
Molar Flow	(kgmole/h)	2.008e+004	2.008e+004	2.008e+004	1134	1.774e+004
Mass Flow	(kg/s)	100.5	100.5 *	100.5	5.677	88.78
Std Ideal Liq Vol Flow	(m3/h)	362.5	362.5	362.5	20.48	320.3
Heat Flow	(MW)	-1493	-1481	-1496	-71.53	-1119
Molar Enthalpy	(kJ/kgmole)	-2.677e+005	-2.655e+005	-2.681e+005	-2.270e+005	-2.270e+005

Name		11 @TPL1	16 @TPL1	18 @TPL1	23 @TPL1	22 @TPL1
Vapour Fraction		0.6368	1.0000	0.3742	1.0000	1.0000
Temperature	(C)	246.7	365.7	215.4	274.7	274.7
Pressure	(MPa)	3.760	2.120	2.120	0.9299	0.9299
Molar Flow	(kgmole/h)	2341	1.668e+004	3408	1.567e+004	1002
Mass Flow	(kg/s)	11.72	83.45	17.05	78.43	5.015
Std Ideal Liq Vol Flow	(m3/h)	42.27	301.0	61.51	282.9	18.09
Heat Flow	(MW)	-161.1	-1064	-243.8	-1014	-64.83
Molar Enthalpy	(kJ/kgmole)	-2.477e+005	-2.298e+005	-2.576e+005	-2.329e+005	-2.329e+005

Name		49 @TPL1	14 @TPL1	20 @TPL1	47 @TPL1	48 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	177.2	215.1	182.7	142.0	176.6
Pressure	(MPa)	3.550 *	3.760	2.078	0.9299	0.9299
Molar Flow	(kgmole/h)	2.008e+004	2341	3408	1.567e+004	2.008e+004
Mass Flow	(kg/s)	100.5	11.72	17.05	78.43	100.5
Std Ideal Liq Vol Flow	(m3/h)	362.5	42.27	61.51	282.9	362.5
Heat Flow	(MW)	-1525	-175.8	-258.3	-1202	-1525
Molar Enthalpy	(kJ/kgmole)	-2.733e+005	-2.703e+005	-2.729e+005	-2.761e+005	-2.734e+005

Name		21 @TPL1	25 @TPL1	26 @TPL1	27 @TPL1	30 @TPL1
Vapour Fraction		0.0132	1.0000	1.0000	0.0000	1.0000
Temperature	(C)	176.8	202.0	202.0	113.9	126.4
Pressure	(MPa)	0.9299	0.4380	0.4380	0.4292	0.1660
Molar Flow	(kgmole/h)	3408	1.473e+004	942.0	942.0	1.385e+004
Mass Flow	(kg/s)	17.05	73.72	4.714	4.714	69.29
Std Ideal Liq Vol Flow	(m3/h)	61.51	265.9	17.00	17.00	249.9
Heat Flow	(MW)	-258.3	-962.9	-61.57	-72.81	-914.7
Molar Enthalpy	(kJ/kgmole)	-2.729e+005	-2.353e+005	-2.353e+005	-2.783e+005	-2.378e+005

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1
Vapour Fraction		1.0000	0.9633	0.0000	0.0000	0.0000
Temperature	(C)	126.4	80.22	79.77	45.74	40.18
Pressure	(MPa)	0.1660	4.780e-002	0.1627	4.684e-002	0.9880 *
Molar Flow	(kgmole/h)	885.3	1.301e+004	1827	2659	1.567e+004
Mass Flow	(kg/s)	4.430	65.12	9.144	13.31	78.43
Std Ideal Liq Vol Flow	(m3/h)	15.98	234.9	32.99	48.01	282.9
Heat Flow	(MW)	-58.49	-870.4	-142.6	-209.4	-1236
Molar Enthalpy	(kJ/kgmole)	-2.378e+005	-2.408e+005	-2.809e+005	-2.834e+005	-2.838e+005

Name		40 @TPL1	38 @TPL1	42 @TPL1	33 @TPL1	41 @TPL1
Vapour Fraction		0.9072	0.3009	0.0000	0.4895	0.0098
Temperature	(C)	40.51	80.22	38.92	114.4	40.13
Pressure	(MPa)	7.584e-003 *	4.780e-002	7.433e-003	0.1660	7.433e-003
Molar Flow	(kgmole/h)	1.301e+004	2659	1.301e+004	1827	2659
Mass Flow	(kg/s)	65.12	13.31	65.12	9.144	13.31
Std Ideal Liq Vol Flow	(m3/h)	234.9	48.01	234.9	32.99	48.01
Heat Flow	(MW)	-883.9	-198.2	-1026	-131.3	-209.4
Molar Enthalpy	(kJ/kgmole)	-2.445e+005	-2.683e+005	-2.839e+005	-2.587e+005	-2.834e+005

Name		1 @TPL1	3 @TPL1	2 @TPL1	4 @TPL1	Sodium In @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
Molar Flow	(kgmole/h)	1.585e+005	2.725e+004	1.585e+005	2.725e+004	1.857e+005
Mass Flow	(kg/s)	1012	174.0	1012	174.0	1186
Std Ideal Liq Vol Flow	(m3/h)	3877	666.8	3877	666.8	4544
Heat Flow	(MW)	698.6	120.2	484.7	83.37	818.8
Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004

Name		Sodium Out @TPL1	5 @TPL1	10 @TPL1	7 @TPL1	13 @TPL1
Vapour Fraction		0.0000	1.0000	0.0122	1.0000	1.0000
Temperature	(C)	374.9	354.8	246.7	445.6	365.7
Pressure	(MPa)	0.6870	5.850 *	3.760	3.760 *	2.120 *
Molar Flow	(kgmole/h)	1.857e+005	2.008e+004	1207	1.888e+004	1.774e+004
Mass Flow	(kg/s)	1186	100.5	6.040	94.46	88.78
Std Ideal Liq Vol Flow	(m3/h)	4544	362.5	21.79	340.7	320.3
Heat Flow	(MW)	568.1	-1293	-89.59	-1190	-1132
Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.318e+005	-2.672e+005	-2.270e+005	-2.298e+005

Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	0.9633	0.0000
Temperature	(C)	274.7	202.0	126.4	80.22	74.22
Pressure	(MPa)	0.9299	0.4380 *	0.1660 *	4.780e-002 *	0.9682
Molar Flow	(kgmole/h)	1.668e+004	1.567e+004	1.473e+004	1.385e+004	1.567e+004
Mass Flow	(kg/s)	83.45	78.43	73.72	69.29	78.43
Std Ideal Liq Vol Flow	(m3/h)	301.0	282.9	265.9	249.9	282.9
Heat Flow	(MW)	-1079	-1024	-973.2	-926.0	-1225
Molar Enthalpy	(kJ/kgmole)	-2.329e+005	-2.353e+005	-2.378e+005	-2.408e+005	-2.813e+005

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28 @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	108.4	209.6	365.7	215.2	114.0
Pressure	(MPa)	0.9489	3.479	2.120	2.120	0.1660
Molar Flow	(kgmole/h)	1.567e+004	2.008e+004	1066	2341	942.0
Mass Flow	(kg/s)	78.43	100.5	5.336	11.72	4.714
Std Ideal Liq Vol Flow	(m3/h)	282.9	362.5	19.25	42.27	17.00
Heat Flow	(MW)	-1213	-1510	-68.06	-175.8	-72.81
Molar Enthalpy	(kJ/kgmole)	-2.787e+005	-2.707e+005	-2.298e+005	-2.703e+005	-2.783e+005
Name		36 @TPL1	35 @TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
Vapour Fraction		0.9633	0.0000	0.0000	---	---
Temperature	(C)	80.22	79.80	40.07	---	---
Pressure	(MPa)	4.780e-002	4.780e-002	7.433e-003	---	---
Molar Flow	(kgmole/h)	832.1	1827	1.567e+004	---	---
Mass Flow	(kg/s)	4.164	9.144	78.43	---	---
Std Ideal Liq Vol Flow	(m3/h)	15.02	32.99	282.9	---	---
Heat Flow	(MW)	-55.65	-142.6	-1236	25.37	11.85
Molar Enthalpy	(kJ/kgmole)	-2.408e+005	-2.809e+005	-2.838e+005	---	---
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 @T
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	13.70	14.28	0.3937	10.65	10.28
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---
Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated @
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	11.37	13.52	2.335	0.1033	106.8
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---
Name		Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL	Total Cooling Tower P	
Vapour Fraction		0.0000	0.0000	0.0000	---	
Temperature	(C)	34.96	25.00	20.00	---	
Pressure	(MPa)	0.1015	0.1035	0.1013	---	
Molar Flow	(kgmole/h)	6.631e+005	6.631e+005	1.363e+004	---	
Mass Flow	(kg/s)	3318	3318	68.19	---	
Std Ideal Liq Vol Flow	(m3/h)	1.197e+004	1.197e+004	246.0	---	
Heat Flow	(MW)	-5.258e+004	-5.272e+004	-1080	0.6472	
Molar Enthalpy	(kJ/kgmole)	-2.854e+005	-2.862e+005	-2.854e+005	---	

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Expanders

Fluid Pkg: All

Name		High Pressure Turbine	Intermdiate Pressure T	Intermediatte Pressure	Low Pressure Turbine	Low Pressure Turbine
Power	(MW)	25.37	11.85	13.70	14.28	10.65
Capacity (act feed vol flow) (ACT_m3/h)		6648	2.052e+004	2.709e+004	4.032e+004	7.463e+004
Feed Pressure	(MPa)	17.00	5.733	3.760	2.120	0.9299
Product Pressure	(MPa)	5.850 *	3.760 *	2.120 *	0.9299	0.4380 *
Product Temperature	(C)	354.8	445.6	365.7	274.7	202.0
Adiabatic Efficiency		85 *	90 *	90 *	80 *	80 *
Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
Power	(MW)	10.28	11.37	13.52		
Capacity (act feed vol flow) (ACT_m3/h)		1.298e+005	2.720e+005	7.634e+005		
Feed Pressure	(MPa)	0.4380	0.1660	4.780e-002		
Product Pressure	(MPa)	0.1660 *	4.780e-002 *	7.584e-003 *		
Product Temperature	(C)	126.4	80.22	40.51		
Adiabatic Efficiency		75 *	80 *	80 *		

Pumps

Fluid Pkg: All

Name		Boiler Feed Pump @T	Booster Pump @TPL1	Condensate Pump @T		
Power	(MW)	2.335	0.3937	0.1033		
Capacity(Actual Vol. Flow)	(m3/h)	445.5	406.2	284.6		
Feed Pressure	(MPa)	3.409	0.9299	7.433e-003		
Product Pressure	(MPa)	17.70 *	3.550 *	0.9880 *		
Product Temperature	(C)	245.6	177.2	40.18		
Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		

Heat Exchangers

Fluid Pkg: All

Name		Feedwater Heater 6 @	Feedwater Heater 5 @	Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
Duty	(MW)	11.89	14.66	14.48	11.24	11.26
Tube Side Feed Mass Flow	(kg/s)	100.5	100.5	100.5	78.43	78.43
Shell Side Feed Mass Flow	(kg/s)	6.040	11.72	17.05	4.714	9.144
Tube Inlet Temperature	(C)	245.6	209.6	177.2	108.4	74.22
Tube Outlet Temperature	(C)	270.4	241.0	209.6	142.0	108.4
Shell Inlet Temperature	(C)	354.8	246.7	215.4	202.0	114.4
Shell Outlet Temperature	(C)	251.1	215.1	182.7	113.9	79.77
LMTD	(C)	15.17	15.61	15.24	17.42	16.65
Minimum Approach	(C)	5.556	5.556	5.556	5.556	5.556
UA	(kJ/C-h)	2.821e+006	3.382e+006	3.420e+006	2.322e+006	2.436e+006
Name		Feedwater Heater 1 @	Steam Generator @TP	Reheater @TPL1	Condenser @TPL1	
Duty	(MW)	11.16	213.9	36.79	142.5	
Tube Side Feed Mass Flow	(kg/s)	78.43	1012	174.0	3318	
Shell Side Feed Mass Flow	(kg/s)	13.31	100.5 *	94.46	65.12	
Tube Inlet Temperature	(C)	40.18	530.0	530.0	25.00	
Tube Outlet Temperature	(C)	74.22	374.9	374.9 *	34.96	
Shell Inlet Temperature	(C)	80.22	270.4	354.8	40.51	
Shell Outlet Temperature	(C)	45.74	510.0	510.0	38.92	
LMTD	(C)	16.02	78.05	22.07	9.555	
Minimum Approach	(C)	5.555	20.00	20.00	5.556	
UA	(kJ/C-h)	2.509e+006	9.866e+006	6.001e+006	5.369e+007	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
High Pressure Turbine @TPL	Expander	Steam Generator Out @TPL1	5 @TPL1 HP Trbn Pwr @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Intermdiate Pressure Turbine	Expander	6 @TPL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *
Intermediatte Pressure Turbin	Expander	12 @TPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 1	Expander	16 @TPL1	19 @TPL1 LP Trb Stg 1 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 2	Expander	23 @TPL1	24 @TPL1 LP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 3	Expander	25 @TPL1	29 @TPL1 LP Trbn Stg 3 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 4	Expander	30 @TPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 5	Expander	37 @TPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *
Feedwater Heater 6 @TPL1	Heat Exchanger	52 @TPL1 To FW Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *
Feedwater Heater 5 @TPL1	Heat Exchanger	50 @TPL1 11 @TPL1	51 @TPL1 14 @TPL1	No	500.0 *
Feedwater Heater 4 @TPL1	Heat Exchanger	49 @TPL1 18 @TPL1	50 @TPL1 20 @TPL1	No	500.0 *
Feedwater Heater 3 @TPL1	Heat Exchanger	46 @TPL1 26 @TPL1	47 @TPL1 27 @TPL1	No	500.0 *
Feedwater Heater 2 @TPL1	Heat Exchanger	45 @TPL1 33 @TPL1	46 @TPL1 34 @TPL1	No	500.0 *
Feedwater Heater 1 @TPL1	Heat Exchanger	44 @TPL1 38 @TPL1	45 @TPL1 39 @TPL1	No	500.0 *
Steam Generator @TPL1	Heat Exchanger	1 @TPL1 Steam Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *
Reheater @TPL1	Heat Exchanger	3 @TPL1 To Reheater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *
Condenser @TPL1	Heat Exchanger	Cooling Water In @TPL1 40 @TPL1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *
Boiler Feed Pump @TPL1	Pump	51 @TPL1 BF Pmp Pwr @TPL1	52 @TPL1	No	500.0 *
Booster Pump @TPL1	Pump	48 @TPL1 Bstr Pmp Pwr @TPL1	49 @TPL1	No	500.0 *
Condensate Pump @TPL1	Pump	43 @TPL1 Cnd Pmp Pwr @TPL1	44 @TPL1	No	500.0 *
M1 @TPL1	Mixer	10 @TPL1 8 @TPL1	11 @TPL1	No	500.0 *
M2 @TPL1	Mixer	17 @TPL1 15 @TPL1	18 @TPL1	No	500.0 *
Deaerating Heater @TPL1	Mixer	47 @TPL1 21 @TPL1 22 @TPL1	48 @TPL1	No	500.0 *
M4 @TPL1	Mixer	36 @TPL1 35 @TPL1	38 @TPL1	No	500.0 *
M3 @TPL1	Mixer	32 @TPL1 28 @TPL1	33 @TPL1	No	500.0 *
M5 @TPL1	Mixer	41 @TPL1 42 @TPL1	43 @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC
	Unit Set:	AFR
	Date/Time:	Fri Mar 28 10:00:36 2014

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M7 @TPL1	Mixer	2 @TPL1 4 @TPL1	Sodium Out @TPL1	No	500.0 *
VLV 3 @TPL1	Valve	20 @TPL1	21 @TPL1	No	500.0 *
VLV 4 @TPL1	Valve	27 @TPL1	28 @TPL1	No	500.0 *
VLV 5 @TPL1	Valve	34 @TPL1	35 @TPL1	No	500.0 *
VLV 1 @TPL1	Valve	9 @TPL1	10 @TPL1	No	500.0 *
VLV 2 @TPL1	Valve	14 @TPL1	15 @TPL1	No	500.0 *
VLV 6 @TPL1	Valve	39 @TPL1	41 @TPL1	No	500.0 *
SG tb dP @TPL1	Set			No	500.0 *
SG sh dP @TPL1	Set			No	500.0 *
FW6 tb dP @TPL1	Set			No	500.0 *
FW6 sh dP @TPL1	Set			No	500.0 *
FW4 tb dP @TPL1	Set			No	500.0 *
FW5 tb dP @TPL1	Set			No	500.0 *
FW5 sh dP @TPL1	Set			No	500.0 *
FW4 sh dP @TPL1	Set			No	500.0 *
Cnd sh dP @TPL1	Set			No	500.0 *
FW1 tb dP @TPL1	Set			No	500.0 *
FW1 sh dP @TPL1	Set			No	500.0 *
FW2 tb dP @TPL1	Set			No	500.0 *
FW2 sh dP @TPL1	Set			No	500.0 *
FW3 tb dP @TPL1	Set			No	500.0 *
FW3 sh dP @TPL1	Set			No	500.0 *
Rht tb dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Cnd Tb dP @TPL1	Set			No	500.0 *
SET-3 @TPL1	Set			No	500.0 *
SET-4 @TPL1	Set			No	500.0 *
SET-5 @TPL1	Set			No	500.0 *
SET-6 @TPL1	Set			No	500.0 *
SET-7 @TPL1	Set			No	500.0 *
SET-8 @TPL1	Set			No	500.0 *
T1 @TPL1	Tee	5 @TPL1	To FW Heater 6 @TPL1 To Reheater @TPL1	No	500.0 *
T2 @TPL1	Tee	7 @TPL1	8 @TPL1 12 @TPL1	No	500.0 *
T3 @TPL1	Tee	13 @TPL1	17 @TPL1 16 @TPL1	No	500.0 *
T4 @TPL1	Tee	19 @TPL1	22 @TPL1 23 @TPL1	No	500.0 *
T5 @TPL1	Tee	24 @TPL1	26 @TPL1 25 @TPL1	No	500.0 *
T6 @TPL1	Tee	29 @TPL1	32 @TPL1 30 @TPL1	No	500.0 *
T7 @TPL1	Tee	31 @TPL1	36 @TPL1 37 @TPL1	No	500.0 *
T13 @TPL1	Tee	Sodium In @TPL1	3 @TPL1 1 @TPL1	No	500.0 *
Efficiency Calculations @TPL	Spreadsheet			No	500.0 *
Cooling Tower @TPL1	Standard Sub-Flowsheet	Cooling Water Out @TPL1 Make Up Water @TPL1	Cooling Water In @TPL1	No	2500 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Cooling Tower @TPL1	Standard Sub-Flowsheet	Total Cooling Tower Power @		No	2500 *

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC
		Unit Set:	AFR
		Date/Time:	Fri Mar 28 10:00:36 2014

Spreadsheet: Efficiency Calculations @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
B1	Energy Stream: HP Trbn Pwr @TPL1	Power	25.37 MW
B2	Energy Stream: IP Trbn Stg 1 Pwr @TPL1	Power	11.85 MW
B3	Energy Stream: IP Trbn Stg 2 Pwr @TPL1	Power	13.70 MW
B4	Energy Stream: LP Trb Stg 1 Pwr @TPL1	Power	14.28 MW
B5	Energy Stream: LP Trbn Stg 2 Pwr @TPL1	Power	10.65 MW
B6	Energy Stream: LP Trbn Stg 3 Pwr @TPL1	Power	10.28 MW
B7	Energy Stream: LP Trbn Stg 4 Pwr @TPL1	Power	11.37 MW
B8	Energy Stream: LP Trg Stg 5 Pwr @TPL1	Power	13.52 MW
B9	Energy Stream: Cnd Pmp Pwr @TPL1	Power	0.1033 MW
B10	Energy Stream: Bstr Pmp Pwr @TPL1	Power	0.3937 MW
D1	Energy Stream: BF Pmp Pwr @TPL1	Power	2.335 MW
D2	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
D3	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
D4	Energy Stream: Total Cooling Tower Powe	Power	0.6472 MW
D5	Energy Stream: Reactor Heat	Heat Flow	250.0 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
D7	Electricity Generated @TPL1	Power	106.8 MW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
D8	D8: Thermal Efficiency of Power Cycle	Thermal Efficiency of Power Cycle	Percent	42.74
D7	D7: Power	Power	Power	106.8 MW
D6	D6: Total Turbine Power	Total Turbine Power	Power	111.0 MW

User Variables

FORMULAS

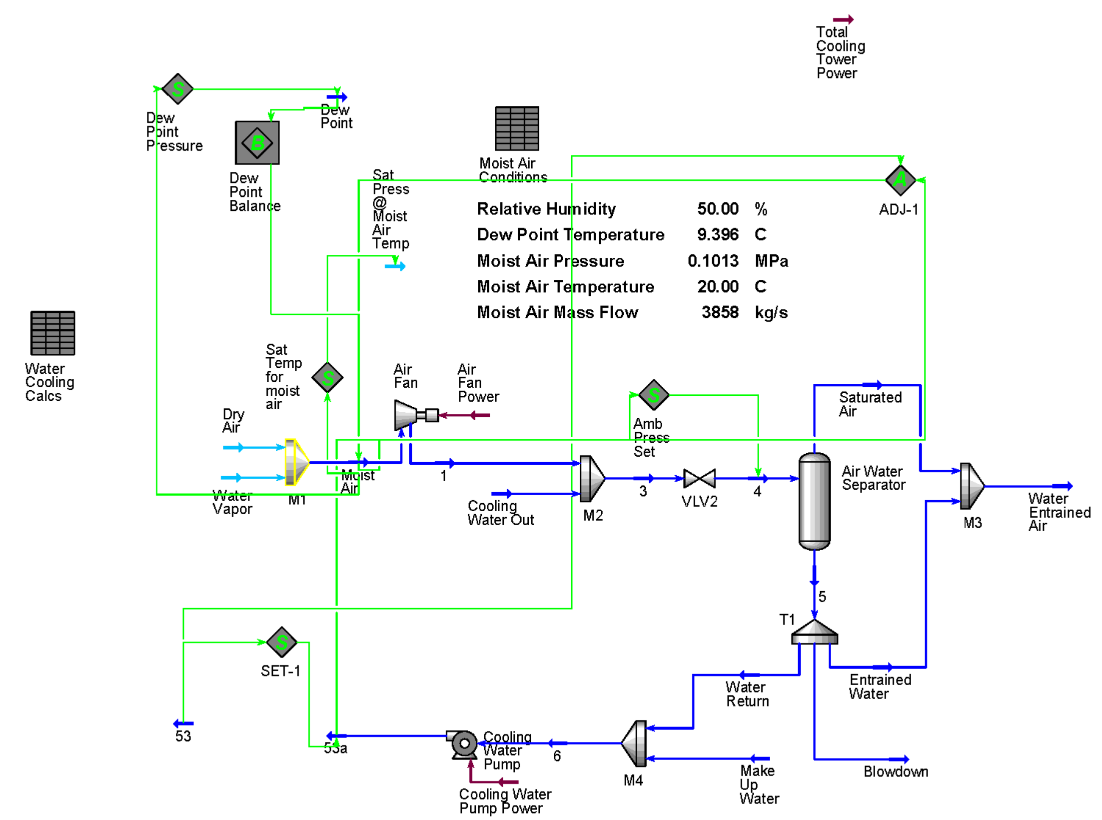
Cell	Formula	Result
D6	=B1+B2+B3+B4+B5+B6+B7+B8	111.0 MW
D7	=D6-B9-B10-D1-D2-D3-D4	106.8 MW
D8	=D7/D5*100	42.74

Spreadsheet

	A	B	C	D
1	HP Trb Pwr *	25.37 MW *	BF Pmp Pwr *	2.335 MW *
2	IP Trb Stg 1 Pwr *	11.85 MW *	Primary Pump Power *	0.4345 MW *
3	IP Trb Stg 2 Pwr *	13.70 MW *	Secondary Pump Power *	0.2606 MW *
4	LP Trb Stg 1 Pwr *	14.28 MW *	Cooling Tower Power *	0.6472 MW *
5	LP Trb Stg 2 Pwr *	10.65 MW *	Reactor Heat *	250.0 MW *
6	LP Trb Stg 3 Pwr *	10.28 MW *	Total Turbine Power *	111.0 MW *
7	LP Trb Stg 4 Pwr *	11.37 MW *	Electricity Generated *	106.8 MW *
8	LP Trb Stg 5 Pwr *	13.52 MW *	Thermal Efficiency of Power Cycle *	42.74 *
9	Cnd Pmp Pwr *	0.1033 MW *		<empty> *
10	Bstr Pmp Pwr *	0.3937 MW *		<empty> *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.



Fri Mar 28 08:33:01 2014 Case: C:\VMWARE-HOST\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V4.HSC Flowsheet: Cooling Tower (TPL2)

aspentech

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED SUB CRITICAL RANKINE CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 10:00:36 2014

Workbook: Cooling Tower (TPL2)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Vapour Fraction		0.0000	0.0000	---	---	1.0000
Temperature	(C)	34.96	25.00 *	---	---	20.00 *
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
Molar Flow	(kgmole/h)	6.631e+005	6.631e+005	4.779e+005	5561	4.835e+005
Mass Flow	(kg/s)	3318	3318	3830	27.83	3858 *
Liquid Volume Flow	(m3/h)	1.197e+004	1.197e+004	1.594e+004	100.4	1.604e+004
Heat Flow	(MW)	-5.258e+004	-5.272e+004	---	---	-394.4

Name		Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Vapour Fraction		1.0000 *	1.0000	0.4303	1.0000 *	0.4303
Temperature	(C)	20.00	20.16	25.11	9.396	25.11
Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013
Molar Flow	(kgmole/h)	---	4.835e+005	1.147e+006	4.835e+005	1.147e+006
Mass Flow	(kg/s)	---	3858	7176	3858	7176
Liquid Volume Flow	(m3/h)	---	1.604e+004	2.801e+004	1.604e+004	2.801e+004
Heat Flow	(MW)	---	-393.7	-5.297e+004	-436.0	-5.297e+004

Name		Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.11	25.11	25.11	25.11	25.11
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	4.934e+005	6.533e+005	663.1	3088	6.495e+005
Mass Flow	(kg/s)	3907	3269	3.318	15.45	3250
Liquid Volume Flow	(m3/h)	1.622e+004	1.179e+004	11.97	55.74	1.172e+004
Heat Flow	(MW)	-1038	-5.194e+004	-52.72	-245.5	-5.164e+004

Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Vapour Fraction		0.9987	0.0000	0.0000	0.0000	
Temperature	(C)	25.10	20.00 *	25.00	25.00	
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1035	
Molar Flow	(kgmole/h)	4.940e+005	1.363e+004	6.631e+005	6.631e+005	
Mass Flow	(kg/s)	3911	68.19	3318	3318	
Liquid Volume Flow	(m3/h)	1.623e+004	246.0	1.197e+004	1.197e+004	
Heat Flow	(MW)	-1091	-1085	-5.272e+004	-5.272e+004	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000

Name	Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Comp Mole Frac (H2O)	1.0000 *	0.0115	0.5832	0.0115	0.5832
Comp Mole Frac (Nitrogen)	***	0.7809	0.3293	0.7809	0.3293
Comp Mole Frac (Oxygen)	***	0.2076	0.0875	0.2076	0.0875
Comp Mole Frac (Hydrogen)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	0.0000	0.0000	0.0000	0.0000

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Cooling Tower (TPL2) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Comp Mole Frac (H2O)	0.0313	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (Nitrogen)	0.7653	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.2034	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000	0.0000	0.0000	0.0000

Name	Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Comp Mole Frac (H2O)	0.0326	1.0000 *	1.0000	1.0000	
Comp Mole Frac (Nitrogen)	0.7643	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Oxygen)	0.2032	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000	0.0000	

Energy Streams

Fluid Pkg: All

Name	Air Fan Power @TPL2	Cooling Water Pump F	Total Cooling Tower P		
Heat Flow (MW)	0.6376	9.565e-003	0.6472		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL2	Mixer	Dry Air @TPL2 Water Vapor @TPL2	Moist Air @TPL2	No	500.0 *
M2 @TPL2	Mixer	1 @TPL2 Cooling Water Out @TPL2	3 @TPL2	No	500.0 *
M3 @TPL2	Mixer	Saturated Air @TPL2 Entrained Water @TPL2	Water Entrained Air @TPL2	No	500.0 *
M4 @TPL2	Mixer	Water Return @TPL2 Make Up Water @TPL2	6 @TPL2	No	500.0 *
Moist Air Conditions @TPL2	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL2	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL2	Set			No	500.0 *
Dew Point Pressure @TPL2	Set			No	500.0 *
Amb Press Set @TPL2	Set			No	500.0 *
SET-1 @TPL2	Set			No	500.0 *
Air Fan @TPL2	Compressor	Moist Air @TPL2 Air Fan Power @TPL2	1 @TPL2	No	500.0 *
VLV2 @TPL2	Valve	3 @TPL2	4 @TPL2	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Water Cooling Calcs @TPL2

Units Set: NGNP1

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
B1	Material Stream:	Cooling Water Out @TPL2	Mass Flow	3318 kg/s
B5	Material Stream:	Moist Air @TPL2	Actual Volume Flow	3228 m3/s
B3	Material Stream:	Saturated Air @TPL2	Master Comp Mass Flow (H2O)	77.2562 kg/s
B7	Material Stream:	Water Return @TPL2	Mass Flow	3250 kg/s
D1	Energy Stream:	Cooling Water Pump Powe	Power	9.565 kW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
B2	Entrained Water @TPL2	Mass Flow	3.318 kg/s
B6	Air Fan Power @TPL2	Power	637.6 kW
B4	Blowdown @TPL2	Mass Flow	15.45 kg/s
B8	Make Up Water @TPL2	Mass Flow	68.19 kg/s
D2	Total Cooling Tower Power @TPL2	Power	647.2 kW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B9	B9:		---	<empty>
B8	B8: Mass Flow	Mass Flow	Mass Flow	68.19 kg/s
B4	B4: Mass Flow	Mass Flow	Mass Flow	15.45 kg/s
B6	B6: Power	Power	Power	637.6 kW
B2	B2: Mass Flow	Mass Flow	Mass Flow	3.318 kg/s
D7	D7:		---	<empty>
D2	D2: Power	Power	Power	647.2 kW

User Variables

FORMULAS

Cell	Formula	Result
B2	=.001*B1	3.318 kg/s
B4	=.20*B3	15.45 kg/s
B6	=B5/5.063	637.6 kW
B8	=B1-B7	68.19 kg/s
D2	=(D1+B6)	647.2 kW

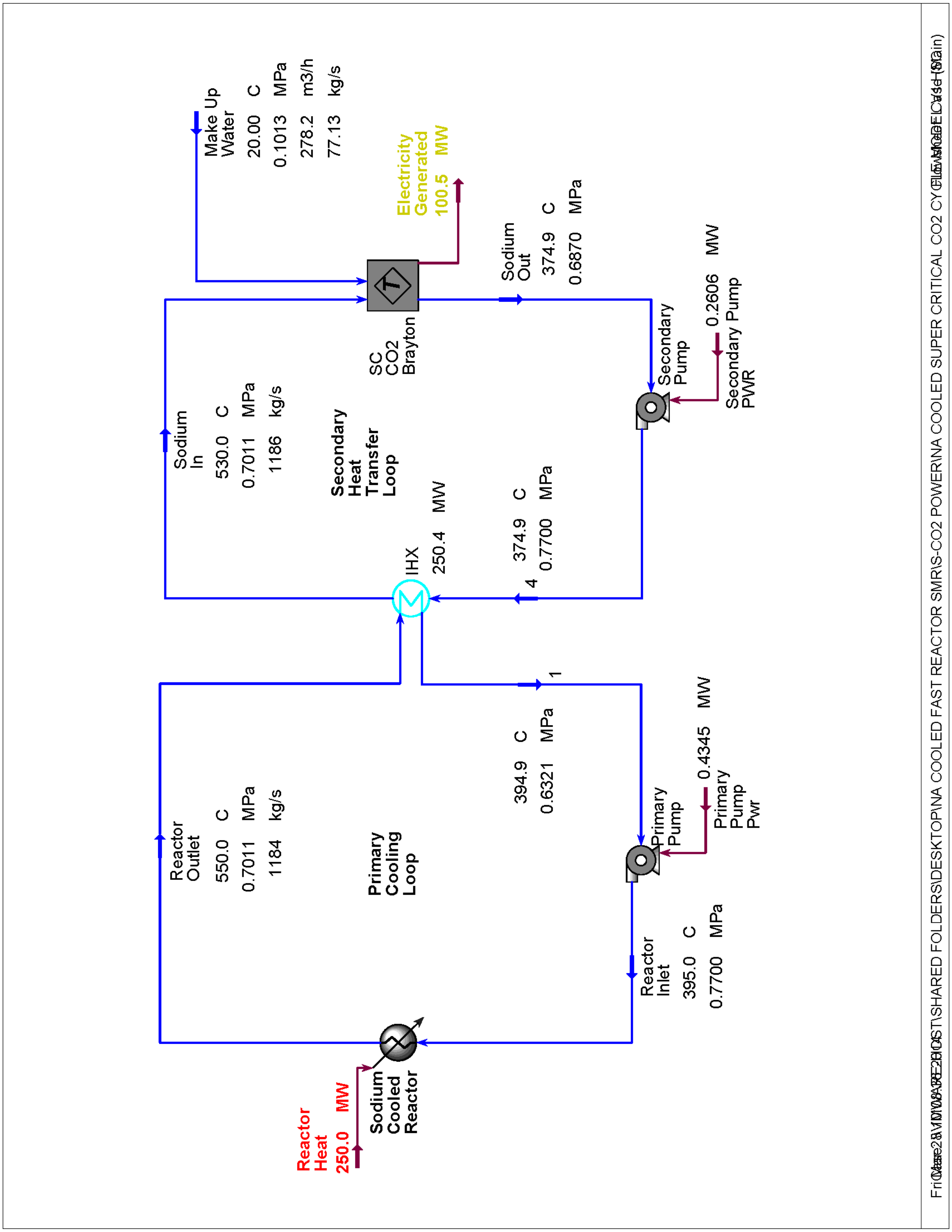
Spreadsheet

	A	B	C	D
1	Cooling Water Mass Flow *	3318 kg/s *	Cooling Water Pump Power *	9.565 kW *
2	Entrained Water Mass Flow *	3.318 kg/s *	Total Cooling Tower Power *	647.2 kW *
3	Evaporated Water Mass Flow *	77.2562 kg/s *		
4	Blowdown Mass Flow *	15.45 kg/s *		
5	Moist Air Volume Flow *	3228 m3/s *		
6	Fan Power *	637.6 kW *		
7	Water Return Flow *	3250 kg/s *		<empty> *
8	Make Up Water Flow *	68.19 kg/s *		
9		<empty> *		
10		<empty> *		

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

6.3 Supercritical CO_2 Modified Brayton Power Cycle Model



Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	1186	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	4544	4544	4537	4537	4537
Heat Flow	(MW)	818.8	568.3	849.9	599.9	599.5
Name		**Sodium Out**	**Make Up Water**			
Vapour Fraction		0.0000	0.0000			
Temperature	(C)	374.9	20.00			
Pressure	(MPa)	0.6870	0.1013			
Molar Flow	(kgmole/h)	1.857e+005	1.541e+004			
Mass Flow	(kg/s)	1186	77.13			
Liquid Volume Flow	(m3/h)	4544	278.2			
Heat Flow	(MW)	568.1	-1222			

Compositions

Fluid Pkg: All

Name	Sodium In	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***
Name	**Sodium Out**	**Make Up Water**			
Comp Mole Frac (H2O)	***	1.0000			
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	***			
Comp Mole Frac (Air)	***	***			

Energy Streams

Fluid Pkg: All

Name		Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWI	
Heat Flow	(MW)	250.0 *	100.5	0.4345	0.2606	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
SC CO2 Brayton	Standard Sub-Flowsheet	Sodium In Make Up Water	Sodium Out Electricity Generated	No	2500 *
Efficiency Calcs	Spreadsheet			No	500.0 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Case (Main) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Efficiency Calcs

Units Set: NuScale1

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A1	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
A4	Energy Stream: Electricity Generated	Power	100.5 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A2	A2:		---	<empty>
A3	A3: Heat to Rankine Cycle	Heat to Rankine Cycle	---	<empty>
A5	A5: Power Cycle Efficiency	Power Cycle Efficiency	Percent	<empty>
A6	A6: Reactor Heat to HTSE	Reactor Heat to HTSE	---	<empty>
B1	B1:		Mass Flow	<empty>
B2	B2:		Mass Heating Value	<empty>
B3	B3: Hydrogen Production Efficiency	Hydrogen Production Efficiency	Percent	<empty>
C1	C1:		Molar Enthalpy	<empty>
C2	C2:		Molar Enthalpy	<empty>
C3	C3:		Molar Flow	<empty>
C4	C4:		---	<empty>

User Variables

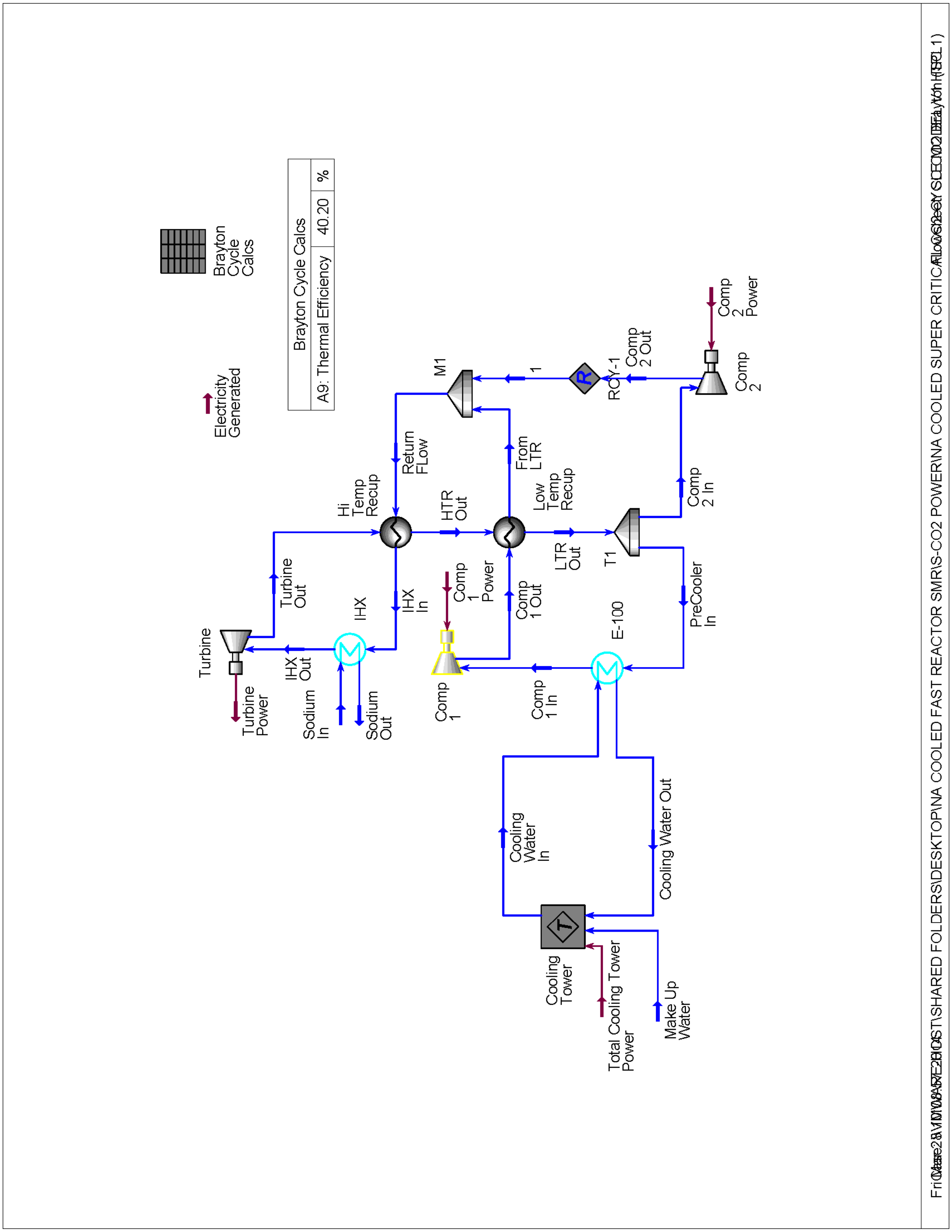
FORMULAS

Cell	Formula	Result
A3	=A1*A2	<empty>
A5	=A4/A3*100	<empty>
A6	=A1-A3	<empty>
B3	=(B1*B2/1000)/A1*100	<empty>
C4	=C3*(C2-C1)/3600000	<empty>

Spreadsheet

	A	B	C	D
1	250.0 MW *	<empty> *	<empty> *	
2	<empty> *	<empty> *	<empty> *	
3	<empty> *	<empty> *	<empty> *	
4	100.5 MW *		<empty> *	
5	<empty> *			
6	<empty> *			
7				
8				
9				
10				

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.


Brayton Cycle Calcs
A9: Thermal Efficiency 40.20 %
Electricity Generated
Turbine
Turbine Power
Turbine Out
IHX
IHX Out
IHX In
Sodium In
Sodium Out
Hi Temp Recup
HTR Out
Low Temp Recup
LTR Out
Return FLow
From LTR
M1
1
RCY-1
Comp 2 Out
Comp 2
Comp 2 Power
Comp 2 In
T1
PreCooler In
E-100
Comp 1
Comp 1 Power
Comp 1 Out
Comp 1 In
Cooling Water In
Cooling Water Out
Cooling Tower
Total Cooling Tower Power
Make Up Water

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:05:37 2014

Workbook: SC CO2 Brayton (TPL1)

Material Streams

Fluid Pkg: All

Name		Sodium In @TPL1	Sodium Out @TPL1	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	1.0000	1.0000
Temperature	(C)	530.0	374.9	510.0	354.9	403.8
Pressure	(MPa)	0.7011	0.6870	19.60	20.00	7.866 *
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.075e+005	1.075e+005	1.075e+005
Mass Flow	(kg/s)	1186	1186	1314	1314	1314
Liquid Volume Flow	(m3/h)	4544	4544	5733	5733	5733
Heat Flow	(MW)	818.8	568.1	-1.114e+004	-1.139e+004	-1.128e+004
Name		HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	0.0000	0.0000
Temperature	(C)	139.3	133.7	74.30	30.56	68.74
Pressure	(MPa)	7.709	20.41	7.555	7.404	20.83
Molar Flow	(kgmole/h)	1.075e+005	1.075e+005	1.075e+005	7.464e+004	7.464e+004
Mass Flow	(kg/s)	1314	1314	1314	912.5	912.5
Liquid Volume Flow	(m3/h)	5733	5733	5733	3980	3980
Heat Flow	(MW)	-1.168e+004	-1.178e+004	-1.179e+004	-8334	-8311
Name		From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	120.2	74.30	74.30	168.4	168.4 *
Pressure	(MPa)	20.41	7.555	7.555	20.41 *	20.41 *
Molar Flow	(kgmole/h)	7.464e+004	7.464e+004	3.287e+004	3.287e+004	3.287e+004 *
Mass Flow	(kg/s)	912.5	912.5	401.9	401.9	401.9
Liquid Volume Flow	(m3/h)	3980	3980	1753	1753	1753
Heat Flow	(MW)	-8202	-8185	-3605	-3580	-3580
Name		Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL		
Vapour Fraction		0.0000	0.0000	0.0000		
Temperature	(C)	28.70	25.00 *	20.00		
Pressure	(MPa)	0.1015	0.1035	0.1013		
Molar Flow	(kgmole/h)	1.866e+006	1.866e+006	1.541e+004		
Mass Flow	(kg/s)	9339	9339	77.13		
Liquid Volume Flow	(m3/h)	3.369e+004	3.369e+004	278.2		
Heat Flow	(MW)	-1.482e+005	-1.484e+005	-1227		

Compositions

Fluid Pkg: All

Name	Sodium In @TPL1	Sodium Out @TPL1	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	***	***	1.0000 *	1.0000	1.0000
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	1.0000	1.0000	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	1.0000	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: SC CO2 Brayton (TPL1) (continued)

Compositions (continued)

Fluid Pkg: All

Name	From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1 @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	1.0000	1.0000	1.0000	1.0000	1.0000 *
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL		
Comp Mole Frac (H2O)	1.0000	1.0000	1.0000		
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000		
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000		
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000		
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000		
Comp Mole Frac (CO)	0.0000	0.0000	0.0000		
Comp Mole Frac (Sodium)	***	***	***		
Comp Mole Frac (Air)	***	***	***		

Energy Streams

Fluid Pkg: All

Name		Turbine Power @TPL1	Comp 1 Power @TPL	Comp 2 Power @TPL	Electricity Generated (	Total Cooling Tower P
Heat Flow	(MW)	149.8	22.86	25.06	100.5	0.6971

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
IHX @TPL1	Heat Exchanger	Sodium In @TPL1 IHX In @TPL1	Sodium Out @TPL1 IHX Out @TPL1	No	500.0 *
Hi Temp Recup @TPL1	Heat Exchanger	Return FLow @TPL1 Turbine Out @TPL1	IHX In @TPL1 HTR Out @TPL1	No	500.0 *
Low Temp Recup @TPL1	Heat Exchanger	Comp 1 Out @TPL1 HTR Out @TPL1	From LTR @TPL1 LTR Out @TPL1	No	500.0 *
E-100 @TPL1	Heat Exchanger	Cooling Water In @TPL1 PreCooler In @TPL1	Cooling Water Out @TPL1 Comp 1 In @TPL1	No	500.0 *
IHX tb dP @TPL1	Set			No	500.0 *
IHX sh dP @TPL1	Set			No	500.0 *
HTR tb dP @TPL1	Set			No	500.0 *
HTR sh dP @TPL1	Set			No	500.0 *
LTR sh dP @TPL1	Set			No	500.0 *
LTR tb dP @TPL1	Set			No	500.0 *
Pre Cooler tb dP @TPL1	Set			No	500.0 *
Pre Cooler sh dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Turbine @TPL1	Expander	IHX Out @TPL1	Turbine Out @TPL1 Turbine Power @TPL1	No	500.0 *
M1 @TPL1	Mixer	From LTR @TPL1 1 @TPL1	Return FLow @TPL1	No	500.0 *
T1 @TPL1	Tee	LTR Out @TPL1	PreCooler In @TPL1 Comp 2 In @TPL1	No	500.0 *
Comp 1 @TPL1	Compressor	Comp 1 In @TPL1 Comp 1 Power @TPL1	Comp 1 Out @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: SC CO2 Brayton (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level

Case Name:	NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:05:37 2014

Spreadsheet: Brayton Cycle Calcs @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A1	Energy Stream: Turbine Power @TPL1	Power	149.8 MW
A2	Energy Stream: Comp 1 Power @TPL1	Power	22.86 MW
A3	Energy Stream: Comp 2 Power @TPL1	Power	25.06 MW
A4	Energy Stream: Total Cooling Tower Powe	Power	0.6971 MW
A5	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
A6	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
A8	Energy Stream: Reactor Heat	Heat Flow	250.0 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
A7	Electricity Generated @TPL1	Power	100.5 MW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A7	A7: Power	Power	Power	100.5 MW
A9	A9: Thermal Efficiency	Thermal Efficiency	Percent	40.20

User Variables

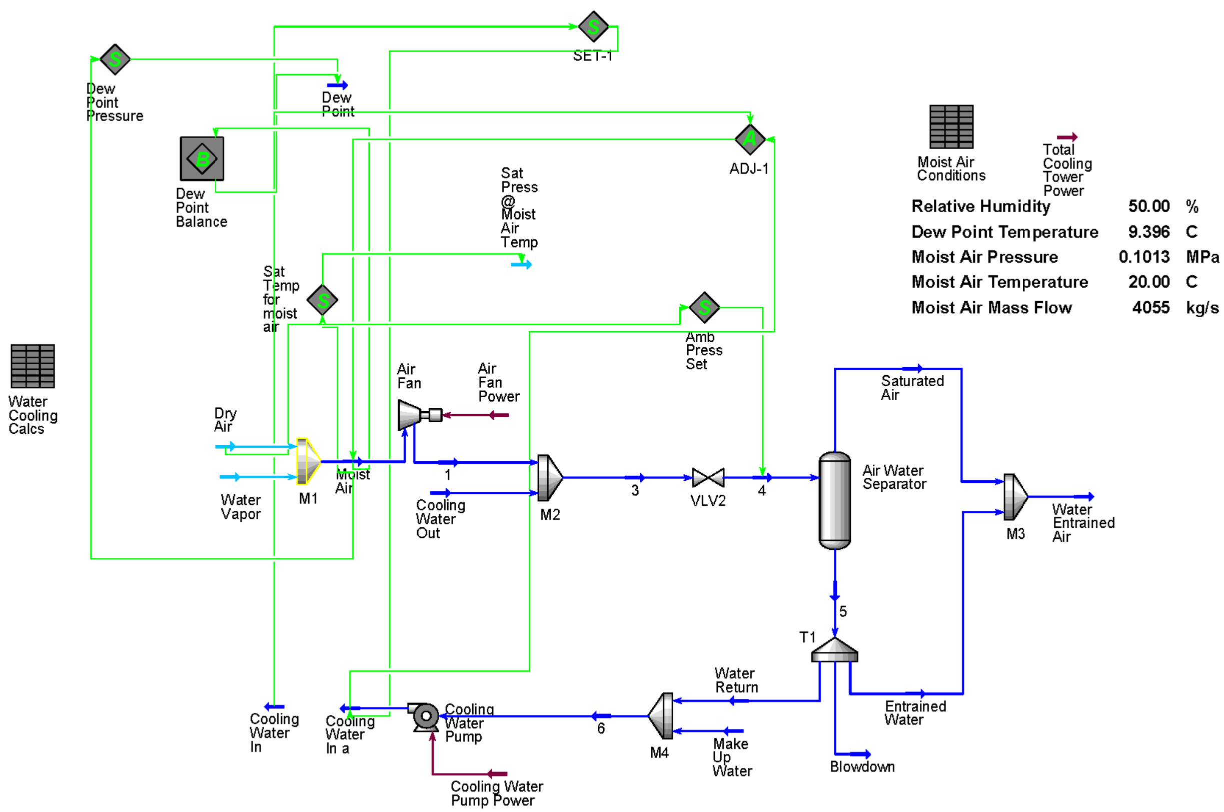
FORMULAS

Cell	Formula	Result
A7	=A1-A2-A3-A4-A5-A6	100.5 MW
A9	=A7/A8*100	40.20

Spreadsheet

	A	B	C	D
1	149.8 MW *			
2	22.86 MW *			
3	25.06 MW *			
4	0.6971 MW *			
5	0.4345 MW *			
6	0.2606 MW *			
7	100.5 MW *			
8	250.0 MW *			
9	40.20 *			
10				

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.



Fri Mar 28 ... \\...\\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\S-CO2 POWER\NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1 ... Flowsheet: Cooling Tower (FPL4)

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED SUPER CRITICAL CO2 CYCLE MODEL V1.HSC
	Unit Set:	AFR
	Date/Time:	Fri Mar 28 11:05:37 2014

Workbook: Cooling Tower (TPL4)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	Cooling Water In @TP	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air
Vapour Fraction		0.0000	0.0000	---	---	1.0000 *
Temperature	(C)	28.70	25.00	---	---	20.00
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	2.339e-003
Molar Flow	(kgmole/h)	1.866e+006	1.866e+006	5.023e+005	5845	---
Mass Flow	(kg/s)	9339	9339	4026	29.25	---
Liquid Volume Flow	(m3/h)	3.369e+004	3.369e+004	1.675e+004	105.5	---
Heat Flow	(MW)	-1.482e+005	-1.484e+005	---	---	---
Name		1 @TPL4	3 @TPL4	Dew Point @TPL4	4 @TPL4	Saturated Air @TPL4
Vapour Fraction		1.0000	0.2184	1.0000 *	0.2184	1.0000
Temperature	(C)	20.16	25.05	9.396	25.04	25.04
Pressure	(MPa)	0.1015	0.1015	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	5.082e+005	2.374e+006	5.082e+005	2.374e+006	5.185e+005
Mass Flow	(kg/s)	4055	1.339e+004	4055	1.339e+004	4107
Liquid Volume Flow	(m3/h)	1.686e+004	5.055e+004	1.686e+004	5.055e+004	1.705e+004
Heat Flow	(MW)	-413.9	-1.486e+005	-458.2	-1.486e+005	-1087
Name		5 @TPL4	Entrained Water @TP	Blowdown @TPL4	Water Return @TPL4	Water Entrained Air @
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.9964
Temperature	(C)	25.04	25.04	25.04	25.04	25.04
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	1.856e+006	1866	3233	1.851e+006	5.204e+005
Mass Flow	(kg/s)	9287	9.339	16.18	9262	4116
Liquid Volume Flow	(m3/h)	3.350e+004	33.69	58.36	3.341e+004	1.708e+004
Heat Flow	(MW)	-1.475e+005	-148.4	-257.0	-1.471e+005	-1235
Name		Make Up Water @TPL	Cooling Water In a @T	6 @TPL4	Moist Air @TPL4	
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	
Temperature	(C)	20.00 *	25.00	25.00	20.00 *	
Pressure	(MPa)	0.1013	0.1035	0.1013	0.1013 *	
Molar Flow	(kgmole/h)	1.541e+004	1.866e+006	1.866e+006	5.082e+005	
Mass Flow	(kg/s)	77.13	9339	9339	4055 *	
Liquid Volume Flow	(m3/h)	278.2	3.369e+004	3.369e+004	1.686e+004	
Heat Flow	(MW)	-1227	-1.484e+005	-1.484e+005	-414.5	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	Cooling Water In @TP	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	1.0000 *
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	***
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	***
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	1 @TPL4	3 @TPL4	Dew Point @TPL4	4 @TPL4	Saturated Air @TPL4
Comp Mole Frac (H2O)	0.0115	0.7884	0.0115	0.7884	0.0312
Comp Mole Frac (Nitrogen)	0.7809	0.1671	0.7809	0.1671	0.7654
Comp Mole Frac (Oxygen)	0.2076	0.0444	0.2076	0.0444	0.2035
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Cooling Tower (TPL4) (continued)

Compositions (continued)

Fluid Pkg: All

Name	5 @TPL4	Entrained Water @TP	Blowdown @TPL4	Water Return @TPL4	Water Entrained Air @
Comp Mole Frac (H2O)	1.0000	1.0000	1.0000	1.0000	0.0346
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.7626
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.2027
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	Make Up Water @TPL	Cooling Water In a @T	6 @TPL4	Moist Air @TPL4	
Comp Mole Frac (H2O)	1.0000 *	1.0000	1.0000	0.0115	
Comp Mole Frac (Nitrogen)	0.0000 *	0.0000	0.0000	0.7809	
Comp Mole Frac (Oxygen)	0.0000 *	0.0000	0.0000	0.2076	
Comp Mole Frac (Hydrogen)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	***	***	***	***	

Energy Streams

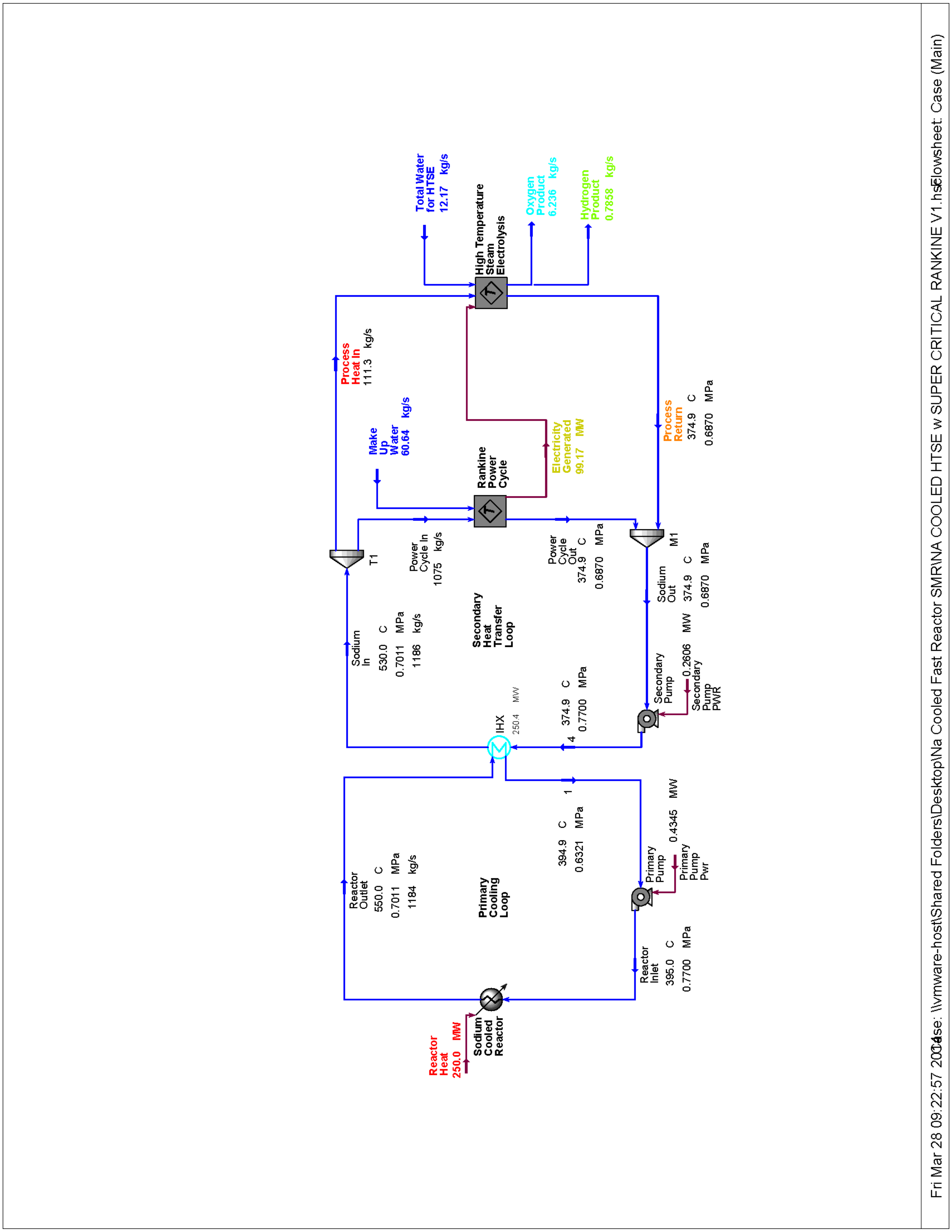
Fluid Pkg: All

Name		Air Fan Power @TPL4	Cooling Water Pump P	Total Cooling Tower P		
Heat Flow	(MW)	0.6702	2.692e-002	0.6971		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL4	Mixer	Dry Air @TPL4 Water Vapor @TPL4	Moist Air @TPL4	No	500.0 *
M2 @TPL4	Mixer	1 @TPL4 Cooling Water Out @TPL4	3 @TPL4	No	500.0 *
M3 @TPL4	Mixer	Saturated Air @TPL4 Entrained Water @TPL4	Water Entrained Air @TPL4	No	500.0 *
M4 @TPL4	Mixer	Water Return @TPL4 Make Up Water @TPL4	6 @TPL4	No	500.0 *
Moist Air Conditions @TPL4	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL4	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL4	Set			No	500.0 *
Dew Point Pressure @TPL4	Set			No	500.0 *
Amb Press Set @TPL4	Set			No	500.0 *
SET-1 @TPL4	Set			No	500.0 *
Air Fan @TPL4	Compressor	Moist Air @TPL4 Air Fan Power @TPL4	1 @TPL4	No	500.0 *
VLV2 @TPL4	Valve	3 @TPL4	4 @TPL4	No	500.0 *

6.4 Supercritical Rankine HTSE Model



Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	1186	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	4544	4544	4537	4537	4537
Heat Flow	(MW)	818.8	568.3	849.9	599.9	599.5
Name		Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE
Vapour Fraction		0.0000	0.0000	1.0000	1.0000	0.0000
Temperature	(C)	374.9	20.00	54.44	54.44	21.11
Pressure	(MPa)	0.6870	0.1013	6.901	6.901	0.1013
Molar Flow	(kgmole/h)	1.857e+005	1.212e+004	1403	701.6	2431
Mass Flow	(kg/s)	1186	60.64	0.7858	6.236	12.17
Liquid Volume Flow	(m3/h)	4544	218.8	40.49	19.73	43.89
Heat Flow	(MW)	568.1	-960.6	0.3318	6.804e-002	-193.5
Name		Process Heat In	Process Return	Power Cycle In	Power Cycle Out	
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	
Temperature	(C)	530.0	374.9	530.0	374.9	
Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	
Molar Flow	(kgmole/h)	1.743e+004	1.743e+004	1.683e+005	1.683e+005	
Mass Flow	(kg/s)	111.3	111.3	1075	1075	
Liquid Volume Flow	(m3/h)	426.5	426.5	4117	4117	
Heat Flow	(MW)	76.85	53.32	741.9	514.8	

Compositions

Fluid Pkg: All

Name	Sodium In	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***
Name	Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE
Comp Mole Frac (H2O)	***	1.0000	0.0000	0.0000	1.0000
Comp Mole Frac (Nitrogen)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	***	***	0.0000	1.0000	0.0000
Comp Mole Frac (Hydrogen)	***	***	1.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	1.0000	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Case (Main) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Process Heat In	Process Return	Power Cycle In	Power Cycle Out
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	1.0000	1.0000	1.0000
Comp Mole Frac (Air)	***	***	***	***

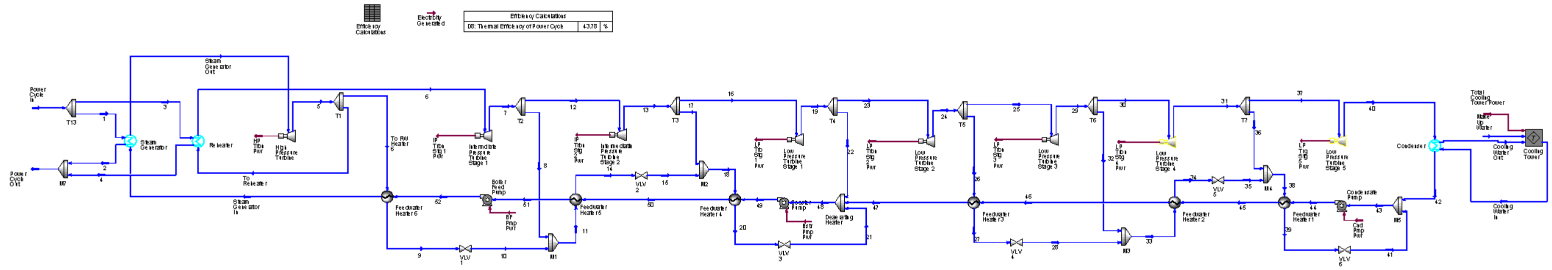
Energy Streams

Fluid Pkg: All

Name	Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWR
Heat Flow (MW)	250.0 *	99.17	0.4345	0.2606

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
Rankine Power Cycle	Standard Sub-Flowsheet	Power Cycle In Make Up Water	Power Cycle Out Electricity Generated	No	2500 *
High Temperature Steam Elec	Standard Sub-Flowsheet	Process Heat In Total Water for HTSE Electricity Generated	Hydrogen Product Oxygen Product Process Return	No	2500 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *
T1	Tee	Sodium In	Power Cycle In Process Heat In	No	500.0 *
M1	Mixer	Process Return Power Cycle Out	Sodium Out	No	500.0 *



Fri Mar 28 09:23:37 2014 Case: \\vmware-host\Shared Folders\Desktop\Na Cooled Fast Reactor SMR\NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc Flowsheet: Rankine Power Cycle (TPL1)

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc Unit Set: AFR Date/Time: Fri Mar 28 11:16:39 2014

Workbook: Rankine Power Cycle (TPL1)

Streams

Fluid Pkg: All

Name		Steam Generator Out	To Reheater @TPL1	To FW Heater 6 @TPI	6 @TPL1	9 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	510.0	354.9	354.9	510.0	276.0
Pressure	(MPa)	24.00	8.510	8.510	8.340	8.340
Molar Flow	(kgmole/h)	1.965e+004	1.828e+004	1363	1.828e+004	1363
Mass Flow	(kg/s)	98.32	91.49	6.823	91.49	6.823
Std Ideal Liq Vol Flow	(m3/h)	354.7	330.0	24.61	330.0	24.61
Heat Flow	(MW)	-1249	-1184	-88.27	-1144	-100.4
Molar Enthalpy	(kJ/kgmole)	-2.289e+005	-2.330e+005	-2.330e+005	-2.253e+005	-2.650e+005
Name		52 @TPL1	Steam Generator In @	51 @TPL1	8 @TPL1	12 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
Temperature	(C)	270.5	295.3	263.1	442.4	442.4
Pressure	(MPa)	24.99 *	24.49	4.936	5.390	5.390
Molar Flow	(kgmole/h)	1.965e+004	1.965e+004	1.965e+004	1269	1.701e+004
Mass Flow	(kg/s)	98.32	98.32	98.32	6.350	85.14
Std Ideal Liq Vol Flow	(m3/h)	354.7	354.7	354.7	22.90	307.1
Heat Flow	(MW)	-1449	-1437	-1453	-80.20	-1075
Molar Enthalpy	(kJ/kgmole)	-2.655e+005	-2.633e+005	-2.662e+005	-2.276e+005	-2.276e+005
Name		11 @TPL1	16 @TPL1	18 @TPL1	23 @TPL1	22 @TPL1
Vapour Fraction		0.6439	1.0000	0.3688	1.0000	1.0000
Temperature	(C)	268.7	363.6	235.4	272.6	272.6
Pressure	(MPa)	5.390	3.080	3.080	1.365	1.365
Molar Flow	(kgmole/h)	2632	1.583e+004	3813	1.473e+004	1099
Mass Flow	(kg/s)	13.17	79.23	19.08	73.74	5.499
Std Ideal Liq Vol Flow	(m3/h)	47.52	285.8	68.83	266.0	19.84
Heat Flow	(MW)	-180.6	-1013	-271.9	-954.5	-71.18
Molar Enthalpy	(kJ/kgmole)	-2.469e+005	-2.302e+005	-2.567e+005	-2.332e+005	-2.332e+005
Name		49 @TPL1	14 @TPL1	20 @TPL1	47 @TPL1	48 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	194.5	235.2	200.1	155.2	193.6
Pressure	(MPa)	5.140 *	5.390	3.018	1.365	1.365
Molar Flow	(kgmole/h)	1.965e+004	2632	3813	1.473e+004	1.965e+004
Mass Flow	(kg/s)	98.32	13.17	19.08	73.74	98.32
Std Ideal Liq Vol Flow	(m3/h)	354.7	47.52	68.83	266.0	354.7
Heat Flow	(MW)	-1484	-196.4	-287.6	-1126	-1485
Molar Enthalpy	(kJ/kgmole)	-2.719e+005	-2.686e+005	-2.715e+005	-2.751e+005	-2.720e+005
Name		21 @TPL1	25 @TPL1	26 @TPL1	27 @TPL1	30 @TPL1
Vapour Fraction		0.0145	1.0000	1.0000	0.0000	0.9923
Temperature	(C)	193.9	196.4	196.4	123.1	123.1
Pressure	(MPa)	1.365	0.6210	0.6210	0.6086	0.2190
Molar Flow	(kgmole/h)	3813	1.371e+004	1023	1023	1.276e+004
Mass Flow	(kg/s)	19.08	68.62	5.117	5.117	63.86
Std Ideal Liq Vol Flow	(m3/h)	68.83	247.5	18.46	18.46	230.3
Heat Flow	(MW)	-287.6	-897.8	-66.95	-78.84	-844.8
Molar Enthalpy	(kJ/kgmole)	-2.715e+005	-2.357e+005	-2.357e+005	-2.776e+005	-2.383e+005

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc Unit Set: AFR Date/Time: Fri Mar 28 11:16:39 2014

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1
Vapour Fraction		0.9923	0.9421	0.0000	0.0000	0.0000
Temperature	(C)	123.1	84.55	84.50	45.88	40.33
Pressure	(MPa)	0.2190	5.680e-002	0.2146	5.566e-002	1.450 *
Molar Flow	(kgmole/h)	951.6	1.187e+004	1974	2860	1.473e+004
Mass Flow	(kg/s)	4.762	59.42	9.879	14.31	73.74
Std Ideal Liq Vol Flow	(m3/h)	17.18	214.4	35.64	51.62	266.0
Heat Flow	(MW)	-63.00	-796.7	-153.8	-225.1	-1162
Molar Enthalpy	(kJ/kgmole)	-2.383e+005	-2.415e+005	-2.805e+005	-2.834e+005	-2.838e+005

Name		40 @TPL1	38 @TPL1	42 @TPL1	33 @TPL1	41 @TPL1
Vapour Fraction		0.8839	0.2917	0.0000	0.4783	0.0100
Temperature	(C)	40.51	84.55	38.79	123.1	40.13
Pressure	(MPa)	7.584e-003 *	5.680e-002	7.433e-003	0.2190	7.433e-003
Molar Flow	(kgmole/h)	1.187e+004	2860	1.187e+004	1974	2860
Mass Flow	(kg/s)	59.42	14.31	59.42	9.879	14.31
Std Ideal Liq Vol Flow	(m3/h)	214.4	51.62	214.4	35.64	51.62
Heat Flow	(MW)	-809.9	-213.2	-936.6	-141.8	-225.1
Molar Enthalpy	(kJ/kgmole)	-2.455e+005	-2.684e+005	-2.839e+005	-2.587e+005	-2.834e+005

Name		1 @TPL1	3 @TPL1	2 @TPL1	4 @TPL1	Power Cycle In @TPL
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
Molar Flow	(kgmole/h)	1.390e+005	2.926e+004	1.390e+005	2.926e+004	1.683e+005
Mass Flow	(kg/s)	887.8	186.9	887.8	186.9	1075
Std Ideal Liq Vol Flow	(m3/h)	3401	715.9	3401	715.9	4117
Heat Flow	(MW)	612.9	129.0	425.3	89.51	741.9
Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004

Name		Power Cycle Out @TF	5 @TPL1	10 @TPL1	7 @TPL1	13 @TPL1
Vapour Fraction		0.0000	1.0000	0.0226	1.0000	1.0000
Temperature	(C)	374.9	354.9	268.7	442.4	363.6
Pressure	(MPa)	0.6870	8.510 *	5.390	5.390 *	3.080 *
Molar Flow	(kgmole/h)	1.683e+005	1.965e+004	1363	1.828e+004	1.701e+004
Mass Flow	(kg/s)	1075	98.32	6.823	91.49	85.14
Std Ideal Liq Vol Flow	(m3/h)	4117	354.7	24.61	330.0	307.1
Heat Flow	(MW)	514.8	-1272	-100.4	-1156	-1088
Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.330e+005	-2.650e+005	-2.276e+005	-2.302e+005

Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45 @TPL1
Vapour Fraction		1.0000	1.0000	0.9923	0.9421	0.0000
Temperature	(C)	272.6	196.4	123.1	84.55	78.94
Pressure	(MPa)	1.365	0.6210 *	0.2190 *	5.680e-002 *	1.421
Molar Flow	(kgmole/h)	1.583e+004	1.473e+004	1.371e+004	1.276e+004	1.473e+004
Mass Flow	(kg/s)	79.23	73.74	68.62	63.86	73.74
Std Ideal Liq Vol Flow	(m3/h)	285.8	266.0	247.5	230.3	266.0
Heat Flow	(MW)	-1026	-964.7	-907.8	-856.1	-1150
Molar Enthalpy	(kJ/kgmole)	-2.332e+005	-2.357e+005	-2.383e+005	-2.415e+005	-2.809e+005

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28 @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	117.5	229.7	363.6	235.3	123.1
Pressure	(MPa)	1.393	5.037	3.080	3.080	0.2190
Molar Flow	(kgmole/h)	1.473e+004	1.965e+004	1181	2632	1023
Mass Flow	(kg/s)	73.74	98.32	5.909	13.17	5.117
Std Ideal Liq Vol Flow	(m3/h)	266.0	354.7	21.32	47.52	18.46
Heat Flow	(MW)	-1138	-1468	-75.51	-196.4	-78.84
Molar Enthalpy	(kJ/kgmole)	-2.780e+005	-2.691e+005	-2.302e+005	-2.686e+005	-2.776e+005

Name		36 @TPL1	35 @TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
Vapour Fraction		0.9421	0.0000	0.0001	---	---
Temperature	(C)	84.55	84.53	40.13	---	---
Pressure	(MPa)	5.680e-002	5.680e-002	7.433e-003	---	---
Molar Flow	(kgmole/h)	885.6	1974	1.473e+004	---	---
Mass Flow	(kg/s)	4.432	9.879	73.74	---	---
Std Ideal Liq Vol Flow	(m3/h)	15.99	35.64	266.0	---	---
Heat Flow	(MW)	-59.41	-153.8	-1162	22.40	11.61
Molar Enthalpy	(kJ/kgmole)	-2.415e+005	-2.805e+005	-2.838e+005	---	---

Name		IP Trbn Stg 2 Pwr @T	LP Trb Stg 1 Pwr @TP	Bstr Pmp Pwr @TPL1	LP Trbn Stg 2 Pwr @T	LP Trbn Stg 3 Pwr @T
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	12.54	13.13	0.5664	10.24	10.06
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---

Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TP	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated @
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	11.26	13.23	3.319	0.1429	99.17
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---

Name		Cooling Water Out @T	Cooling Water In @TP	Make Up Water @TPL	Total Cooling Tower P	
Vapour Fraction		0.0000	0.0000	0.0000	---	
Temperature	(C)	34.95	25.00	20.00	---	
Pressure	(MPa)	0.1015	0.1035	0.1013	---	
Molar Flow	(kgmole/h)	5.899e+005	5.899e+005	1.212e+004	---	
Mass Flow	(kg/s)	2952	2952	60.64	---	
Std Ideal Liq Vol Flow	(m3/h)	1.065e+004	1.065e+004	218.8	---	
Heat Flow	(MW)	-4.678e+004	-4.690e+004	-960.6	0.5756	
Molar Enthalpy	(kJ/kgmole)	-2.854e+005	-2.862e+005	-2.854e+005	---	

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Expanders

Fluid Pkg: All

Name		High Pressure Turbine	Intermdiate Pressure T	Intermediatte Pressure	Low Pressure Turbine	Low Pressure Turbine
Power	(MW)	22.40	11.61	12.54	13.13	10.24
Capacity (act feed vol flow)	(ACT_m3/h)	4274	1.337e+004	1.768e+004	2.579e+004	4.692e+004
Feed Pressure	(MPa)	24.00	8.340	5.390	3.080	1.365
Product Pressure	(MPa)	8.510 *	5.390 *	3.080 *	1.365	0.6210 *
Product Temperature	(C)	354.9	442.4	363.6	272.6	196.4
Adiabatic Efficiency		85 *	90 *	90 *	80 *	80 *
Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
Power	(MW)	10.06	11.26	13.23		
Capacity (act feed vol flow)	(ACT_m3/h)	8.315e+004	1.856e+005	5.797e+005		
Feed Pressure	(MPa)	0.6210	0.2190	5.680e-002		
Product Pressure	(MPa)	0.2190 *	5.680e-002 *	7.584e-003 *		
Product Temperature	(C)	123.1	84.55	40.51		
Adiabatic Efficiency		75 *	80 *	80 *		

Pumps

Fluid Pkg: All

Name		Boiler Feed Pump @T	Booster Pump @TPL1	Condensate Pump @T		
Power	(MW)	3.319	0.5664	0.1429		
Capacity(Actual Vol. Flow)	(m3/h)	454.4	405.8	618.0		
Feed Pressure	(MPa)	4.936	1.365	7.433e-003		
Product Pressure	(MPa)	24.99 *	5.140 *	1.450 *		
Product Temperature	(C)	270.5	194.5	40.33		
Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		

Heat Exchangers

Fluid Pkg: All

Name		Feedwater Heater 6 @	Feedwater Heater 5 @	Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
Duty	(MW)	12.10	15.82	15.67	11.89	11.98
Tube Side Feed Mass Flow	(kg/s)	98.32	98.32	98.32	73.74	73.74
Shell Side Feed Mass Flow	(kg/s)	6.823	13.17	19.08	5.117	9.879
Tube Inlet Temperature	(C)	270.5	229.7	194.5	117.5	78.94
Tube Outlet Temperature	(C)	295.3	263.1	229.7	155.2	117.5
Shell Inlet Temperature	(C)	354.9	268.7	235.4	196.4	123.1
Shell Outlet Temperature	(C)	276.0	235.2	200.1	123.1	84.50
LMTD	(C)	15.08	15.75	15.48	18.00	17.06
Minimum Approach	(C)	5.556	5.556	5.556	5.556	5.556
UA	(kJ/C-h)	2.888e+006	3.617e+006	3.643e+006	2.378e+006	2.527e+006
Name		Feedwater Heater 1 @	Steam Generator @TF	Reheater @TPL1	Condenser @TPL1	
Duty	(MW)	11.90	187.7	39.50	126.7	
Tube Side Feed Mass Flow	(kg/s)	73.74	887.8	186.9	2952	
Shell Side Feed Mass Flow	(kg/s)	14.31	98.32	91.49	59.42	
Tube Inlet Temperature	(C)	40.33	530.0	530.0	25.00	
Tube Outlet Temperature	(C)	78.94	374.9	374.9 *	34.95	
Shell Inlet Temperature	(C)	84.55	295.3	354.9	40.51	
Shell Outlet Temperature	(C)	45.88	510.0	510.0	38.79	
LMTD	(C)	16.44	57.33	23.77	9.558	
Minimum Approach	(C)	5.556	20.00	20.00	5.556	
UA	(kJ/C-h)	2.607e+006	1.178e+007	5.983e+006	4.773e+007	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
High Pressure Turbine @TPL	Expander	Steam Generator Out @TPL1	5 @TPL1 HP Trbn Pwr @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:16:39 2014

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Intermdiate Pressure Turbine	Expander	6 @TPL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *
Intermediatte Pressure Turbin	Expander	12 @TPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 1	Expander	16 @TPL1	19 @TPL1 LP Trb Stg 1 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 2	Expander	23 @TPL1	24 @TPL1 LP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 3	Expander	25 @TPL1	29 @TPL1 LP Trbn Stg 3 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 4	Expander	30 @TPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 5	Expander	37 @TPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *
Feedwater Heater 6 @TPL1	Heat Exchanger	52 @TPL1 To FW Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *
Feedwater Heater 5 @TPL1	Heat Exchanger	50 @TPL1 11 @TPL1	51 @TPL1 14 @TPL1	No	500.0 *
Feedwater Heater 4 @TPL1	Heat Exchanger	49 @TPL1 18 @TPL1	50 @TPL1 20 @TPL1	No	500.0 *
Feedwater Heater 3 @TPL1	Heat Exchanger	46 @TPL1 26 @TPL1	47 @TPL1 27 @TPL1	No	500.0 *
Feedwater Heater 2 @TPL1	Heat Exchanger	45 @TPL1 33 @TPL1	46 @TPL1 34 @TPL1	No	500.0 *
Feedwater Heater 1 @TPL1	Heat Exchanger	44 @TPL1 38 @TPL1	45 @TPL1 39 @TPL1	No	500.0 *
Steam Generator @TPL1	Heat Exchanger	1 @TPL1 Steam Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *
Reheater @TPL1	Heat Exchanger	3 @TPL1 To Reheater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *
Condenser @TPL1	Heat Exchanger	Cooling Water In @TPL1 40 @TPL1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *
Boiler Feed Pump @TPL1	Pump	51 @TPL1 BF Pmp Pwr @TPL1	52 @TPL1	No	500.0 *
Booster Pump @TPL1	Pump	48 @TPL1 Bstr Pmp Pwr @TPL1	49 @TPL1	No	500.0 *
Condensate Pump @TPL1	Pump	43 @TPL1 Cnd Pmp Pwr @TPL1	44 @TPL1	No	500.0 *
M1 @TPL1	Mixer	10 @TPL1 8 @TPL1	11 @TPL1	No	500.0 *
M2 @TPL1	Mixer	17 @TPL1 15 @TPL1	18 @TPL1	No	500.0 *
Deaerating Heater @TPL1	Mixer	47 @TPL1 21 @TPL1 22 @TPL1	48 @TPL1	No	500.0 *
M4 @TPL1	Mixer	36 @TPL1 35 @TPL1	38 @TPL1	No	500.0 *
M3 @TPL1	Mixer	32 @TPL1 28 @TPL1	33 @TPL1	No	500.0 *
M5 @TPL1	Mixer	41 @TPL1 42 @TPL1	43 @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M7 @TPL1	Mixer	2 @TPL1 4 @TPL1	Power Cycle Out @TPL1	No	500.0 *
VLV 3 @TPL1	Valve	20 @TPL1	21 @TPL1	No	500.0 *
VLV 4 @TPL1	Valve	27 @TPL1	28 @TPL1	No	500.0 *
VLV 5 @TPL1	Valve	34 @TPL1	35 @TPL1	No	500.0 *
VLV 1 @TPL1	Valve	9 @TPL1	10 @TPL1	No	500.0 *
VLV 2 @TPL1	Valve	14 @TPL1	15 @TPL1	No	500.0 *
VLV 6 @TPL1	Valve	39 @TPL1	41 @TPL1	No	500.0 *
SG tb dP @TPL1	Set			No	500.0 *
SG sh dP @TPL1	Set			No	500.0 *
FW6 tb dP @TPL1	Set			No	500.0 *
FW6 sh dP @TPL1	Set			No	500.0 *
FW4 tb dP @TPL1	Set			No	500.0 *
FW5 tb dP @TPL1	Set			No	500.0 *
FW5 sh dP @TPL1	Set			No	500.0 *
FW4 sh dP @TPL1	Set			No	500.0 *
Cnd sh dP @TPL1	Set			No	500.0 *
FW1 tb dP @TPL1	Set			No	500.0 *
FW1 sh dP @TPL1	Set			No	500.0 *
FW2 tb dP @TPL1	Set			No	500.0 *
FW2 sh dP @TPL1	Set			No	500.0 *
FW3 tb dP @TPL1	Set			No	500.0 *
FW3 sh dP @TPL1	Set			No	500.0 *
Rht tb dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Cnd Tb dP @TPL1	Set			No	500.0 *
SET-3 @TPL1	Set			No	500.0 *
SET-4 @TPL1	Set			No	500.0 *
SET-5 @TPL1	Set			No	500.0 *
SET-6 @TPL1	Set			No	500.0 *
SET-7 @TPL1	Set			No	500.0 *
SET-8 @TPL1	Set			No	500.0 *
T1 @TPL1	Tee	5 @TPL1	To FW Heater 6 @TPL1 To Reheater @TPL1	No	500.0 *
T2 @TPL1	Tee	7 @TPL1	8 @TPL1 12 @TPL1	No	500.0 *
T3 @TPL1	Tee	13 @TPL1	17 @TPL1 16 @TPL1	No	500.0 *
T4 @TPL1	Tee	19 @TPL1	22 @TPL1 23 @TPL1	No	500.0 *
T5 @TPL1	Tee	24 @TPL1	26 @TPL1 25 @TPL1	No	500.0 *
T6 @TPL1	Tee	29 @TPL1	32 @TPL1 30 @TPL1	No	500.0 *
T7 @TPL1	Tee	31 @TPL1	36 @TPL1 37 @TPL1	No	500.0 *
T13 @TPL1	Tee	Power Cycle In @TPL1	3 @TPL1 1 @TPL1	No	500.0 *
Efficiency Calculations @TPL	Spreadsheet			No	500.0 *
Cooling Tower @TPL1	Standard Sub-Flowsheet	Cooling Water Out @TPL1 Make Up Water @TPL1	Cooling Water In @TPL1	No	2500 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Cooling Tower @TPL1	Standard Sub-Flowsheet	Total Cooling Tower Power @		No	2500 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Efficiency Calculations @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
B1	Energy Stream: HP Trbn Pwr @TPL1	Power	22.40 MW
B2	Energy Stream: IP Trbn Stg 1 Pwr @TPL1	Power	11.61 MW
B3	Energy Stream: IP Trbn Stg 2 Pwr @TPL1	Power	12.54 MW
B4	Energy Stream: LP Trb Stg 1 Pwr @TPL1	Power	13.13 MW
B5	Energy Stream: LP Trbn Stg 2 Pwr @TPL1	Power	10.24 MW
B6	Energy Stream: LP Trbn Stg 3 Pwr @TPL1	Power	10.06 MW
B7	Energy Stream: LP Trbn Stg 4 Pwr @TPL1	Power	11.26 MW
B8	Energy Stream: LP Trg Stg 5 Pwr @TPL1	Power	13.23 MW
B9	Energy Stream: Cnd Pmp Pwr @TPL1	Power	0.1429 MW
B10	Energy Stream: Bstr Pmp Pwr @TPL1	Power	0.5664 MW
D1	Energy Stream: BF Pmp Pwr @TPL1	Power	3.319 MW
D2	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
D3	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
D4	Energy Stream: Total Cooling Tower Powe	Power	0.5756 MW
D5	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
C9	Tee: T1	Flow Ratio (Flow Ratio_1)	0.9061

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
D7	Electricity Generated @TPL1	Power	99.17 MW
F1	Steam Generator In @TPL1	Mass Flow	98.32 kg/s

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
F1	F1: Mass Flow	Mass Flow	Mass Flow	98.32 kg/s
D7	D7: Power	Power	Power	99.17 MW
D10	D10: Power	Power	Mass Flow	108.5 kg/s
D8	D8: Thermal Efficiency of Power Cycle	Thermal Efficiency of Power Cycle	Percent	43.78
D6	D6: Total Turbine Power	Total Turbine Power	Power	104.5 MW

User Variables

FORMULAS

Cell	Formula	Result
D6	=B1+B2+B3+B4+B5+B6+B7+B8	104.5 MW
D7	=D6-B9-B10-D1-D2-D3-D4	99.17 MW
D8	=D7/(D5*C9)*100	43.78
F1	=C9*D10	98.32 kg/s

Spreadsheet

	A	B	C	D
1	HP Trb Pwr *	22.40 MW *	BF Pmp Pwr *	3.319 MW *
2	IP Trb Stg 1 Pwr *	11.61 MW *	Primary Pump Power *	0.4345 MW *
3	IP Trb Stg 2 Pwr *	12.54 MW *	Secondary Pump Power *	0.2606 MW *
4	LP Trb Stg 1 Pwr *	13.13 MW *	Cooling Tower Power *	0.5756 MW *
5	LP Trb Stg 2 Pwr *	10.24 MW *	Reactor Heat *	250.0 MW *
6	LP Trb Stg 3 Pwr *	10.06 MW *	Total Turbine Power *	104.5 MW *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

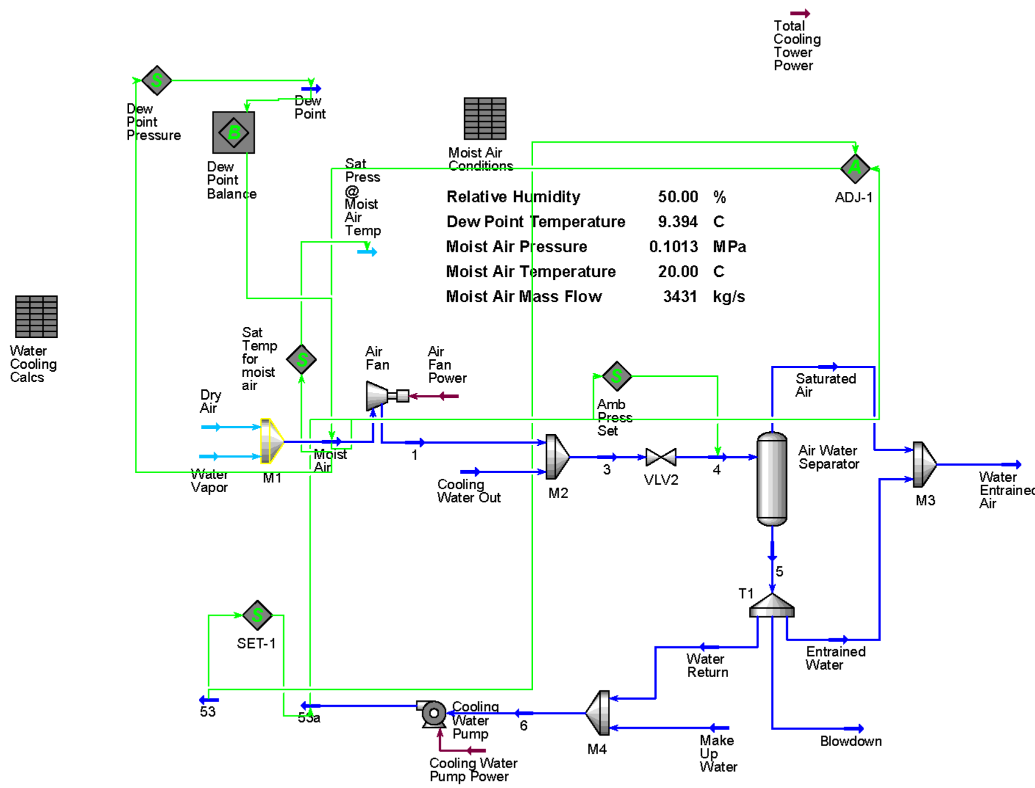
Spreadsheet: Efficiency Calculations @TPL1 (continu

Units Set: NuScale2

Spreadsheet

7	LP Trb Stg 4 Pwr *	11.26 MW *	Electricity Generated *	99.17 MW *
8	LP Trb Stg 5 Pwr *	13.23 MW *	Thermal Efficiency of Power Cycle *	43.78 *
9	Cnd Pmp Pwr *	0.1429 MW *	0.9061 *	Power flow split *
10	Bstr Pmp Pwr *	0.5664 MW *	100% Rankine Flow *	108.5 kg/s *

	E	F		
1	Mass Flow @ Steam Generator In *	98.32 kg/s *		
2				
3				
4				
5				
6				
7				
8				
9				
10				



Fri Mar 28 09:24:23 2014 Case: \\vmware-host\Shared Folders\Desktop\Na Cooled Fast Reactor SMR\NA COOLED HTSE w SUPER CRITICAL RANKINE V1 test Flowsheet: Cooling Tower (TPL2)

Workbook: Cooling Tower (TPL2)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Vapour Fraction		0.0000	0.0000	---	---	1.0000
Temperature	(C)	34.95	25.00 *	---	---	20.00 *
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
Molar Flow	(kgmole/h)	5.899e+005	5.899e+005	4.250e+005	4946	4.300e+005
Mass Flow	(kg/s)	2952	2952	3406	24.75	3431 *
Liquid Volume Flow	(m3/h)	1.065e+004	1.065e+004	1.418e+004	89.28	1.426e+004
Heat Flow	(MW)	-4.678e+004	-4.690e+004	---	---	-350.7
Name		Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Vapour Fraction		1.0000 *	1.0000	0.4302	1.0000 *	0.4302
Temperature	(C)	20.00	20.16	25.11	9.394	25.10
Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013
Molar Flow	(kgmole/h)	---	4.300e+005	1.020e+006	4.300e+005	1.020e+006
Mass Flow	(kg/s)	---	3431	6383	3431	6383
Liquid Volume Flow	(m3/h)	---	1.426e+004	2.491e+004	1.426e+004	2.491e+004
Heat Flow	(MW)	---	-350.2	-4.713e+004	-387.7	-4.713e+004
Name		Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.10	25.10	25.10	25.10	25.10
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	4.388e+005	5.812e+005	589.9	2746	5.778e+005
Mass Flow	(kg/s)	3475	2908	2.952	13.74	2892
Liquid Volume Flow	(m3/h)	1.442e+004	1.049e+004	10.65	49.57	1.043e+004
Heat Flow	(MW)	-923.1	-4.620e+004	-46.90	-218.3	-4.594e+004
Name		Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Vapour Fraction		0.9987	0.0000	0.0000	0.0000	
Temperature	(C)	25.10	20.00 *	25.00	25.00	
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1035	
Molar Flow	(kgmole/h)	4.394e+005	1.212e+004	5.899e+005	5.899e+005	
Mass Flow	(kg/s)	3478	60.64	2952	2952	
Liquid Volume Flow	(m3/h)	1.443e+004	218.8	1.065e+004	1.065e+004	
Heat Flow	(MW)	-970.0	-964.8	-4.690e+004	-4.690e+004	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Name	Sat Press @ Moist Air	1 @TPL2	3 @TPL2	Dew Point @TPL2	4 @TPL2
Comp Mole Frac (H2O)	1.0000 *	0.0115	0.5833	0.0115	0.5833
Comp Mole Frac (Nitrogen)	***	0.7809	0.3292	0.7809	0.3292
Comp Mole Frac (Oxygen)	***	0.2076	0.0875	0.2076	0.0875
Comp Mole Frac (Hydrogen)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	0.0000	0.0000	0.0000	0.0000

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Cooling Tower (TPL2) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Comp Mole Frac (H2O)	0.0313	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (Nitrogen)	0.7653	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.2034	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000	0.0000	0.0000	0.0000

Name	Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Comp Mole Frac (H2O)	0.0326	1.0000 *	1.0000	1.0000	
Comp Mole Frac (Nitrogen)	0.7643	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Oxygen)	0.2032	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000	0.0000	

Energy Streams

Fluid Pkg: All

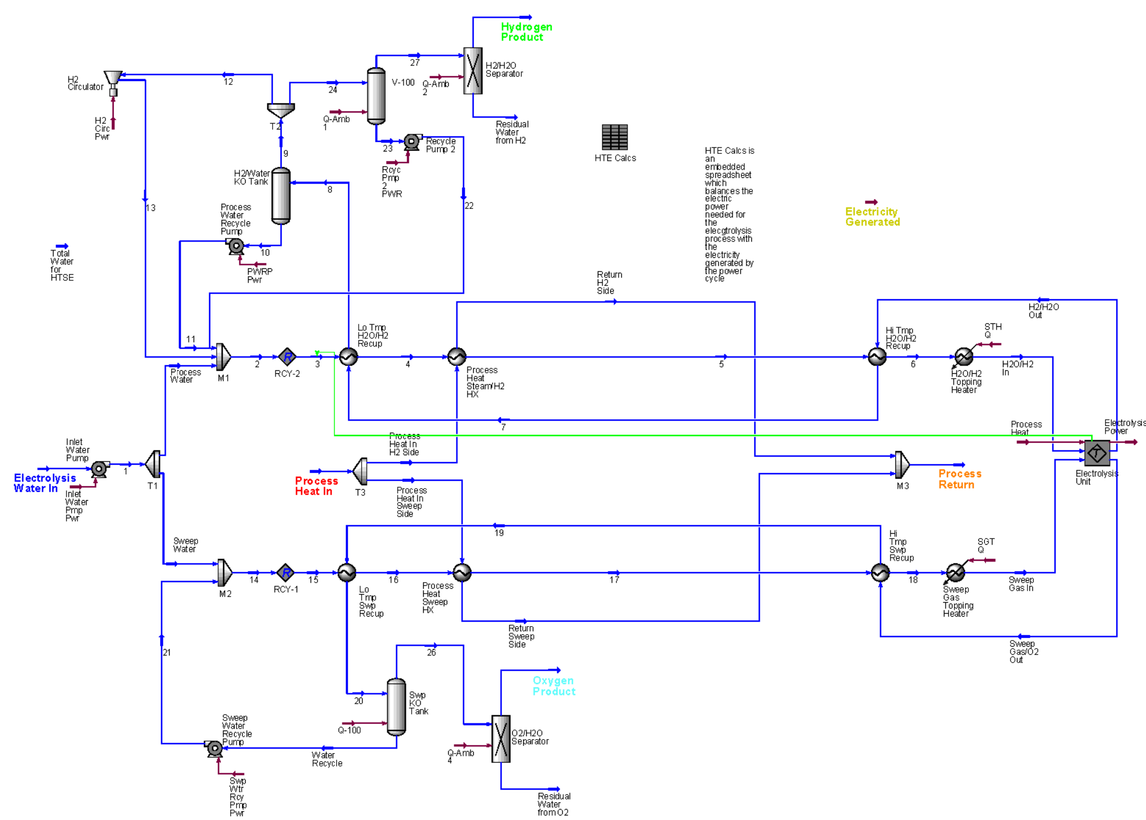
Name		Air Fan Power @TPL2	Cooling Water Pump P	Total Cooling Tower P		
Heat Flow	(MW)	0.5670	8.509e-003	0.5756		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL2	Mixer	Dry Air @TPL2 Water Vapor @TPL2	Moist Air @TPL2	No	500.0 *
M2 @TPL2	Mixer	1 @TPL2 Cooling Water Out @TPL2	3 @TPL2	No	500.0 *
M3 @TPL2	Mixer	Saturated Air @TPL2 Entrained Water @TPL2	Water Entrained Air @TPL2	No	500.0 *
M4 @TPL2	Mixer	Water Return @TPL2 Make Up Water @TPL2	6 @TPL2	No	500.0 *
Moist Air Conditions @TPL2	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL2	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL2	Set			No	500.0 *
Dew Point Pressure @TPL2	Set			No	500.0 *
Amb Press Set @TPL2	Set			No	500.0 *
SET-1 @TPL2	Set			No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.



Fri Mar 28 09:25:11 2014 Case: \\vmware-host\Shared Folders\Desktop\Na Cooled Fast Reactor SMR\NA COOLED HTSE w SUPERCRITICAL RANKINE V1.hsc Flowsheet: High Temperature Steam Electrolysis (TPL3)

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:16:39 2014

Workbook: High Temperature Steam Electrolysis (TPL3)

Material Streams

Fluid Pkg: All

Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6
Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042
Molar Flow	(kgmole/h)	3509	3509	1406	704.2	3509
Mass Flow	(kg/s)	12.88	6.643	9.762	3.526	6.643
Liquid Volume Flow	(m3/h)	74.71	89.88	32.45	12.72	89.88
Heat Flow	(MW)	-138.8	-46.60	-36.73	-41.72	-55.95

Name		6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	757.2	510.0 *	794.4	641.2	510.0 *
Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482
Molar Flow	(kgmole/h)	3509	3509	704.2	1406	704.2
Mass Flow	(kg/s)	12.88	12.88	3.526	9.762	3.526
Liquid Volume Flow	(m3/h)	74.71	74.71	12.72	32.45	12.72
Heat Flow	(MW)	-140.4	-149.8	-41.77	-39.15	-44.18

Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.6276
Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5
Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634
Molar Flow	(kgmole/h)	1.559e+004	1.559e+004	1838	1838	3509
Mass Flow	(kg/s)	99.58	99.58	11.74	11.74	12.88
Liquid Volume Flow	(m3/h)	381.5	381.5	44.96	44.96	74.71
Heat Flow	(MW)	68.75	47.70	8.102	5.622	-170.8

Name		20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21 @TPL3
Vapour Fraction		0.8415	1.0000	0.0000	0.0000	0.0000
Temperature	(C)	222.8	100.0 *	100.0	21.77	100.1
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	1406	716.3	689.4	14.75	689.4
Mass Flow	(kg/s)	9.762	6.310	3.452	7.380e-002	3.452
Liquid Volume Flow	(m3/h)	32.45	20.00	12.45	0.2662	12.45
Heat Flow	(MW)	-47.28	-0.6359	-53.62	-1.173	-53.62

Name		14 @TPL3	15 @TPL3	16 @TPL3	8 @TPL3	9 @TPL3
Vapour Fraction		0.0000	0.0000	0.9063	0.7769	1.0000
Temperature	(C)	98.49	98.48 *	290.8	158.5	158.5
Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901
Molar Flow	(kgmole/h)	704.2	704.2	704.2	3509	2726
Mass Flow	(kg/s)	3.526	3.526 *	3.526	6.643	2.729
Liquid Volume Flow	(m3/h)	12.72	12.72	12.72	89.88	75.74
Heat Flow	(MW)	-54.79	-54.79	-46.66	-75.15	-15.30

Name		10 @TPL3	12 @TPL3	24 @TPL3	13 @TPL3	11 @TPL3
Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	158.5	158.5	158.5	178.6	158.6
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	782.8	1168	1558	1168	782.8
Mass Flow	(kg/s)	3.914	1.169	1.560	1.169	3.914
Liquid Volume Flow	(m3/h)	14.14	32.45	43.29	32.45	14.14
Heat Flow	(MW)	-59.85	-6.556	-8.745	-6.362	-59.84

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Material Streams (continued)

Fluid Pkg: All

Name		Electrolysis Water In @	3 @TPL3	2 @TPL3	1 @TPL3	Process Water @TPL3
Vapour Fraction		0.0000	0.3055	0.3055	0.0000	0.0000
Temperature	(C)	21.11 *	104.8 *	104.8	21.77	21.77
Pressure	(MPa)	0.1013 *	7.790 *	7.790	7.790 *	7.790
Molar Flow	(kgmole/h)	1422	3509	3509	1422	1407
Mass Flow	(kg/s)	7.116	12.88 *	12.88	7.116	7.042
Liquid Volume Flow	(m3/h)	25.67	74.71	74.71	25.67	25.40
Heat Flow	(MW)	-113.2	-190.0	-190.0	-113.1	-111.9
Name		Hydrogen Product @T	23 @TPL3	Oxygen Product @TPL	Residual Water from C	Process Heat In @TPL
Vapour Fraction		1.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	54.44 *	54.44 *	54.44 *	54.44 *	530.0
Pressure	(MPa)	6.901	6.901	6.901	0.1013 *	0.7011
Molar Flow	(kgmole/h)	1403	150.7	701.6	14.75	1.743e+004
Mass Flow	(kg/s)	0.7858	0.7540	6.236	7.380e-002	111.3
Liquid Volume Flow	(m3/h)	40.49	2.720	19.73	0.2662	426.5
Heat Flow	(MW)	0.3318	-11.88	6.804e-002	-1.163	76.85
Name		Process Return @TPL	22 @TPL3	27 @TPL3	Residual Water from H	Total Water for HTSE
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	374.9	54.53	54.44	54.44 *	21.11 *
Pressure	(MPa)	0.6870	7.790	6.901	0.1013 *	0.1013 *
Molar Flow	(kgmole/h)	1.743e+004	150.7	1407	3.981	2431
Mass Flow	(kg/s)	111.3	0.7540	0.8057	1.992e-002	12.17
Liquid Volume Flow	(m3/h)	426.5	2.720	40.57	7.186e-002	43.89
Heat Flow	(MW)	53.32	-11.88	6.378e-002	-0.3140	-193.5

Compositions

Fluid Pkg: All

Name	H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
Comp Mole Frac (H2O)	0.6999	0.3000	0.5005	0.9992	0.3000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.4995	0.0008	0.0000
Comp Mole Frac (Hydrogen)	0.3001	0.7000	0.0000	0.0000	0.7000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17 @TPL3
Comp Mole Frac (H2O)	0.6999	0.6999	0.9992	0.5005	0.9992
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0008	0.4995	0.0008
Comp Mole Frac (Hydrogen)	0.3001	0.3001	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
Comp Mole Frac (H2O)	***	***	***	***	0.6999
Comp Mole Frac (Nitrogen)	***	***	***	***	0.0000
Comp Mole Frac (Oxygen)	***	***	***	***	0.0000
Comp Mole Frac (Hydrogen)	***	***	***	***	0.3001
Comp Mole Frac (CO2)	***	***	***	***	0.0000
Comp Mole Frac (CO)	***	***	***	***	0.0000
Comp Mole Frac (Sodium)	1.0000	1.0000	1.0000	1.0000	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	**20 @TPL3**	**26 @TPL3**	**Water Recycle @TPL3**	**Sweep Water @TPL3**	**21 @TPL3**
Comp Mole Frac (H2O)	0.5005	0.0206	0.9992	1.0000 *	0.9992
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (Oxygen)	0.4995	0.9794	0.0008	0.0000 *	0.0008
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	**14 @TPL3**	**15 @TPL3**	**16 @TPL3**	**8 @TPL3**	**9 @TPL3**
Comp Mole Frac (H2O)	0.9992	0.9992 *	0.9992	0.3000	0.0993
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0008	0.0008 *	0.0008	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.7000	0.9007
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	**10 @TPL3**	**12 @TPL3**	**24 @TPL3**	**13 @TPL3**	**11 @TPL3**
Comp Mole Frac (H2O)	0.9989	0.0993	0.0993	0.0993	0.9989
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0011	0.9007	0.9007	0.9007	0.0011
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	**Electrolysis Water In @**	**3 @TPL3**	**2 @TPL3**	**1 @TPL3**	**Process Water @TPL3**
Comp Mole Frac (H2O)	1.0000 *	0.6999 *	0.6999	1.0000	1.0000 *
Comp Mole Frac (Nitrogen)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Oxygen)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Hydrogen)	0.0000 *	0.3001 *	0.3001	0.0000	0.0000 *
Comp Mole Frac (CO2)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (CO)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Hydrogen Product @T	23 @TPL3	Oxygen Product @TPl	Residual Water from C	Process Heat In @TPl
Comp Mole Frac (H2O)	0.0000	0.9998	0.0000	1.0000	***
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (Oxygen)	0.0000	0.0000	1.0000	0.0000	***
Comp Mole Frac (Hydrogen)	1.0000	0.0002	0.0000	0.0000	***
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (Sodium)	***	***	***	***	1.0000
Comp Mole Frac (Air)	***	***	***	***	***

Name	Process Return @TPL	22 @TPL3	27 @TPL3	Residual Water from H	Total Water for HTSE (
Comp Mole Frac (H2O)	***	0.9998	0.0028	1.0000	1.0000 *
Comp Mole Frac (Nitrogen)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Oxygen)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Hydrogen)	***	0.0002	0.9972	0.0000	0.0000 *
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Sodium)	1.0000	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Energy Streams

Fluid Pkg: All

Name		Process Heat @TPL3	Electrolysis Power @T	SGT Q @TPL3	Swp Wtr Rcy Pmp Pw	H2 Circ Pwr @TPL3
Heat Flow	(MW)	2.762e-003	-97.14	5.078e-002	4.305e-003	0.1935
Name		PWRP Pwr @TPL3	STH Q @TPL3	Inlet Water Pmp Pwr @	Electricity Generated @	Q-Amb 2 @TPL3
Heat Flow	(MW)	5.168e-003	1.656	7.221e-002	99.17	-4.594e-002
Name		Q-Amb 4 @TPL3	Rcyc Pmp 2 PWR @T	Q-Amb 1 @TPL3	Q-100 @TPL3	
Heat Flow	(MW)	-0.4592	9.060e-004	-3.070	-6.982	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Electrolysis Unit @TPL3	Standard Sub-Flowsheet	H2O/H2 In @TPL3 Sweep Gas In @TPL3 Process Heat @TPL3	H2/H2O Out @TPL3 Sweep Gas/O2 Out @TPL3 Electrolysis Power @TPL3	No	2500 *
H2O/H2 Topping Heater @TP	Heater	6 @TPL3 STH Q @TPL3	H2O/H2 In @TPL3	No	500.0 *
Sweep Gas Topping Heater @	Heater	18 @TPL3 SGT Q @TPL3	Sweep Gas In @TPL3	No	500.0 *
Hi Tmp H2O/H2 Recup @TPL	Heat Exchanger	5 @TPL3 H2/H2O Out @TPL3	6 @TPL3 7 @TPL3	No	500.0 *
Hi Tmp Swp Recup @TPL3	Heat Exchanger	17 @TPL3 Sweep Gas/O2 Out @TPL3	18 @TPL3 19 @TPL3	No	500.0 *
Process Heat Steam/H2 HX @	Heat Exchanger	4 @TPL3 Process Heat In H2 Side @TF	5 @TPL3 Return H2 Side @TPL3	No	500.0 *
Process Heat Sweep HX @TF	Heat Exchanger	16 @TPL3 Process Heat In Sweep Side (	17 @TPL3 Return Sweep Side @TPL3	No	500.0 *
Lo Tmp Swp Recup @TPL3	Heat Exchanger	15 @TPL3 19 @TPL3	16 @TPL3 20 @TPL3	No	500.0 *
Lo Tmp H2O/H2 Recup @TPL	Heat Exchanger	3 @TPL3 7 @TPL3	4 @TPL3 8 @TPL3	No	500.0 *
Swp KO Tank @TPL3	Separator	20 @TPL3 Q-100 @TPL3	Water Recycle @TPL3 26 @TPL3 Q-100 @TPL3	No	500.0 *
H2/Water KO Tank @TPL3	Separator	8 @TPL3	10 @TPL3	No	500.0 *

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
H2/Water KO Tank @TPL3	Separator		9 @TPL3	No	500.0 *
V-100 @TPL3	Separator	24 @TPL3 Q-Amb 1 @TPL3	23 @TPL3 27 @TPL3 Q-Amb 1 @TPL3	No	500.0 *
Sweep Water Recycle Pump @	Pump	Water Recycle @TPL3 Swp Wtr Rcy Pmp Pwr @TPL	21 @TPL3	No	500.0 *
Process Water Recycle Pump	Pump	10 @TPL3 PWRP Pwr @TPL3	11 @TPL3	No	500.0 *
Inlet Water Pump @TPL3	Pump	Electrolysis Water In @TPL3 Inlet Water Pmp Pwr @TPL3	1 @TPL3	No	500.0 *
Recycle Pump 2 @TPL3	Pump	23 @TPL3 Rcyc Pmp 2 PWR @TPL3	22 @TPL3	No	500.0 *
M2 @TPL3	Mixer	Sweep Water @TPL3 21 @TPL3	14 @TPL3	No	500.0 *
M1 @TPL3	Mixer	13 @TPL3 11 @TPL3 Process Water @TPL3 22 @TPL3	2 @TPL3	No	500.0 *
M3 @TPL3	Mixer	Return Sweep Side @TPL3 Return H2 Side @TPL3	Process Return @TPL3	No	500.0 *
RCY-1 @TPL3	Recycle	14 @TPL3	15 @TPL3	No	3500 *
RCY-2 @TPL3	Recycle	2 @TPL3	3 @TPL3	No	3500 *
H2 Circulator @TPL3	Compressor	12 @TPL3 H2 Circ Pwr @TPL3	13 @TPL3	No	500.0 *
T2 @TPL3	Tee	9 @TPL3	24 @TPL3 12 @TPL3	No	500.0 *
T1 @TPL3	Tee	1 @TPL3	Sweep Water @TPL3 Process Water @TPL3	No	500.0 *
T3 @TPL3	Tee	Process Heat In @TPL3	Process Heat In H2 Side @TF Process Heat In Sweep Side (	No	500.0 *
HTE Calcs @TPL3	Spreadsheet			No	500.0 *
LTHR Tb dP @TPL3	Set			No	500.0 *
PHSH Tb dP @TPL3	Set			No	500.0 *
HTHR Tb dP @TPL3	Set			No	500.0 *
HTH dP @TPL3	Set			No	500.0 *
HTHR Sh dP @TPL3	Set			No	500.0 *
LTSR Sh dP @TPL3	Set			No	500.0 *
LTSR Tb dP @TPL3	Set			No	500.0 *
PHSH Sh dP @TPL3	Set			No	500.0 *
SET-1 @TPL3	Set			No	500.0 *
SET-2 @TPL3	Set			No	500.0 *
HTSR Sh dP @TPL3	Set			No	500.0 *
SET-3 @TPL3	Set			No	500.0 *

* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
		Unit Set:	AFR
		Date/Time:	Fri Mar 28 11:16:39 2014

Spreadsheet: HTE Calcs @TPL3

Units Set: NuScale

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
B1	Material Stream:	Residual Water from H2 @	Mass Flow	1.992e-002 kg/s
B2	Material Stream:	Residual Water from O2 @	Mass Flow	7.380e-002 kg/s
B3	Material Stream:	H2O/H2 In @TPL3	Master Comp Mass Flow (H2O)	44240.7588 kg/h
B4	Material Stream:	H2/H2O Out @TPL3	Master Comp Mass Flow (H2O)	18961.5892 kg/h
D1	Energy Stream:	Rcyc Pmp 2 PWR @TPL3	Power	9.060e-004 MW
D2	Energy Stream:	H2 Circ Pwr @TPL3	Power	0.1935 MW
D3	Energy Stream:	PWRP Pwr @TPL3	Power	5.168e-003 MW
D4	Energy Stream:	Inlet Water Pmp Pwr @TP	Power	7.221e-002 MW
D5	Energy Stream:	Swp Wtr Rcy Pmp Pwr @	Power	4.305e-003 MW
D7	Energy Stream:	STH Q @TPL3	Heat Flow	1.656 MW
D8	Energy Stream:	SGT Q @TPL3	Heat Flow	5.078e-002 MW
D10	Energy Stream:	Electrolysis Power @TPL3	Power	-97.14 MW
B6	Heat Exchanger:	Process Heat Steam/H2 H	Exchanger Cold Duty	21.05 MW
B7	Heat Exchanger:	Process Heat Sweep HX @	Exchanger Cold Duty	2.480 MW
B10	Energy Stream:	Electricity Generated @TP	Power	99.17 MW
E1	Energy Stream:	Q-100 @TPL3	Heat Flow	-6.982 MW
E2	Energy Stream:	Q-Amb 1 @TPL3	Heat Flow	-3.070 MW
E3	Energy Stream:	Q-Amb 2 @TPL3	Heat Flow	-4.594e-002 MW
E4	Energy Stream:	Q-Amb 4 @TPL3	Heat Flow	-0.4592 MW
F6	Heat Exchanger:	Condenser @TPL1	Exchanger Cold Duty	126.7 MW
F7	Energy Stream:	Total Cooling Tower Powe	Power	0.5756 MW
F8	Material Stream:	Make Up Water @TPL2	Mass Flow	60.64 kg/s
F1	Material Stream:	Hydrogen Product @TPL3	Mass Higher Heating Value	1.404e+005 kJ/kg
F2	Material Stream:	Hydrogen Product @TPL3	Mass Flow	0.7858 kg/s
F3	Energy Stream:	Reactor Heat	Heat Flow	250.0 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
F11	Total Water for HTSE @TPL3	Mass Flow	12.17 kg/s

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B5	B5: Water Loss	Water Loss	Mass Flow	7.116 kg/s
D6	D6: Total Power for flow	Total Power for flow	Power	0.2761 MW
D9	D9: Total Topping Heat	Total Topping Heat	Energy	1.707 MW
B8	B8:		Energy	23.53 MW
B9	B9:		Power	99.17 MW
B11	B11:		Power	1.912e-004 MW
C11	C11:		Power	0.1912 MW
F5	F5:		Energy	10.56 MW
F9	F9:		Power	4.795e-002 MW
F10	F10:		Mass Flow	5.052 kg/s
F11	F11: Mass Flow	Mass Flow	Mass Flow	12.17 kg/s
D11	D11:		Power	8.259e-002 MW
F4	F4: Hydrogen Production Efficiency	Hydrogen Production Efficiency	Percent	44.12

User Variables

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: HTE Calcs @TPL3 (continued)

Units Set: NuScale

FORMULAS

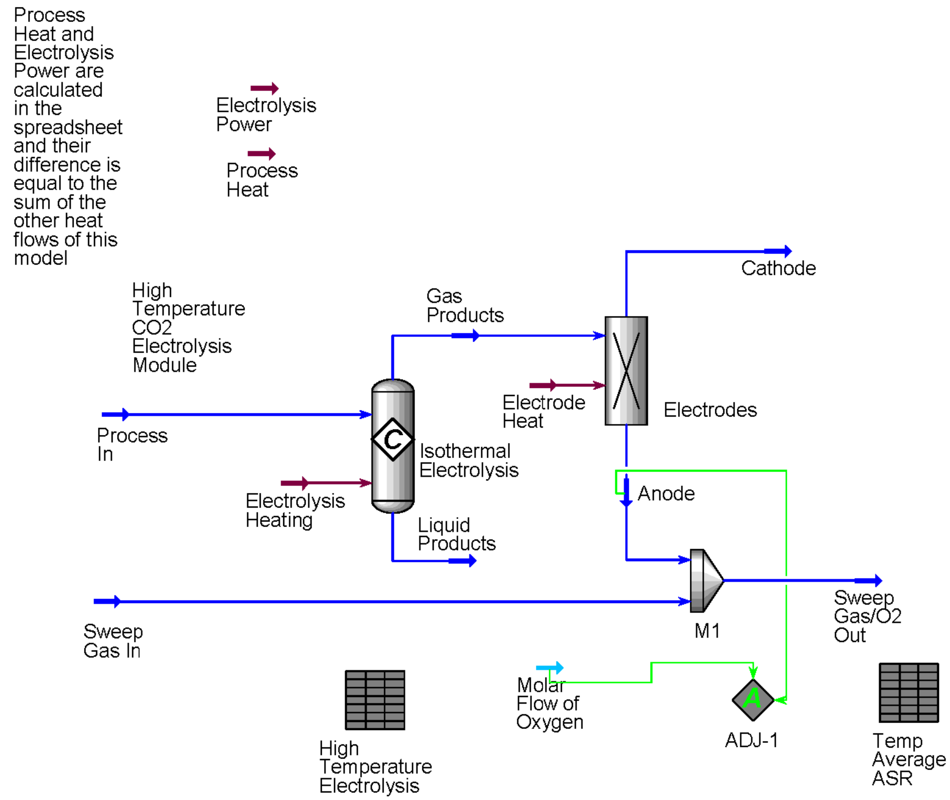
Cell	Formula	Result
B5	=B1+B2+(B3-B4)/3600	7.116 kg/s
B8	=B6+B7	23.53 MW
B9	=D6+D9-D10+F9	99.17 MW
B11	=B10-B9	1.912e-004 MW
C11	=B11*1000	0.1912 MW
D6	=D1+D2+D3+D4+D5	0.2761 MW
D9	=D7+D8	1.707 MW
D11	=D1+D3+D4+D5	8.259e-002 MW
F4	=F1*F2/F3*100/1000	44.12
F5	=-(E1+E2+E3+E4)	10.56 MW
F9	=F5/F6*F7	4.795e-002 MW
F10	=F5/F6*F8	5.052 kg/s
F11	=B5+F10	12.17 kg/s

Spreadsheet

	A	B	C	D
1	Resid H2O from H2 *	1.992e-002 kg/s *	Rcyc Pmp 2 PWR *	9.060e-004 MW *
2	Resid H2O from O2 *	7.380e-002 kg/s *	H2 Circ Pwr *	0.1935 MW *
3	Water into Cells *	44240.7588 kg/h *	PWR Pwr *	5.168e-003 MW *
4	Water out of Cells *	18961.5892 kg/h *	Inlet Water Pmp Pwr *	7.221e-002 MW *
5	Water loss *	7.116 kg/s *	Swp Wtr Pmp Pwr *	4.305e-003 MW *
6	Process Heat Steam/H2 HX Duty *	21.05 MW *	Total Power for flow *	0.2761 MW *
7	Process Heat Sweep HX Duty *	2.480 MW *	STH Q *	1.656 MW *
8	Total Heat from Reactor *	23.53 MW *	SGT Q *	5.078e-002 MW *
9	Power Needed for Electrolysis *	99.17 MW *	Total Topping Heat *	1.707 MW *
10	Electricity Generated *	99.17 MW *	Electrolysis Power *	-97.14 MW *
11	Excess Electricity *	1.912e-004 MW *	0.1912 MW *	8.259e-002 MW *

	E	F		
1	-6.982 MW *	1.404e+005 kJ/kg *		
2	-3.070 MW *	0.7858 kg/s *		
3	-4.594e-002 MW *	250.0 MW *		
4	-0.4592 MW *	44.12 *		
5	Total HTSE Ambient Heat *	10.56 MW *		
6	Condenser Heat *	126.7 MW *		
7	Cooling Tower Power *	0.5756 MW *		
8	Cooling Tower Make Up Water *	60.64 kg/s *		
9	HTSE Cooling Power *	4.795e-002 MW *		
10	Water needed to cool for HTSE *	5.052 kg/s *		
11	Total Water for HTSE *	12.17 kg/s *		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.



Fri Mar 28 09:25:52 2014 Case: \\vmware-host\Shared Folders\Desktop\Na Cooled Fast Reactor SMR\NA COOLED HTSE w SUPER CRITICAL RANKINE.hsc Flowsheet: Electrolysis Unit (TPL4)

Workbook: Electrolysis Unit (TPL4)

Streams

Fluid Pkg: All

Name		Process In @TPL4	Sweep Gas In @TPL4	Cathode @TPL4	Sweep Gas/O2 Out @	Gas Products @TPL4
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	800.0	800.0	800.0 *	800.0	800.0
Pressure	(MPa)	7.185	7.185	7.185	7.185	7.185
Molar Flow	(kgmole/h)	3509	704.2	3509	1406	4210
Mass Flow	(kg/s)	12.88	3.526	6.643	9.762	12.88
Liquid Volume Flow	(m3/h)	74.71	12.72	89.88	32.45	109.6
Heat Flow	(MW)	-138.8	-41.72	-46.60	-36.73	-41.66
Molar Enthalpy	(kJ/kgmole)	-1.424e+005	-2.133e+005	-4.781e+004	-9.407e+004	-3.563e+004

Name		Liquid Products @TPL	Anode @TPL4	Molar Flow of Oxygen	Electrolysis Heating @	Electrode Heat @TPL4
Vapour Fraction		0.0000	1.0000	---	---	---
Temperature	(C)	800.0	807.2	---	---	---
Pressure	(MPa)	7.185	7.185	---	---	---
Molar Flow	(kgmole/h)	0.0000	701.6	701.6	---	---
Mass Flow	(kg/s)	0.0000	6.236	6.236	---	---
Liquid Volume Flow	(m3/h)	0.0000	19.73	19.73	---	---
Heat Flow	(MW)	0.0000	4.984	---	97.09	4.650e-002
Molar Enthalpy	(kJ/kgmole)	-3.412e+004	2.558e+004	---	---	---

Name		Process Heat @TPL4	Electrolysis Power @T			
Vapour Fraction		---	---			
Temperature	(C)	---	---			
Pressure	(MPa)	---	---			
Molar Flow	(kgmole/h)	---	---			
Mass Flow	(kg/s)	---	---			
Liquid Volume Flow	(m3/h)	---	---			
Heat Flow	(MW)	2.762e-003	-97.14			
Molar Enthalpy	(kJ/kgmole)	---	---			

Conversion Reactors

Fluid Pkg: All

Name		Isothermal Electrolysis				
Separator Type		---				
Vessel Temperature	(C)	800.0				
Vessel Pressure	(MPa)	7.185				
Vapour Molar Flow	(kgmole/h)	4210				
Liquid Molar Flow	(kgmole/h)	0.0000				
Heat Flow	(MW)	97.09				

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Isothermal Electrolysis @TPL4	Conversion Reactor	Process In @TPL4 Electrolysis Heating @TPL4	Liquid Products @TPL4 Gas Products @TPL4 Electrolysis Heating @TPL4	No	500.0 *
Electrodes @TPL4	Component Splitter	Gas Products @TPL4 Electrode Heat @TPL4	Cathode @TPL4 Anode @TPL4	No	500.0 *
Gas Product Temperature @T	Set			No	500.0 *
Outlet Temperature @TPL4	Set			No	500.0 *
Inlet Temperature @TPL4	Set			No	500.0 *
SET-1 @TPL4	Set			No	500.0 *
High Temperature Electrolysis	Spreadsheet			No	500.0 *
Temp Average ASR @TPL4	Spreadsheet			No	500.0 *
M1 @TPL4	Mixer	Anode @TPL4 Sweep Gas In @TPL4	Sweep Gas/O2 Out @TPL4	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Electrolysis Unit (TPL4) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
ADJ-1 @TPL4	Adjust			No	3500 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: High Temperature Electrolysis @TPL4

Units Set: Electrolysis_

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
D2	Material Stream:	Process In @TPL4	Temperature	1073 K
D3	Material Stream:	Cathode @TPL4	Temperature	1073 K
A8	Material Stream:	Sweep Gas/O2 Out @TPL	Pressure	7.185e+006 N/m2
E2	Material Stream:	Process In @TPL4	Master Comp Mole Frac (H2O)	0.6999
F2	Material Stream:	Process In @TPL4	Master Comp Mole Frac (Hydrogen)	0.3001
G2	Material Stream:	Sweep Gas In @TPL4	Master Comp Mole Frac (Oxygen)	0.0008
E3	Material Stream:	Cathode @TPL4	Master Comp Mole Frac (H2O)	0.3000
F3	Material Stream:	Cathode @TPL4	Master Comp Mole Frac (Hydrogen)	0.7000
G3	Material Stream:	Sweep Gas/O2 Out @TPL	Master Comp Mole Frac (Oxygen)	0.4995
B16	SpreadSheetCell:	Temp Average ASR@B2	B2: Temp Aver ASR	0.4000
D11	Energy Stream:	Electrolysis Heating @TPL	Heat Flow	9.709e+004 kW
D12	Energy Stream:	Electrode Heat @TPL4	Heat Flow	46.50 kW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
B15	Molar Flow of Oxygen @TPL4	Molar Flow	194.9 gmole/s
B19	Electrolysis Power @TPL4	Power	-9.714e+004 kW
B20	Process Heat @TPL4	Heat Flow	2.762 kW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
E9	E9:		---	<empty>
C20	C20:		Energy	<empty>
E8	E8:		Temperature	<empty>
F10	F10:		Vapour Fraction	<empty>
C18	C18:		---	<empty>
F20	F20:		---	<empty>
H5	H5:		---	91.15
J2	J2:		Entropy	2.321e+008 J/gmole-K
J3	J3:		Entropy	2.321e+008 J/gmole-K
K2	K2:		---	0.8721
K3	K3:		---	1.099
B17	B17:		Vapour Fraction	1.0373
H2	H2:		---	5.663e-002
I11	I11:		---	<empty>
I2	I2:		Molar Enthalpy	1.887e+005 J/gmole
I3	I3:		Molar Enthalpy	1.887e+005 J/gmole
I6	I6:		Molar Enthalpy	1.887e+005 J/gmole
E4	E4:		Vapour Fraction	-0.3999
F4	F4:		Vapour Fraction	0.3999
D4	D4:		Temperature	-2.319e-011 K
D6	D6:		Temperature	1073 K
K6	K6:		Vapour Fraction	1.0373
K7	K7:		---	1.032
B18	B18:		Vapour Fraction	1.2915
D8	D8:		---	3.664e-007
D9	D9:		---	1.580e+004

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A9	A9: Standard Pressure	Standard Pressure	Pressure	1.013e+005 N/m2
A6	A6: Fa Faraday Number (J/Volt-gmole)	Fa Faraday Number (J/Volt-gmole)	---	9.649e+004
A5	A5: A5 for Gibbs Formation Energy	A5 for Gibbs Formation Energy	Gibbs. Coeff. CB	-12.85 J/gmole-K
A4	A4: A4 for Gibbs Formation Energy (kJ/gmol-K^3)	A4 for Gibbs Formation Energy (kJ/gmol-K^3)	---	-3.532e-008
A3	A3: A3 for Gibbs Formation Energy	A3 for Gibbs Formation Energy	Gibbs. Coeff. CC	3.319e-003 kJ/gmol-K^
A2	A2: A2 for Gibbs Formation Energy	A2 for Gibbs Formation Energy	Gibbs. Coeff. CB	39.95 J/gmole-K
A7	A7: R Universal Gas Constant	R Universal Gas Constant	Entropy	8.314 J/gmole-K
G4	G4:		Vapour Fraction	0.4987
H3	H3:		---	35.42
H4	H4:		---	35.36
E5	E5:		Vapour Fraction	0.2885
F5	F5:		Vapour Fraction	-0.2884
G5	G5:		Vapour Fraction	-0.8397
B11	B11: B2: Number of Cells	B2: Number of Cells	---	5.260e+005
B12	B12: B3: Cell Area	B3: Cell Area	Small Area	225.0 cm2
B13	B13: B4: Current Density (Amperes/cm^2)	B4: Current Density (Amperes/cm^2)	---	0.6355
B14	B14:		---	143.0
B15	B15: Molar Flow	Molar Flow	Molar Flow	194.9 gmole/s
A1	A1: A1 for Gibbs Formation Energy	A1 for Gibbs Formation Energy	Gibbs. Coeff. CA	2.382e+005 J/gmole
B19	B19: Power	Power	Power	-9.714e+004 kW
B20	B20: Heat Flow	Heat Flow	Energy	2.762 kW

User Variables

FORMULAS

Cell	Formula	Result
B14	=B12*B13	143.0
B15	=B11*B14/(4*A6)	194.9 gmole/s
B17	@IF(@ABS(D4)<1e-3,K6,K7)	1.0373
B18	=B17+B13*B16	1.2915
B19	=-B11*B18*B14/1000	-9.714e+004 kW
B20	=B19+D11+D12	2.762 kW
D4	=D2-D3	-2.319e-011 K
D6	=(D2+D3)/2	1073 K
D8	=1/(2*A6*H4*F4)	3.664e-007
D9	=-1/(2*A6*H4*F4*D4)	1.580e+004
E4	=E3-E2	-0.3999
E5	=(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2)	0.2885
F4	=F3-F2	0.3999
F5	=(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2)	-0.2884
G4	=G3-G2	0.4987
G5	=(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2)	-0.8397
H2	=G2*A8/A9	5.663e-002
H3	=G3*A8/A9	35.42
H4	=H3-H2	35.36
H5	=(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2)	91.15
I2	=A1 + A2*D2+ A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2)	1.887e+005 J/gmole
I3	=A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3)	1.887e+005 J/gmole
I6	=A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6)	1.887e+005 J/gmole

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
		Unit Set:	AFR
		Date/Time:	Fri Mar 28 11:16:39 2014

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
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
J3	= A1*D3 + A2/2*D3^2 + A3/3*D3^3 + A4/4*D3^4 + A5/2*D3^2*(@LN(D3)-0.5)	2.321e+008 J/gmole-K
K2	=1/(2*A6)*(I2-A7*D2*@LN(E2/(F2*H2^0.5)))	0.8721
K3	=1/(2*A6)*(I3-A7*D3*@LN(E3/(F3*H3^0.5)))	1.099
K6	=D8*(I6*F4*H4 + A7*D6*((E5+F5)*H4 + H5/2*F4))	1.0373
K7	=D9*(A7/2*(D3^2-D2^2)*((E5+F5)*H4 + H5/2*F4) + F4*H4*(J3-J2))	1.032

Spreadsheet

	A	B	C	D
1	2.382e+005 J/gmole *	A1 for Gibbs Formation Energy *		Temperature *
2	39.95 J/gmole-K *	A2 for Gibbs Formation Energy *	in *	1073 K *
3	3.319e-003 kJ/gmol-K^2 *	A3 for Gibbs Formation Energy *	out *	1073 K *
4	-3.532e-008 *	ibbs Formation Energy (kJ/gmol-K^3) *	Delta *	-2.319e-011 K *
5	-12.85 J/gmole-K *	A5 for Gibbs Formation Energy *	Integration Coeff *	
6	9.649e+004 *	Fa Faraday Number (J/Volt-gmole) *	Average *	1073 K *
7	8.314 J/gmole-K *	R Universal Gas Constant *		
8	7.185e+006 N/m2 *	Pressure *	C isothermal *	3.664e-007 *
9	1.013e+005 N/m2 *	Standard Pressure *	C average *	1.580e+004 *
10				
11	Number of Cells *	5.260e+005 *	Electrolysis Heating *	9.709e+004 kW *
12	Cell Area *	225.0 cm2 *	Electrode Heat *	46.50 kW *
13	Current Density (Amperes/cm^2) *	0.6355 *		
14	Current (Amperes) *	143.0 *		
15	Molar Flow of Oxygen *	194.9 gmole/s *		
16	Area Specific Resistance (ohm*cm^2) *	0.4000 *		
17	Nernst Potential (Volts) *	1.0373 *		
18	Operating Voltage (Volts) *	1.2915 *	<empty> *	
19	Electrolysis Power *	-9.714e+004 kW *		
20	Process Heat *	2.762 kW *	<empty> *	

	E	F	G	H
1	y H2O *	y H2 *	y O2 *	y A *
2	0.6999 *	0.3001 *	0.0008 *	5.663e-002 *
3	0.3000 *	0.7000 *	0.4995 *	35.42 *
4	-0.3999 *	0.3999 *	0.4987 *	35.36 *
5	0.2885 *	-0.2884 *	-0.8397 *	91.15 *
6				
7				
8	<empty> *			
9	<empty> *			
10		<empty> *		
11				
12				
13				
14				
15				
16				
17				
18				
19				
20		<empty> *		

	I	J	K	

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE w SUPER CRITICAL RANKINE V1.hsc
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:16:39 2014

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

Spreadsheet

1	Delta G *	Integral Delta G dT *	Nernst Voltage *	
2	1.887e+005 J/gmole *	2.321e+008 J/gmole-K *	0.8721 *	
3	1.887e+005 J/gmole *	2.321e+008 J/gmole-K *	1.099 *	
4				
5				
6	1.887e+005 J/gmole *	Isothermal *	1.0373 *	
7		Average *	1.032 *	
8				
9				
10				
11	<empty> *			
12				
13				
14				
15				
16				
17				
18				
19				
20				

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Temp Average ASR @TPL4

Units Set: Electrolysis_

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
A3	Material Stream:	Process In @TPL4	Temperature	1073 K
E15	Material Stream:	Cathode @TPL4	Temperature	1073 K

Exported Variables' Formula Results

Cell	Object	Variable Description	Value

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B13	B13:		---	0.4000
B14	B14:		---	0.4000
B15	B15:		---	0.4000
B16	B16:		---	0.4000
B17	B17:		---	0.4000
B18	B18:		---	0.4000
B19	B19:		---	0.4000
D15	D15:		---	0.4000
C16	C16:		Temperature	1073 K
D16	D16:		---	0.4000
C17	C17:		Temperature	1073 K
D17	D17:		---	0.4000
C18	C18:		Temperature	1073 K
E14	E14:		Temperature	1073 K
F15	F15:		---	0.4000
F16	F16:		Temperature	4.638e-013 K
F1	F1:		---	0.4000
D2	D2:		---	0.4000
C3	C3:		Temperature	1073 K
D3	D3:		---	0.4000
C4	C4:		Temperature	1073 K
D4	D4:		---	0.4000
C5	C5:		Temperature	1073 K
D5	D5:		---	0.4000
A12	A12:		Temperature	1073 K
A13	A13:		Temperature	1073 K
A14	A14:		Temperature	1073 K
A15	A15:		Temperature	1073 K
A16	A16:		Temperature	1073 K
A17	A17:		Temperature	1073 K
A18	A18:		Temperature	1073 K
F3	F3:		---	0.4000
F4	F4:		---	0.4000
F5	F5:		---	0.4000
F6	F6:		---	0.4000
F7	F7:		---	0.4000
F8	F8:		---	0.4000
F9	F9:		---	0.4000
D12	D12:		---	0.4000

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
C13	C13:		Temperature	1073 K
D13	D13:		---	0.4000
C14	C14:		Temperature	1073 K
D14	D14:		---	0.4000
C15	C15:		Temperature	1073 K
F10	F10:		---	0.4000
F11	F11:		---	0.4000
F12	F12:		---	0.4000
F13	F13:		---	0.4000
F14	F14:		---	0.4000
B20	B20:		---	19.20
B7	B7:		---	0.4000
B8	B8:		---	0.4000
B9	B9:		---	0.4000
B10	B10:		---	0.4000
B11	B11:		---	0.4000
B12	B12:		---	0.4000
A6	A6:		Temperature	1073 K
A7	A7:		Temperature	1073 K
A8	A8:		Temperature	1073 K
A9	A9:		Temperature	1073 K
A10	A10:		Temperature	1073 K
A11	A11:		Temperature	1073 K
E1	E1:		Temperature	1073 K
E2	E2:		Temperature	1073 K
F2	F2:		---	0.4000
C1	C1:		Temperature	1073 K
D1	D1:		---	0.4000
C2	C2:		Temperature	1073 K
C9	C9:		Temperature	1073 K
D9	D9:		---	0.4000
C10	C10:		Temperature	1073 K
D10	D10:		---	0.4000
C11	C11:		Temperature	1073 K
D11	D11:		---	0.4000
C12	C12:		Temperature	1073 K
A19	A19:		Temperature	1073 K
A20	A20:		---	40.00
E3	E3:		Temperature	1073 K
E4	E4:		Temperature	1073 K
E5	E5:		Temperature	1073 K
E6	E6:		Temperature	1073 K
E7	E7:		Temperature	1073 K
E8	E8:		Temperature	1073 K
E9	E9:		Temperature	1073 K
E10	E10:		Temperature	1073 K
E11	E11:		Temperature	1073 K
E12	E12:		Temperature	1073 K
E13	E13:		Temperature	1073 K

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
C6	C6:		Temperature	1073 K
D6	D6:		---	0.4000
C7	C7:		Temperature	1073 K
D7	D7:		---	0.4000
C8	C8:		Temperature	1073 K
D8	D8:		---	0.4000
B1	B1: B5: ASR @ 1100 K (ohms*cm^2)	B5: ASR @ 1100 K (ohms*cm^2)	---	0.2776
B2	B2: Temp Aver ASR	Temp Aver ASR	---	0.4000
B3	B3:		---	0.4000
B4	B4:		---	0.4000
B5	B5:		---	0.4000
B6	B6:		---	0.4000
D18	D18:		---	0.4000
C19	C19:		Temperature	1073 K
D19	D19:		---	0.4000
A4	A4:		Temperature	1073 K
A5	A5:		Temperature	1073 K

User Variables

FORMULAS

Cell	Formula	Result
A4	=A3+F16	1073 K
A5	=A4+F16	1073 K
A6	=A5+F16	1073 K
A7	=A6+F16	1073 K
A8	=A7+F16	1073 K
A9	=A8+F16	1073 K
A10	=A9+F16	1073 K
A11	=A10+F16	1073 K
A12	=A11+F16	1073 K
A13	=A12+F16	1073 K
A14	=A13+F16	1073 K
A15	=A14+F16	1073 K
A16	=A15+F16	1073 K
A17	=A16+F16	1073 K
A18	=A17+F16	1073 K
A19	=A18+F16	1073 K
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
B2	@if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3))	0.4000
B3	@EXP(10300/A3)*0.00003973+(B1-0.463)	0.4000
B4	@EXP(10300/A4)*0.00003973+(B1-0.463)	0.4000
B5	@EXP(10300/A5)*0.00003973+(B1-0.463)	0.4000
B6	@EXP(10300/A6)*0.00003973+(B1-0.463)	0.4000
B7	@EXP(10300/A7)*0.00003973+(B1-0.463)	0.4000
B8	@EXP(10300/A8)*0.00003973+(B1-0.463)	0.4000
B9	@EXP(10300/A9)*0.00003973+(B1-0.463)	0.4000
B10	@EXP(10300/A10)*0.00003973+(B1-0.463)	0.4000
B11	@EXP(10300/A11)*0.00003973+(B1-0.463)	0.4000

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
B12	@EXP(10300/A12)*0.00003973+(B1-0.463)	0.4000
B13	@EXP(10300/A13)*0.00003973+(B1-0.463)	0.4000
B14	@EXP(10300/A14)*0.00003973+(B1-0.463)	0.4000
B15	@EXP(10300/A15)*0.00003973+(B1-0.463)	0.4000
B16	@EXP(10300/A16)*0.00003973+(B1-0.463)	0.4000
B17	@EXP(10300/A17)*0.00003973+(B1-0.463)	0.4000
B18	@EXP(10300/A18)*0.00003973+(B1-0.463)	0.4000
B19	@EXP(10300/A19)*0.00003973+(B1-0.463)	0.4000
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
C1	=A19+F16	1073 K
C2	=C1+F16	1073 K
C3	=C2+F16	1073 K
C4	=C3+F16	1073 K
C5	=C4+F16	1073 K
C6	=C5+F16	1073 K
C7	=C6+F16	1073 K
C8	=C7+F16	1073 K
C9	=C8+F16	1073 K
C10	=C9+F16	1073 K
C11	=C10+F16	1073 K
C12	=C11+F16	1073 K
C13	=C12+F16	1073 K
C14	=C13+F16	1073 K
C15	=C14+F16	1073 K
C16	=C15+F16	1073 K
C17	=C16+F16	1073 K
C18	=C17+F16	1073 K
C19	=C18+F16	1073 K
D1	@EXP(10300/C1)*0.00003973+(B1-0.463)	0.4000
D2	@EXP(10300/C2)*0.00003973+(B1-0.463)	0.4000
D3	@EXP(10300/C3)*0.00003973+(B1-0.463)	0.4000
D4	@EXP(10300/C4)*0.00003973+(B1-0.463)	0.4000
D5	@EXP(10300/C5)*0.00003973+(B1-0.463)	0.4000
D6	@EXP(10300/C6)*0.00003973+(B1-0.463)	0.4000
D7	@EXP(10300/C7)*0.00003973+(B1-0.463)	0.4000
D8	@EXP(10300/C8)*0.00003973+(B1-0.463)	0.4000
D9	@EXP(10300/C9)*0.00003973+(B1-0.463)	0.4000
D10	@EXP(10300/C10)*0.00003973+(B1-0.463)	0.4000
D11	@EXP(10300/C11)*0.00003973+(B1-0.463)	0.4000
D12	@EXP(10300/C12)*0.00003973+(B1-0.463)	0.4000
D13	@EXP(10300/C13)*0.00003973+(B1-0.463)	0.4000
D14	@EXP(10300/C14)*0.00003973+(B1-0.463)	0.4000
D15	@EXP(10300/C15)*0.00003973+(B1-0.463)	0.4000
D16	@EXP(10300/C16)*0.00003973+(B1-0.463)	0.4000
D17	@EXP(10300/C17)*0.00003973+(B1-0.463)	0.4000
D18	@EXP(10300/C18)*0.00003973+(B1-0.463)	0.4000
D19	@EXP(10300/C19)*0.00003973+(B1-0.463)	0.4000
E1	=C19+F16	1073 K
E2	=E1+F16	1073 K
E3	=E2+F16	1073 K
E4	=E3+F16	1073 K

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
E5	=E4+F16	1073 K
E6	=E5+F16	1073 K
E7	=E6+F16	1073 K
E8	=E7+F16	1073 K
E9	=E8+F16	1073 K
E10	=E9+F16	1073 K
E11	=E10+F16	1073 K
E12	=E11+F16	1073 K
E13	=E12+F16	1073 K
E14	=E13+F16	1073 K
F1	@EXP(10300/E1)*0.00003973+(B1-0.463)	0.4000
F2	@EXP(10300/E2)*0.00003973+(B1-0.463)	0.4000
F3	@EXP(10300/E3)*0.00003973+(B1-0.463)	0.4000
F4	@EXP(10300/E4)*0.00003973+(B1-0.463)	0.4000
F5	@EXP(10300/E5)*0.00003973+(B1-0.463)	0.4000
F6	@EXP(10300/E6)*0.00003973+(B1-0.463)	0.4000
F7	@EXP(10300/E7)*0.00003973+(B1-0.463)	0.4000
F8	@EXP(10300/E8)*0.00003973+(B1-0.463)	0.4000
F9	@EXP(10300/E9)*0.00003973+(B1-0.463)	0.4000
F10	@EXP(10300/E10)*0.00003973+(B1-0.463)	0.4000
F11	@EXP(10300/E11)*0.00003973+(B1-0.463)	0.4000
F12	@EXP(10300/E12)*0.00003973+(B1-0.463)	0.4000
F13	@EXP(10300/E13)*0.00003973+(B1-0.463)	0.4000
F14	@EXP(10300/E14)*0.00003973+(B1-0.463)	0.4000
F15	@EXP(10300/E15)*0.00003973+(B1-0.463)	0.4000
F16	=(E15-A3)/50	4.638e-013 K

Spreadsheet

	A	B	C	D
1	ASR @ 1100 K *	0.2776 *	1073 K *	0.4000 *
2	Temp Average ASR *	0.4000 *	1073 K *	0.4000 *
3	1073 K *	0.4000 *	1073 K *	0.4000 *
4	1073 K *	0.4000 *	1073 K *	0.4000 *
5	1073 K *	0.4000 *	1073 K *	0.4000 *
6	1073 K *	0.4000 *	1073 K *	0.4000 *
7	1073 K *	0.4000 *	1073 K *	0.4000 *
8	1073 K *	0.4000 *	1073 K *	0.4000 *
9	1073 K *	0.4000 *	1073 K *	0.4000 *
10	1073 K *	0.4000 *	1073 K *	0.4000 *
11	1073 K *	0.4000 *	1073 K *	0.4000 *
12	1073 K *	0.4000 *	1073 K *	0.4000 *
13	1073 K *	0.4000 *	1073 K *	0.4000 *
14	1073 K *	0.4000 *	1073 K *	0.4000 *
15	1073 K *	0.4000 *	1073 K *	0.4000 *
16	1073 K *	0.4000 *	1073 K *	0.4000 *
17	1073 K *	0.4000 *	1073 K *	0.4000 *
18	1073 K *	0.4000 *	1073 K *	0.4000 *
19	1073 K *	0.4000 *	1073 K *	0.4000 *
20	40.00 *	19.20 *		

	E	F		
1	1073 K *	0.4000 *		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

Spreadsheet

2	1073 K *	0.4000 *		
3	1073 K *	0.4000 *		
4	1073 K *	0.4000 *		
5	1073 K *	0.4000 *		
6	1073 K *	0.4000 *		
7	1073 K *	0.4000 *		
8	1073 K *	0.4000 *		
9	1073 K *	0.4000 *		
10	1073 K *	0.4000 *		
11	1073 K *	0.4000 *		
12	1073 K *	0.4000 *		
13	1073 K *	0.4000 *		
14	1073 K *	0.4000 *		
15	1073 K *	0.4000 *		
16	delta T *	4.638e-013 K *		
17				
18				
19				
20				

* Specified by user.

Adjust: ADJ-1 @TPL4

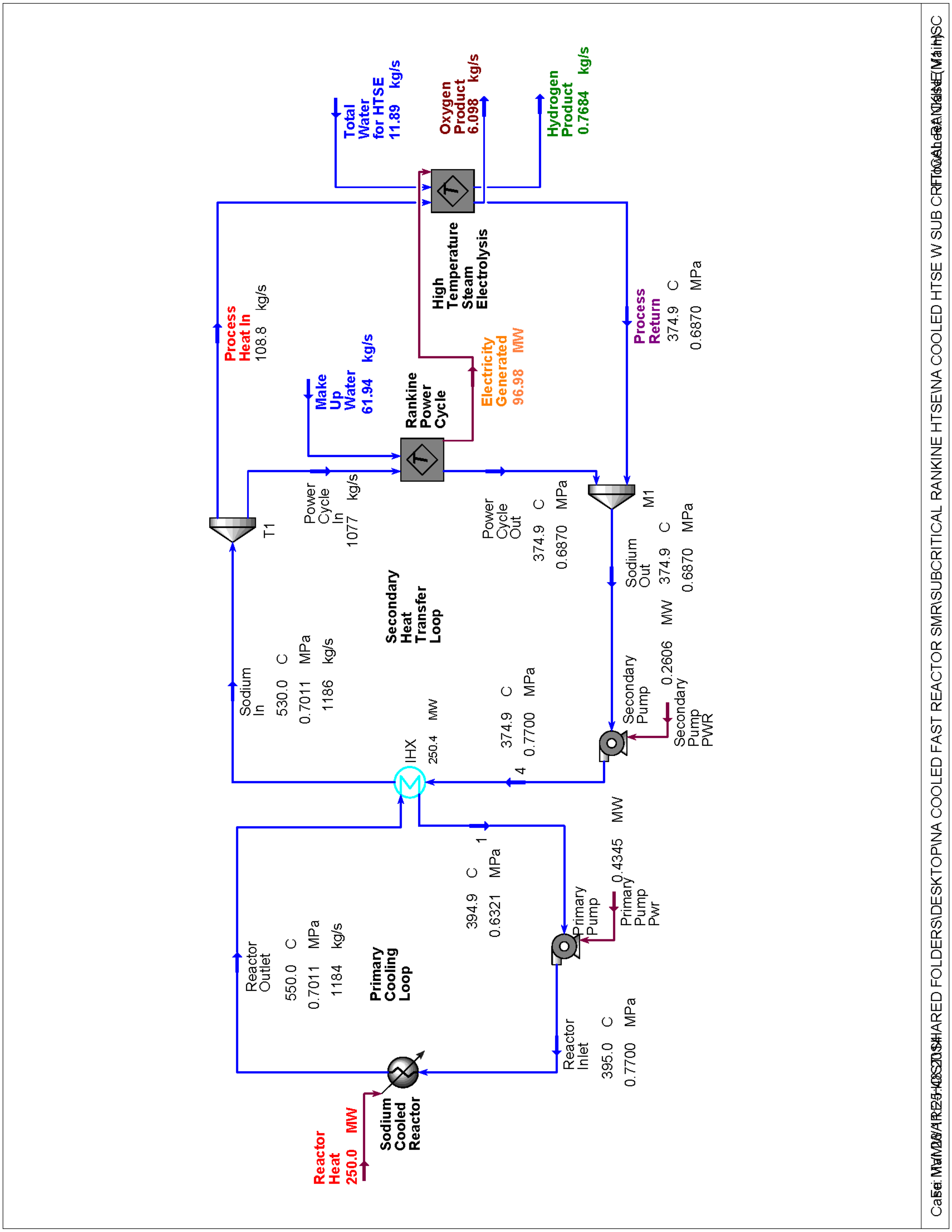
Adjusted Variable		Measured Variable	
OBJECT	VARIABLE	OBJECT	VARIABLE
3	Mass Flow	Anode	Molar Flow

Solving Parameters

Source for Target Value:	Value from Object	Object:	ır Flow of Oxygen @TPL4	Offset:	0.0000 kgmole/h *
Solving Method:	Secant	Tolerance:	0.9000 kgmole/h	Maximum Iterations:	100 *
Step Size:	0.1000 kg/s *	Maximum:	---	Minimum:	---

User Variables

6.5 Subcritical Rankine HTSE Model



BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC
Unit Set: AFR
Date/Time: Fri Mar 28 11:35:17 2014

Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Sodium In	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.7011	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.857e+005	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	1186	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	4544	4544	4537	4537	4537
Heat Flow	(MW)	818.8	568.3	849.9	599.9	599.5

Name		Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE
Vapour Fraction		0.0000	0.0000	1.0000	1.0000	0.0000
Temperature	(C)	374.9	20.00	54.44	54.44	21.11
Pressure	(MPa)	0.6870	0.1013	6.901	6.901	0.1013
Molar Flow	(kgmole/h)	1.857e+005	1.238e+004	1372	686.0	2376
Mass Flow	(kg/s)	1186	61.94	0.7684	6.098	11.89
Liquid Volume Flow	(m3/h)	4544	223.4	39.60	19.30	42.90
Heat Flow	(MW)	568.1	-981.1	0.3244	6.653e-002	-189.1

Name		Process Heat In	Process Return	Power Cycle In	Power Cycle Out	
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	
Temperature	(C)	530.0	374.9	530.0	374.9	
Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	
Molar Flow	(kgmole/h)	1.704e+004	1.704e+004	1.687e+005	1.687e+005	
Mass Flow	(kg/s)	108.8	108.8	1077	1077	
Liquid Volume Flow	(m3/h)	416.8	416.8	4127	4127	
Heat Flow	(MW)	75.11	52.11	743.7	516.0	

Compositions

Fluid Pkg: All

Name	Sodium In	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***

Name	Sodium Out	Make Up Water	Hydrogen Product	Oxygen Product	Total Water for HTSE
Comp Mole Frac (H2O)	***	1.0000	0.0000	0.0000	1.0000
Comp Mole Frac (Nitrogen)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	***	***	0.0000	1.0000	0.0000
Comp Mole Frac (Hydrogen)	***	***	1.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	***	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	1.0000	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC	
	Unit Set:	AFR	
	Date/Time:	Fri Mar 28 11:35:17 2014	

Workbook: Case (Main) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Process Heat In	Process Return	Power Cycle In	Power Cycle Out	
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	1.0000	1.0000	1.0000	
Comp Mole Frac (Air)	***	***	***	***	

Energy Streams

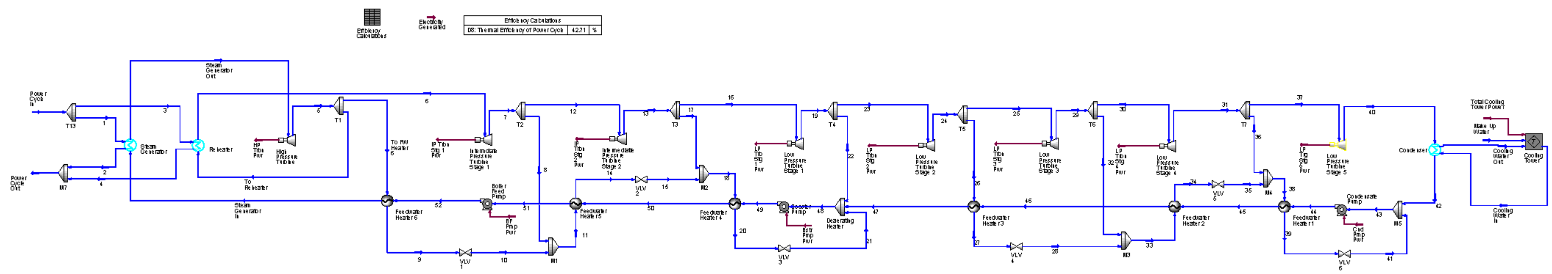
Fluid Pkg: All

Name	Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWR	
Heat Flow (MW)	250.0 *	96.98	0.4345	0.2606	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
Rankine Power Cycle	Standard Sub-Flowsheet	Power Cycle In Make Up Water	Power Cycle Out Electricity Generated	No	2500 *
High Temperature Steam Elec	Standard Sub-Flowsheet	Process Heat In Total Water for HTSE Electricity Generated	Hydrogen Product Oxygen Product Process Return	No	2500 *
Efficiency Calcs	Spreadsheet			No	500.0 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *
T1	Tee	Sodium In	Power Cycle In Process Heat In	No	500.0 *
M1	Mixer	Process Return Power Cycle Out	Sodium Out	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.



Case: MAIN / File: V:\05 SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\SUBCRITICAL RANKINE HTSE\NA COOLED HTSE W SUBCRITICAL RANKINE (TPL1).HSC / Flowsheet: Rankine Power Cycle (TPL1)

Workbook: Rankine Power Cycle (TPL1)

Streams

Fluid Pkg: All

Name		Steam Generator Out	To Reheater @TPL1	To FW Heater 6 @TPL	6 @TPL1	9 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	510.0	354.8	354.8	510.0	251.1
Pressure	(MPa)	17.00	5.850	5.850	5.733	5.733
Molar Flow	(kgmole/h)	1.824e+004	1.714e+004	1096	1.714e+004	1096
Mass Flow	(kg/s)	91.28	85.79	5.486	85.79	5.486
Std Ideal Liq Vol Flow	(m3/h)	329.3	309.5	19.79	309.5	19.79
Heat Flow	(MW)	-1151	-1104	-70.57	-1070	-81.37
Molar Enthalpy	(kJ/kgmole)	-2.272e+005	-2.318e+005	-2.318e+005	-2.247e+005	-2.672e+005
Name		52 @TPL1	Steam Generator In @	51 @TPL1	8 @TPL1	12 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	1.0000
Temperature	(C)	245.6	270.4	241.0	445.6	445.6
Pressure	(MPa)	17.70 *	17.35	3.409	3.760	3.760
Molar Flow	(kgmole/h)	1.824e+004	1.824e+004	1.824e+004	1030	1.611e+004
Mass Flow	(kg/s)	91.28	91.28	91.28	5.156	80.64
Std Ideal Liq Vol Flow	(m3/h)	329.3	329.3	329.3	18.60	290.9
Heat Flow	(MW)	-1356	-1346	-1358	-64.97	-1016
Molar Enthalpy	(kJ/kgmole)	-2.677e+005	-2.655e+005	-2.681e+005	-2.270e+005	-2.270e+005
Name		11 @TPL1	16 @TPL1	18 @TPL1	23 @TPL1	22 @TPL1
Vapour Fraction		0.6368	1.0000	0.3742	1.0000	1.0000
Temperature	(C)	246.7	365.7	215.4	274.7	274.7
Pressure	(MPa)	3.760	2.120	2.120	0.9299	0.9299
Molar Flow	(kgmole/h)	2127	1.515e+004	3095	1.424e+004	910.3
Mass Flow	(kg/s)	10.64	75.79	15.49	71.24	4.555
Std Ideal Liq Vol Flow	(m3/h)	38.39	273.4	55.87	257.0	16.43
Heat Flow	(MW)	-146.3	-966.7	-221.5	-920.8	-58.88
Molar Enthalpy	(kJ/kgmole)	-2.477e+005	-2.298e+005	-2.576e+005	-2.329e+005	-2.329e+005
Name		49 @TPL1	14 @TPL1	20 @TPL1	47 @TPL1	48 @TPL1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	177.2	215.1	182.7	142.0	176.6
Pressure	(MPa)	3.550 *	3.760	2.078	0.9299	0.9299
Molar Flow	(kgmole/h)	1.824e+004	2127	3095	1.424e+004	1.824e+004
Mass Flow	(kg/s)	91.28	10.64	15.49	71.24	91.28
Std Ideal Liq Vol Flow	(m3/h)	329.3	38.39	55.87	257.0	329.3
Heat Flow	(MW)	-1385	-159.7	-234.6	-1092	-1385
Molar Enthalpy	(kJ/kgmole)	-2.733e+005	-2.703e+005	-2.729e+005	-2.761e+005	-2.734e+005
Name		21 @TPL1	25 @TPL1	26 @TPL1	27 @TPL1	30 @TPL1
Vapour Fraction		0.0132	1.0000	1.0000	0.0000	1.0000
Temperature	(C)	176.8	202.0	202.0	113.9	126.4
Pressure	(MPa)	0.9299	0.4380	0.4380	0.4292	0.1660
Molar Flow	(kgmole/h)	3095	1.338e+004	855.5	855.5	1.258e+004
Mass Flow	(kg/s)	15.49	66.96	4.281	4.281	62.93
Std Ideal Liq Vol Flow	(m3/h)	55.87	241.5	15.44	15.44	227.0
Heat Flow	(MW)	-234.6	-874.5	-55.92	-66.13	-830.8
Molar Enthalpy	(kJ/kgmole)	-2.729e+005	-2.353e+005	-2.353e+005	-2.783e+005	-2.378e+005

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name:	NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC
	Unit Set:	AFR
	Date/Time:	Fri Mar 28 11:35:17 2014

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		32 @TPL1	37 @TPL1	34 @TPL1	39 @TPL1	44 @TPL1
Vapour Fraction		1.0000	0.9633	0.0000	0.0000	0.0000
Temperature	(C)	126.4	80.22	79.77	45.74	40.18
Pressure	(MPa)	0.1660	4.780e-002	0.1627	4.684e-002	0.9880 *
Molar Flow	(kgmole/h)	804.1	1.182e+004	1660	2415	1.424e+004
Mass Flow	(kg/s)	4.024	59.15	8.305	12.09	71.24
Std Ideal Liq Vol Flow	(m3/h)	14.52	213.4	29.96	43.60	257.0
Heat Flow	(MW)	-53.12	-790.5	-129.5	-190.2	-1122
Molar Enthalpy	(kJ/kgmole)	-2.378e+005	-2.408e+005	-2.809e+005	-2.834e+005	-2.838e+005

Name		40 @TPL1	38 @TPL1	42 @TPL1	33 @TPL1	41 @TPL1
Vapour Fraction		0.9072	0.3009	0.0000	0.4895	0.0098
Temperature	(C)	40.51	80.22	38.92	114.4	40.13
Pressure	(MPa)	7.584e-003 *	4.780e-002	7.433e-003	0.1660	7.433e-003
Molar Flow	(kgmole/h)	1.182e+004	2415	1.182e+004	1660	2415
Mass Flow	(kg/s)	59.15	12.09	59.15	8.305	12.09
Std Ideal Liq Vol Flow	(m3/h)	213.4	43.60	213.4	29.96	43.60
Heat Flow	(MW)	-802.8	-180.0	-932.3	-119.2	-190.2
Molar Enthalpy	(kJ/kgmole)	-2.445e+005	-2.683e+005	-2.839e+005	-2.587e+005	-2.834e+005

Name		1 @TPL1	3 @TPL1	2 @TPL1	4 @TPL1	Power Cycle In @TPL
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	530.0	530.0	374.9	374.9 *	530.0
Pressure	(MPa)	0.7011	0.7011	0.6870	0.6870	0.7011
Molar Flow	(kgmole/h)	1.439e+005	2.475e+004	1.439e+005	2.475e+004	1.687e+005
Mass Flow	(kg/s)	919.1	158.1	919.1	158.1	1077
Std Ideal Liq Vol Flow	(m3/h)	3521	605.6	3521	605.6	4127
Heat Flow	(MW)	634.5	109.1	440.3	75.72	743.7
Molar Enthalpy	(kJ/kgmole)	1.587e+004	1.587e+004	1.101e+004	1.101e+004	1.587e+004

Name		Power Cycle Out @TF	5 @TPL1	10 @TPL1	7 @TPL1	13 @TPL1
Vapour Fraction		0.0000	1.0000	0.0122	1.0000	1.0000
Temperature	(C)	374.9	354.8	246.7	445.6	365.7
Pressure	(MPa)	0.6870	5.850 *	3.760	3.760 *	2.120 *
Molar Flow	(kgmole/h)	1.687e+005	1.824e+004	1096	1.714e+004	1.611e+004
Mass Flow	(kg/s)	1077	91.28	5.486	85.79	80.64
Std Ideal Liq Vol Flow	(m3/h)	4127	329.3	19.79	309.5	290.9
Heat Flow	(MW)	516.0	-1174	-81.37	-1081	-1029
Molar Enthalpy	(kJ/kgmole)	1.101e+004	-2.318e+005	-2.672e+005	-2.270e+005	-2.298e+005

Name		19 @TPL1	24 @TPL1	29 @TPL1	31 @TPL1	45 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	0.9633	0.0000
Temperature	(C)	274.7	202.0	126.4	80.22	74.22
Pressure	(MPa)	0.9299	0.4380 *	0.1660 *	4.780e-002 *	0.9682
Molar Flow	(kgmole/h)	1.515e+004	1.424e+004	1.338e+004	1.258e+004	1.424e+004
Mass Flow	(kg/s)	75.79	71.24	66.96	62.93	71.24
Std Ideal Liq Vol Flow	(m3/h)	273.4	257.0	241.5	227.0	257.0
Heat Flow	(MW)	-979.7	-930.5	-883.9	-841.1	-1112
Molar Enthalpy	(kJ/kgmole)	-2.329e+005	-2.353e+005	-2.378e+005	-2.408e+005	-2.813e+005

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Streams (continued)

Fluid Pkg: All

Name		46 @TPL1	50 @TPL1	17 @TPL1	15 @TPL1	28 @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	108.4	209.6	365.7	215.2	114.0
Pressure	(MPa)	0.9489	3.479	2.120	2.120	0.1660
Molar Flow	(kgmole/h)	1.424e+004	1.824e+004	968.5	2127	855.5
Mass Flow	(kg/s)	71.24	91.28	4.846	10.64	4.281
Std Ideal Liq Vol Flow	(m3/h)	257.0	329.3	17.48	38.39	15.44
Heat Flow	(MW)	-1102	-1372	-61.81	-159.7	-66.13
Molar Enthalpy	(kJ/kgmole)	-2.787e+005	-2.707e+005	-2.298e+005	-2.703e+005	-2.783e+005
Name		36 @TPL1	35 @TPL1	43 @TPL1	HP Trbn Pwr @TPL1	IP Trbn Stg 1 Pwr @T
Vapour Fraction		0.9633	0.0000	0.0000	---	---
Temperature	(C)	80.22	79.80	40.07	---	---
Pressure	(MPa)	4.780e-002	4.780e-002	7.433e-003	---	---
Molar Flow	(kgmole/h)	755.8	1660	1.424e+004	---	---
Mass Flow	(kg/s)	3.782	8.305	71.24	---	---
Std Ideal Liq Vol Flow	(m3/h)	13.64	29.96	257.0	---	---
Heat Flow	(MW)	-50.55	-129.5	-1122	23.04	10.77
Molar Enthalpy	(kJ/kgmole)	-2.408e+005	-2.809e+005	-2.838e+005	---	---
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 @T
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	12.45	12.97	0.3576	9.674	9.336
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---
Name		LP Trbn Stg 4 Pwr @T	LP Trg Stg 5 Pwr @TF	BF Pmp Pwr @TPL1	Cnd Pmp Pwr @TPL1	Electricity Generated @
Vapour Fraction		---	---	---	---	---
Temperature	(C)	---	---	---	---	---
Pressure	(MPa)	---	---	---	---	---
Molar Flow	(kgmole/h)	---	---	---	---	---
Mass Flow	(kg/s)	---	---	---	---	---
Std Ideal Liq Vol Flow	(m3/h)	---	---	---	---	---
Heat Flow	(MW)	10.32	12.28	2.121	9.384e-002	96.98
Molar Enthalpy	(kJ/kgmole)	---	---	---	---	---
Name		Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL	Total Cooling Tower P	
Vapour Fraction		0.0000	0.0000	0.0000	---	
Temperature	(C)	34.96	25.00	20.00	---	
Pressure	(MPa)	0.1015	0.1035	0.1013	---	
Molar Flow	(kgmole/h)	6.023e+005	6.023e+005	1.238e+004	---	
Mass Flow	(kg/s)	3014	3014	61.94	---	
Std Ideal Liq Vol Flow	(m3/h)	1.087e+004	1.087e+004	223.4	---	
Heat Flow	(MW)	-4.776e+004	-4.788e+004	-981.1	0.5878	
Molar Enthalpy	(kJ/kgmole)	-2.854e+005	-2.862e+005	-2.854e+005	---	

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Expanders

Fluid Pkg: All

Name		High Pressure Turbine	Intermdiate Pressure T	Intermediatte Pressure	Low Pressure Turbine	Low Pressure Turbine
Power	(MW)	23.04	10.77	12.45	12.97	9.674
Capacity (act feed vol flow) (ACT_m3/h)		6038	1.864e+004	2.460e+004	3.662e+004	6.779e+004
Feed Pressure	(MPa)	17.00	5.733	3.760	2.120	0.9299
Product Pressure	(MPa)	5.850 *	3.760 *	2.120 *	0.9299	0.4380 *
Product Temperature	(C)	354.8	445.6	365.7	274.7	202.0
Adiabatic Efficiency		85 *	90 *	90 *	80 *	80 *
Name		Low Pressure Turbine	Low Pressure Turbine	Low Pressure Turbine		
Power	(MW)	9.336	10.32	12.28		
Capacity (act feed vol flow) (ACT_m3/h)		1.179e+005	2.470e+005	6.934e+005		
Feed Pressure	(MPa)	0.4380	0.1660	4.780e-002		
Product Pressure	(MPa)	0.1660 *	4.780e-002 *	7.584e-003 *		
Product Temperature	(C)	126.4	80.22	40.51		
Adiabatic Efficiency		75 *	80 *	80 *		

Pumps

Fluid Pkg: All

Name		Boiler Feed Pump @T	Booster Pump @TPL1	Condensate Pump @T		
Power	(MW)	2.121	0.3576	9.384e-002		
Capacity(Actual Vol. Flow)	(m3/h)	404.6	368.9	258.5		
Feed Pressure	(MPa)	3.409	0.9299	7.433e-003		
Product Pressure	(MPa)	17.70 *	3.550 *	0.9880 *		
Product Temperature	(C)	245.6	177.2	40.18		
Adiabatic Efficiency	(%)	75.00 *	75.00 *	75.00 *		

Heat Exchangers

Fluid Pkg: All

Name		Feedwater Heater 6 @	Feedwater Heater 5 @	Feedwater Heater 4 @	Feedwater Heater 3 @	Feedwater Heater 2 @
Duty	(MW)	10.80	13.31	13.15	10.21	10.23
Tube Side Feed Mass Flow	(kg/s)	91.28	91.28	91.28	71.24	71.24
Shell Side Feed Mass Flow	(kg/s)	5.486	10.64	15.49	4.281	8.305
Tube Inlet Temperature	(C)	245.6	209.6	177.2	108.4	74.22
Tube Outlet Temperature	(C)	270.4	241.0	209.6	142.0	108.4
Shell Inlet Temperature	(C)	354.8	246.7	215.4	202.0	114.4
Shell Outlet Temperature	(C)	251.1	215.1	182.7	113.9	79.77
LMTD	(C)	15.17	15.61	15.24	17.42	16.65
Minimum Approach	(C)	5.556	5.556	5.556	5.556	5.556
UA	(kJ/C-h)	2.562e+006	3.071e+006	3.106e+006	2.109e+006	2.212e+006
Name		Feedwater Heater 1 @	Steam Generator @TF	Reheater @TPL1	Condenser @TPL1	
Duty	(MW)	10.14	194.3	33.42	129.4	
Tube Side Feed Mass Flow	(kg/s)	71.24	919.1	158.1	3014	
Shell Side Feed Mass Flow	(kg/s)	12.09	91.28	85.79	59.15	
Tube Inlet Temperature	(C)	40.18	530.0	530.0	25.00	
Tube Outlet Temperature	(C)	74.22	374.9	374.9 *	34.96	
Shell Inlet Temperature	(C)	80.22	270.4	354.8	40.51	
Shell Outlet Temperature	(C)	45.74	510.0	510.0	38.92	
LMTD	(C)	16.02	78.05	22.08	9.555	
Minimum Approach	(C)	5.556	20.00	20.00	5.556	
UA	(kJ/C-h)	2.278e+006	8.961e+006	5.449e+006	4.876e+007	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
High Pressure Turbine @TPL	Expander	Steam Generator Out @TPL1	5 @TPL1 HP Trbn Pwr @TPL1	No	500.0 *

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Intermdiate Pressure Turbine	Expander	6 @TPL1	7 @TPL1 IP Trbn Stg 1 Pwr @TPL1	No	500.0 *
Intermediatte Pressure Turbin	Expander	12 @TPL1	13 @TPL1 IP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 1	Expander	16 @TPL1	19 @TPL1 LP Trb Stg 1 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 2	Expander	23 @TPL1	24 @TPL1 LP Trbn Stg 2 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 3	Expander	25 @TPL1	29 @TPL1 LP Trbn Stg 3 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 4	Expander	30 @TPL1	31 @TPL1 LP Trbn Stg 4 Pwr @TPL1	No	500.0 *
Low Pressure Turbine Stage 5	Expander	37 @TPL1	40 @TPL1 LP Trg Stg 5 Pwr @TPL1	No	500.0 *
Feedwater Heater 6 @TPL1	Heat Exchanger	52 @TPL1 To FW Heater 6 @TPL1	Steam Generator In @TPL1 9 @TPL1	No	500.0 *
Feedwater Heater 5 @TPL1	Heat Exchanger	50 @TPL1 11 @TPL1	51 @TPL1 14 @TPL1	No	500.0 *
Feedwater Heater 4 @TPL1	Heat Exchanger	49 @TPL1 18 @TPL1	50 @TPL1 20 @TPL1	No	500.0 *
Feedwater Heater 3 @TPL1	Heat Exchanger	46 @TPL1 26 @TPL1	47 @TPL1 27 @TPL1	No	500.0 *
Feedwater Heater 2 @TPL1	Heat Exchanger	45 @TPL1 33 @TPL1	46 @TPL1 34 @TPL1	No	500.0 *
Feedwater Heater 1 @TPL1	Heat Exchanger	44 @TPL1 38 @TPL1	45 @TPL1 39 @TPL1	No	500.0 *
Steam Generator @TPL1	Heat Exchanger	1 @TPL1 Steam Generator In @TPL1	2 @TPL1 Steam Generator Out @TPL1	No	500.0 *
Reheater @TPL1	Heat Exchanger	3 @TPL1 To Reheater @TPL1	4 @TPL1 6 @TPL1	No	500.0 *
Condenser @TPL1	Heat Exchanger	Cooling Water In @TPL1 40 @TPL1	Cooling Water Out @TPL1 42 @TPL1	No	500.0 *
Boiler Feed Pump @TPL1	Pump	51 @TPL1 BF Pmp Pwr @TPL1	52 @TPL1	No	500.0 *
Booster Pump @TPL1	Pump	48 @TPL1 Bstr Pmp Pwr @TPL1	49 @TPL1	No	500.0 *
Condensate Pump @TPL1	Pump	43 @TPL1 Cnd Pmp Pwr @TPL1	44 @TPL1	No	500.0 *
M1 @TPL1	Mixer	10 @TPL1 8 @TPL1	11 @TPL1	No	500.0 *
M2 @TPL1	Mixer	17 @TPL1 15 @TPL1	18 @TPL1	No	500.0 *
Deaerating Heater @TPL1	Mixer	47 @TPL1 21 @TPL1 22 @TPL1	48 @TPL1	No	500.0 *
M4 @TPL1	Mixer	36 @TPL1 35 @TPL1	38 @TPL1	No	500.0 *
M3 @TPL1	Mixer	32 @TPL1 28 @TPL1	33 @TPL1	No	500.0 *
M5 @TPL1	Mixer	41 @TPL1 42 @TPL1	43 @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M7 @TPL1	Mixer	2 @TPL1 4 @TPL1	Power Cycle Out @TPL1	No	500.0 *
VLV 3 @TPL1	Valve	20 @TPL1	21 @TPL1	No	500.0 *
VLV 4 @TPL1	Valve	27 @TPL1	28 @TPL1	No	500.0 *
VLV 5 @TPL1	Valve	34 @TPL1	35 @TPL1	No	500.0 *
VLV 1 @TPL1	Valve	9 @TPL1	10 @TPL1	No	500.0 *
VLV 2 @TPL1	Valve	14 @TPL1	15 @TPL1	No	500.0 *
VLV 6 @TPL1	Valve	39 @TPL1	41 @TPL1	No	500.0 *
SG tb dP @TPL1	Set			No	500.0 *
SG sh dP @TPL1	Set			No	500.0 *
FW6 tb dP @TPL1	Set			No	500.0 *
FW6 sh dP @TPL1	Set			No	500.0 *
FW4 tb dP @TPL1	Set			No	500.0 *
FW5 tb dP @TPL1	Set			No	500.0 *
FW5 sh dP @TPL1	Set			No	500.0 *
FW4 sh dP @TPL1	Set			No	500.0 *
Cnd sh dP @TPL1	Set			No	500.0 *
FW1 tb dP @TPL1	Set			No	500.0 *
FW1 sh dP @TPL1	Set			No	500.0 *
FW2 tb dP @TPL1	Set			No	500.0 *
FW2 sh dP @TPL1	Set			No	500.0 *
FW3 tb dP @TPL1	Set			No	500.0 *
FW3 sh dP @TPL1	Set			No	500.0 *
Rht tb dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Cnd Tb dP @TPL1	Set			No	500.0 *
SET-3 @TPL1	Set			No	500.0 *
SET-4 @TPL1	Set			No	500.0 *
SET-5 @TPL1	Set			No	500.0 *
SET-6 @TPL1	Set			No	500.0 *
SET-7 @TPL1	Set			No	500.0 *
SET-8 @TPL1	Set			No	500.0 *
T1 @TPL1	Tee	5 @TPL1	To FW Heater 6 @TPL1 To Reheater @TPL1	No	500.0 *
T2 @TPL1	Tee	7 @TPL1	8 @TPL1 12 @TPL1	No	500.0 *
T3 @TPL1	Tee	13 @TPL1	17 @TPL1 16 @TPL1	No	500.0 *
T4 @TPL1	Tee	19 @TPL1	22 @TPL1 23 @TPL1	No	500.0 *
T5 @TPL1	Tee	24 @TPL1	26 @TPL1 25 @TPL1	No	500.0 *
T6 @TPL1	Tee	29 @TPL1	32 @TPL1 30 @TPL1	No	500.0 *
T7 @TPL1	Tee	31 @TPL1	36 @TPL1 37 @TPL1	No	500.0 *
T13 @TPL1	Tee	Power Cycle In @TPL1	3 @TPL1 1 @TPL1	No	500.0 *
Efficiency Calculations @TPL	Spreadsheet			No	500.0 *
Cooling Tower @TPL1	Standard Sub-Flowsheet	Cooling Water Out @TPL1 Make Up Water @TPL1	Cooling Water In @TPL1	No	2500 *

Workbook: Rankine Power Cycle (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Cooling Tower @TPL1	Standard Sub-Flowsheet	Total Cooling Tower Power @		No	2500 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Efficiency Calculations @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
B1	Energy Stream: HP Trbn Pwr @TPL1	Power	23.04 MW
B2	Energy Stream: IP Trbn Stg 1 Pwr @TPL1	Power	10.77 MW
B3	Energy Stream: IP Trbn Stg 2 Pwr @TPL1	Power	12.45 MW
B4	Energy Stream: LP Trb Stg 1 Pwr @TPL1	Power	12.97 MW
B5	Energy Stream: LP Trbn Stg 2 Pwr @TPL1	Power	9.674 MW
B6	Energy Stream: LP Trbn Stg 3 Pwr @TPL1	Power	9.336 MW
B7	Energy Stream: LP Trbn Stg 4 Pwr @TPL1	Power	10.32 MW
B8	Energy Stream: LP Trg Stg 5 Pwr @TPL1	Power	12.28 MW
B9	Energy Stream: Cnd Pmp Pwr @TPL1	Power	9.384e-002 MW
B10	Energy Stream: Bstr Pmp Pwr @TPL1	Power	0.3576 MW
D1	Energy Stream: BF Pmp Pwr @TPL1	Power	2.121 MW
D2	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
D3	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
D4	Energy Stream: Total Cooling Tower Powe	Power	0.5878 MW
D5	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
C9	Tee: T1	Flow Ratio (Flow Ratio_1)	0.9083

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
D7	Electricity Generated @TPL1	Power	96.98 MW
F1	Steam Generator In @TPL1	Mass Flow	91.28 kg/s

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
D6	D6: Total Turbine Power	Total Turbine Power	Power	100.8 MW
D7	D7: Power	Power	Power	96.98 MW
D8	D8: Thermal Efficiency of Power Cycle	Thermal Efficiency of Power Cycle	Percent	42.71
D10	D10: Power	Power	Mass Flow	100.5 kg/s
F1	F1: Mass Flow	Mass Flow	Mass Flow	91.28 kg/s

User Variables

FORMULAS

Cell	Formula	Result
D6	=B1+B2+B3+B4+B5+B6+B7+B8	100.8 MW
D7	=D6-B9-B10-D1-D2-D3-D4	96.98 MW
D8	=D7/(D5*C9)*100	42.71
F1	=C9*D10	91.28 kg/s

Spreadsheet

	A	B	C	D
1	HP Trb Pwr *	23.04 MW *	BF Pmp Pwr *	2.121 MW *
2	IP Trb Stg 1 Pwr *	10.77 MW *	Primary Pump Power *	0.4345 MW *
3	IP Trb Stg 2 Pwr *	12.45 MW *	Secondary Pump Power *	0.2606 MW *
4	LP Trb Stg 1 Pwr *	12.97 MW *	Cooling Tower Power *	0.5878 MW *
5	LP Trb Stg 2 Pwr *	9.674 MW *	Reactor Heat *	250.0 MW *
6	LP Trb Stg 3 Pwr *	9.336 MW *	Total Turbine Power *	100.8 MW *

Licensed to: BATTELLE ENERGY ALLIANCE

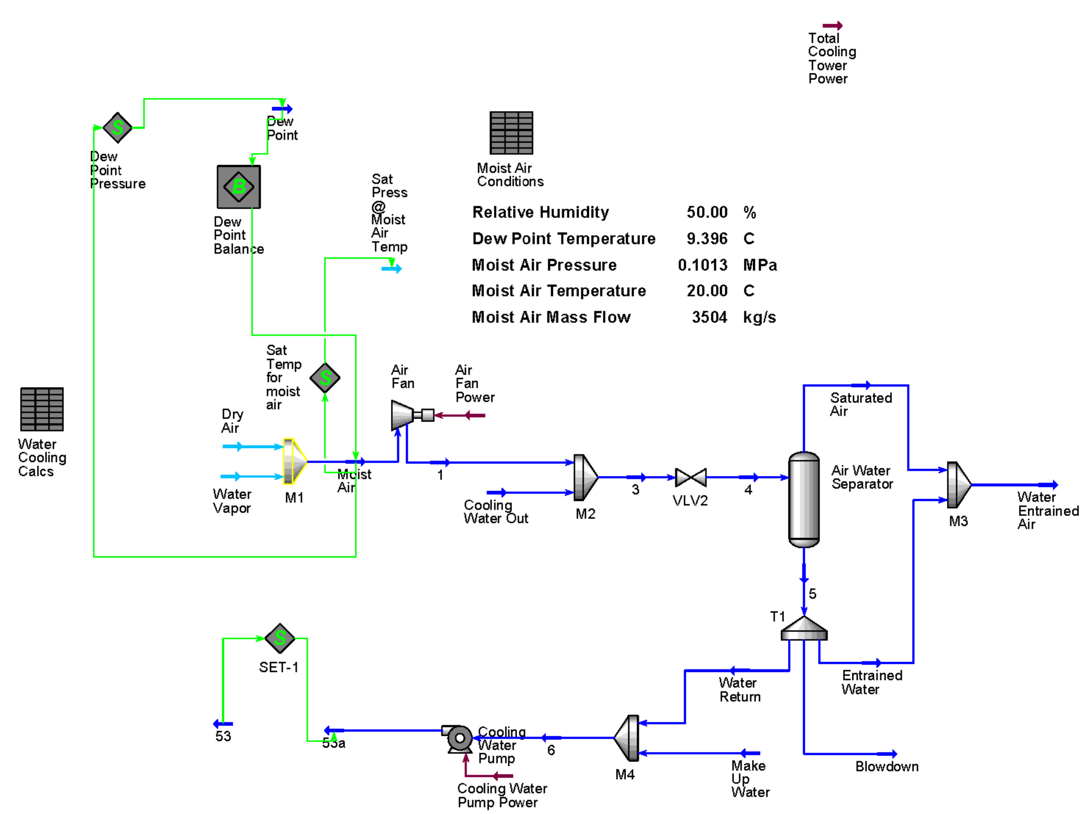
* Specified by user.

Spreadsheet: Efficiency Calculations @TPL1 (continu

Units Set: NuScale2

Spreadsheet

7	LP Trb Stg 4 Pwr *	10.32 MW *	Electricity Generated *	96.98 MW *
8	LP Trb Stg 5 Pwr *	12.28 MW *	Thermal Efficiency of Power Cycle *	42.71 *
9	Cnd Pmp Pwr *	9.384e-002 MW *	0.9083 *	Power flow split *
10	Bstr Pmp Pwr *	0.3576 MW *	100% Rankine Flow *	100.5 kg/s *
	E	F		
1	Mass Flow @ Steam Generator In *	91.28 kg/s *		
2				
3				
4				
5				
6				
7				
8				
9				
10				



Case: Ma\M28\AR24\OS2014HARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\SUBCRITICAL RANKINE HTSE\NA COOLED HTSE WFOUBCRITICAL RANKINE TPL2)SC Flowsheet: Cooling Tower (TPL2)

Workbook: Cooling Tower (TPL2)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Vapour Fraction		0.0000	0.0000	---	---	1.0000
Temperature	(C)	34.96	25.00 *	---	---	20.00 *
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	0.1013 *
Molar Flow	(kgmole/h)	6.023e+005	6.023e+005	4.341e+005	5051	4.392e+005
Mass Flow	(kg/s)	3014	3014	3479	25.28	3504 *
Liquid Volume Flow	(m3/h)	1.087e+004	1.087e+004	1.448e+004	91.18	1.457e+004
Heat Flow	(MW)	-4.776e+004	-4.788e+004	---	---	-358.2
Name		**Sat Press @ Moist Air**	**1 @TPL2**	**3 @TPL2**	**Dew Point @TPL2**	**4 @TPL2**
Vapour Fraction		1.0000 *	1.0000	0.4303	1.0000 *	0.4303
Temperature	(C)	20.00	20.16	25.11	9.396	25.10
Pressure	(MPa)	2.339e-003	0.1015	0.1015	0.1013	0.1013
Molar Flow	(kgmole/h)	---	4.392e+005	1.041e+006	4.392e+005	1.041e+006
Mass Flow	(kg/s)	---	3504	6518	3504	6518
Liquid Volume Flow	(m3/h)	---	1.457e+004	2.544e+004	1.457e+004	2.544e+004
Heat Flow	(MW)	---	-357.6	-4.811e+004	-396.0	-4.811e+004
Name		**Saturated Air @TPL2**	**5 @TPL2**	**Entrained Water @TP**	**Blowdown @TPL2**	**Water Return @TPL2**
Vapour Fraction		1.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.10	25.10	25.10	25.10	25.10
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	4.481e+005	5.933e+005	602.3	2804	5.899e+005
Mass Flow	(kg/s)	3549	2969	3.014	14.03	2952
Liquid Volume Flow	(m3/h)	1.473e+004	1.071e+004	10.87	50.63	1.065e+004
Heat Flow	(MW)	-942.8	-4.717e+004	-47.88	-223.0	-4.690e+004
Name		**Water Entrained Air @**	**Make Up Water @TPL**	**6 @TPL2**	**53a @TPL2**	
Vapour Fraction		0.9987	0.0000	0.0000	0.0000	
Temperature	(C)	25.10	20.00 *	25.00	25.00	
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1035	
Molar Flow	(kgmole/h)	4.487e+005	1.238e+004	6.023e+005	6.023e+005	
Mass Flow	(kg/s)	3552	61.94	3014	3014	
Liquid Volume Flow	(m3/h)	1.474e+004	223.4	1.087e+004	1.087e+004	
Heat Flow	(MW)	-990.7	-985.4	-4.788e+004	-4.788e+004	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	53 @TPL2	Dry Air @TPL2	Water Vapor @TPL2	Moist Air @TPL2
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	0.0115
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	0.7809
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	0.2076
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000 *	0.0000 *	0.0000
Name	**Sat Press @ Moist Air**	**1 @TPL2**	**3 @TPL2**	**Dew Point @TPL2**	**4 @TPL2**
Comp Mole Frac (H2O)	1.0000 *	0.0115	0.5832	0.0115	0.5832
Comp Mole Frac (Nitrogen)	***	0.7809	0.3293	0.7809	0.3293
Comp Mole Frac (Oxygen)	***	0.2076	0.0875	0.2076	0.0875
Comp Mole Frac (Hydrogen)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	0.0000	0.0000	0.0000	0.0000

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: Cooling Tower (TPL2) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Saturated Air @TPL2	5 @TPL2	Entrained Water @TP	Blowdown @TPL2	Water Return @TPL2
Comp Mole Frac (H2O)	0.0313	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (Nitrogen)	0.7653	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.2034	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	0.0000	0.0000	0.0000	0.0000	0.0000

Name	Water Entrained Air @	Make Up Water @TPL	6 @TPL2	53a @TPL2	
Comp Mole Frac (H2O)	0.0326	1.0000 *	1.0000	1.0000	
Comp Mole Frac (Nitrogen)	0.7643	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Oxygen)	0.2032	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	0.0000	0.0000 *	0.0000	0.0000	

Energy Streams

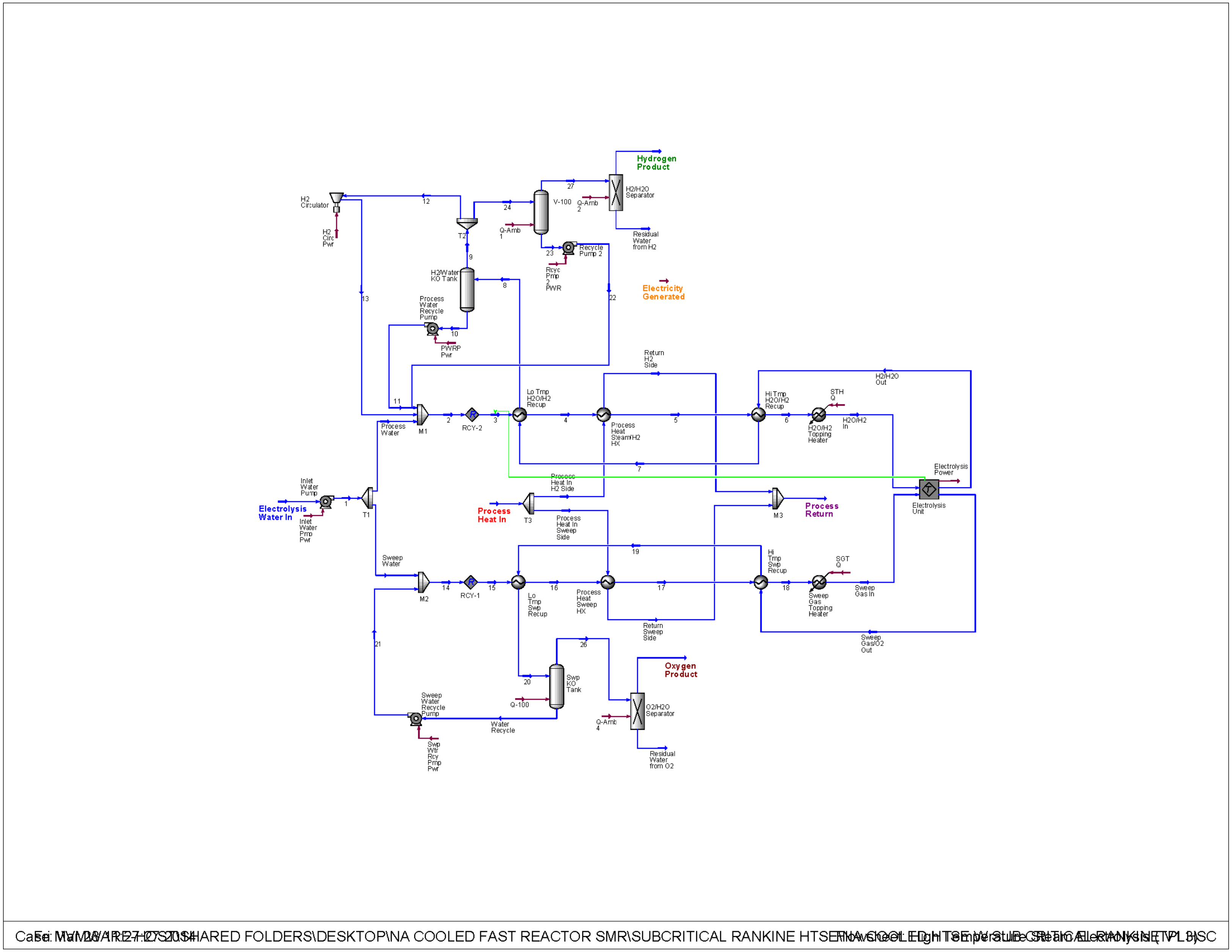
Fluid Pkg: All

Name	Air Fan Power @TPL2	Cooling Water Pump P	Total Cooling Tower P		
Heat Flow (MW)	0.5791	8.687e-003	0.5878		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL2	Mixer	Dry Air @TPL2 Water Vapor @TPL2	Moist Air @TPL2	No	500.0 *
M2 @TPL2	Mixer	1 @TPL2 Cooling Water Out @TPL2	3 @TPL2	No	500.0 *
M3 @TPL2	Mixer	Saturated Air @TPL2 Entrained Water @TPL2	Water Entrained Air @TPL2	No	500.0 *
M4 @TPL2	Mixer	Water Return @TPL2 Make Up Water @TPL2	6 @TPL2	No	500.0 *
Moist Air Conditions @TPL2	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL2	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL2	Set			No	500.0 *
Dew Point Pressure @TPL2	Set			No	500.0 *
Amb Press Set @TPL2	Set			No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.


Hydrogen Product
H2/H2O Separator
Residual Water from H2
H2 Circulator
H2 Circ Pwr
V-100
Q-Amb 1
Q-Amb 2
Recycle Pump 2
Rcyc Pmp 2 PWR
H2/Water KO Tank
Process Water Recycle Pump
PWRP Pwr
Electricity Generated
Return H2 Side
H2/H2O Out
Lo Tmp H2O/H2 Recup
Process Heat Steam/H2 HX
Hi Tmp H2O/H2 Recup
STH Q
H2O/H2 Topping Heater
H2O/H2 In
Electrolysis Power
Electrolysis Unit
Process Water
M1
RCY-2
Inlet Water Pump
Electrolysis Water In
Inlet Water Pmp Pwr
T1
Process Heat In H2 Side
Process Heat In
T3
Process Heat In Sweep Side
M3
Process Return
Sweep Water
M2
RCY-1
Lo Tmp Swp Recup
Process Heat Sweep HX
Hi Tmp Swp Recup
SGT Q
Sweep Gas Topping Heater
Sweep Gas In
Return Sweep Side
Sweep Gas/O2 Out
Swp KO Tank
Q-100
Oxygen Product
O2/H2O Separator
Q-Amb 4
Residual Water from O2
Sweep Water Recycle Pump
Swp Wtr Rcy Pmp Pwr
Water Recycle
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
27

Workbook: High Temperature Steam Electrolysis (TPL3)

Material Streams

Fluid Pkg: All

Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6
Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042
Molar Flow	(kgmole/h)	3431	3431	1373	687.2	3431
Mass Flow	(kg/s)	12.59	6.495	9.539	3.441	6.495
Liquid Volume Flow	(m3/h)	73.06	87.88	31.71	12.41	87.88
Heat Flow	(MW)	-135.7	-45.57	-35.84	-40.71	-54.71
Name		6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	757.2	510.0 *	794.4	641.3	510.0 *
Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482
Molar Flow	(kgmole/h)	3431	3431	687.2	1373	687.2
Mass Flow	(kg/s)	12.59	12.59	3.441	9.539	3.441
Liquid Volume Flow	(m3/h)	73.06	73.06	12.41	31.71	12.41
Heat Flow	(MW)	-137.3	-146.4	-40.76	-38.19	-43.12
Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.6276
Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5
Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634
Molar Flow	(kgmole/h)	1.525e+004	1.525e+004	1788	1788	3431
Mass Flow	(kg/s)	97.37	97.37	11.42	11.42	12.59
Liquid Volume Flow	(m3/h)	373.1	373.1	43.75	43.75	73.06
Heat Flow	(MW)	67.23	46.64	7.885	5.471	-167.0
Name		20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21 @TPL3
Vapour Fraction		0.8417	1.0000	0.0000	0.0000	0.0000
Temperature	(C)	222.7	100.0 *	100.0	21.77	100.1
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	1373	700.4	672.8	14.42	672.8
Mass Flow	(kg/s)	9.539	6.170	3.369	7.216e-002	3.369
Liquid Volume Flow	(m3/h)	31.71	19.56	12.15	0.2603	12.15
Heat Flow	(MW)	-46.14	-0.6218	-52.33	-1.147	-52.32
Name		14 @TPL3	15 @TPL3	16 @TPL3	8 @TPL3	9 @TPL3
Vapour Fraction		0.0000	0.0000	0.9076	0.7769	1.0000
Temperature	(C)	98.49	98.42 *	290.8	158.5	158.5
Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901
Molar Flow	(kgmole/h)	687.2	687.2	687.2	3431	2665
Mass Flow	(kg/s)	3.441	3.441 *	3.441	6.495	2.668
Liquid Volume Flow	(m3/h)	12.41	12.41	12.41	87.88	74.06
Heat Flow	(MW)	-53.47	-53.47	-45.53	-73.48	-14.96
Name		10 @TPL3	12 @TPL3	24 @TPL3	13 @TPL3	11 @TPL3
Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	158.5	158.5	158.5	178.6	158.6
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	765.5	1142	1523	1142	765.5
Mass Flow	(kg/s)	3.827	1.143	1.525	1.143	3.827
Liquid Volume Flow	(m3/h)	13.83	31.73	42.33	31.73	13.83
Heat Flow	(MW)	-58.52	-6.410	-8.551	-6.221	-58.51

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Material Streams (continued)

Fluid Pkg: All

Name		Electrolysis Water In @	3 @TPL3	2 @TPL3	1 @TPL3	Process Water @TPL3
Vapour Fraction		0.0000	0.3055	0.3055	0.0000	0.0000
Temperature	(C)	21.11 *	104.8 *	104.8	21.77	21.77
Pressure	(MPa)	0.1013 *	7.790 *	7.790	7.790 *	7.790
Molar Flow	(kgmole/h)	1390	3431	3431	1390	1376
Mass Flow	(kg/s)	6.958	12.59 *	12.59	6.958	6.886
Liquid Volume Flow	(m3/h)	25.10	73.06	73.06	25.10	24.84
Heat Flow	(MW)	-110.7	-185.8	-185.8	-110.6	-109.4
Name		Hydrogen Product @T	23 @TPL3	Oxygen Product @TP	Residual Water from C	Process Heat In @TP
Vapour Fraction		1.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	54.44 *	54.44 *	54.44 *	54.44 *	530.0
Pressure	(MPa)	6.901	6.901	6.901	0.1013 *	0.7011
Molar Flow	(kgmole/h)	1372	147.3	686.0	14.42	1.704e+004
Mass Flow	(kg/s)	0.7684	0.7373	6.098	7.216e-002	108.8
Liquid Volume Flow	(m3/h)	39.60	2.660	19.30	0.2603	416.8
Heat Flow	(MW)	0.3244	-11.61	6.653e-002	-1.137	75.11
Name		Process Return @TPL	22 @TPL3	27 @TPL3	Residual Water from H	Total Water for HTSE
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	(C)	374.9	54.53	54.44	54.44 *	21.11 *
Pressure	(MPa)	0.6870	7.790	6.901	0.1013 *	0.1013 *
Molar Flow	(kgmole/h)	1.704e+004	147.3	1376	3.893	2376
Mass Flow	(kg/s)	108.8	0.7373	0.7879	1.948e-002	11.89
Liquid Volume Flow	(m3/h)	416.8	2.660	39.67	7.027e-002	42.90
Heat Flow	(MW)	52.11	-11.61	6.236e-002	-0.3070	-189.1

Compositions

Fluid Pkg: All

Name	H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
Comp Mole Frac (H2O)	0.6999	0.3000	0.5000	0.9992	0.3000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.5000	0.0008	0.0000
Comp Mole Frac (Hydrogen)	0.3001	0.7000	0.0000	0.0000	0.7000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17 @TPL3
Comp Mole Frac (H2O)	0.6999	0.6999	0.9992	0.5000	0.9992
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0008	0.5000	0.0008
Comp Mole Frac (Hydrogen)	0.3001	0.3001	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
Comp Mole Frac (H2O)	***	***	***	***	0.6999
Comp Mole Frac (Nitrogen)	***	***	***	***	0.0000
Comp Mole Frac (Oxygen)	***	***	***	***	0.0000
Comp Mole Frac (Hydrogen)	***	***	***	***	0.3001
Comp Mole Frac (CO2)	***	***	***	***	0.0000
Comp Mole Frac (CO)	***	***	***	***	0.0000
Comp Mole Frac (Sodium)	1.0000	1.0000	1.0000	1.0000	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21 @TPL3
Comp Mole Frac (H2O)	0.5000	0.0206	0.9992	1.0000 *	0.9992
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (Oxygen)	0.5000	0.9794	0.0008	0.0000 *	0.0008
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000 *	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	14 @TPL3	15 @TPL3	16 @TPL3	8 @TPL3	9 @TPL3
Comp Mole Frac (H2O)	0.9992	0.9992 *	0.9992	0.3000	0.0993
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0008	0.0008 *	0.0008	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000	0.7000	0.9007
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	10 @TPL3	12 @TPL3	24 @TPL3	13 @TPL3	11 @TPL3
Comp Mole Frac (H2O)	0.9989	0.0993	0.0993	0.0993	0.9989
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.0011	0.9007	0.9007	0.9007	0.0011
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	Electrolysis Water In @	3 @TPL3	2 @TPL3	1 @TPL3	Process Water @TPL3
Comp Mole Frac (H2O)	1.0000 *	0.6999 *	0.6999	1.0000	1.0000 *
Comp Mole Frac (Nitrogen)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Oxygen)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Hydrogen)	0.0000 *	0.3001 *	0.3001	0.0000	0.0000 *
Comp Mole Frac (CO2)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (CO)	0.0000 *	0.0000 *	0.0000	0.0000	0.0000 *
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Hydrogen Product @T	23 @TPL3	Oxygen Product @TP	Residual Water from C	Process Heat In @TP
Comp Mole Frac (H2O)	0.0000	0.9998	0.0000	1.0000	***
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (Oxygen)	0.0000	0.0000	1.0000	0.0000	***
Comp Mole Frac (Hydrogen)	1.0000	0.0002	0.0000	0.0000	***
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	***
Comp Mole Frac (Sodium)	***	***	***	***	1.0000
Comp Mole Frac (Air)	***	***	***	***	***

Name	Process Return @TPL	22 @TPL3	27 @TPL3	Residual Water from H	Total Water for HTSE
Comp Mole Frac (H2O)	***	0.9998	0.0028	1.0000	1.0000 *
Comp Mole Frac (Nitrogen)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Oxygen)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Hydrogen)	***	0.0002	0.9972	0.0000	0.0000 *
Comp Mole Frac (CO2)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (CO)	***	0.0000	0.0000	0.0000	0.0000 *
Comp Mole Frac (Sodium)	1.0000	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Energy Streams

Fluid Pkg: All

Name	Process Heat @TPL3	Electrolysis Power @T	SGT Q @TPL3	Swp Wtr Rcy Pmp Pw	H2 Circ Pwr @TPL3
Heat Flow (MW)	-1.050e-002	-94.99	4.956e-002	4.201e-003	0.1892
Name	**PWRP Pwr @TPL3**	**STH Q @TPL3**	**Inlet Water Pmp Pwr @**	**Electricity Generated @**	**Q-Amb 2 @TPL3**
Heat Flow (MW)	5.054e-003	1.620	7.060e-002	96.98	-4.492e-002
Name	**Q-Amb 4 @TPL3**	**Rcyc Pmp 2 PWR @T**	**Q-Amb 1 @TPL3**	**Q-100 @TPL3**	
Heat Flow (MW)	-0.4490	8.859e-004	-3.002	-6.815	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Electrolysis Unit @TPL3	Standard Sub-Flowsheet	H2O/H2 In @TPL3 Sweep Gas In @TPL3 Process Heat @TPL3	H2/H2O Out @TPL3 Sweep Gas/O2 Out @TPL3 Electrolysis Power @TPL3	No	2500 *
H2O/H2 Topping Heater @TP	Heater	6 @TPL3 STH Q @TPL3	H2O/H2 In @TPL3	No	500.0 *
Sweep Gas Topping Heater @	Heater	18 @TPL3 SGT Q @TPL3	Sweep Gas In @TPL3	No	500.0 *
Hi Tmp H2O/H2 Recup @TPL	Heat Exchanger	5 @TPL3 H2/H2O Out @TPL3	6 @TPL3 7 @TPL3	No	500.0 *
Hi Tmp Swp Recup @TPL3	Heat Exchanger	17 @TPL3 Sweep Gas/O2 Out @TPL3	18 @TPL3 19 @TPL3	No	500.0 *
Process Heat Steam/H2 HX @	Heat Exchanger	4 @TPL3 Process Heat In H2 Side @TP	5 @TPL3 Return H2 Side @TPL3	No	500.0 *
Process Heat Sweep HX @TP	Heat Exchanger	16 @TPL3 Process Heat In Sweep Side @	17 @TPL3 Return Sweep Side @TPL3	No	500.0 *
Lo Tmp Swp Recup @TPL3	Heat Exchanger	15 @TPL3 19 @TPL3	16 @TPL3 20 @TPL3	No	500.0 *
Lo Tmp H2O/H2 Recup @TPL	Heat Exchanger	3 @TPL3 7 @TPL3	4 @TPL3 8 @TPL3	No	500.0 *
Swp KO Tank @TPL3	Separator	20 @TPL3 Q-100 @TPL3	Water Recycle @TPL3 26 @TPL3 Q-100 @TPL3	No	500.0 *
H2/Water KO Tank @TPL3	Separator	8 @TPL3	10 @TPL3	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
H2/Water KO Tank @TPL3	Separator		9 @TPL3	No	500.0 *
V-100 @TPL3	Separator	24 @TPL3 Q-Amb 1 @TPL3	23 @TPL3 27 @TPL3 Q-Amb 1 @TPL3	No	500.0 *
Sweep Water Recycle Pump @	Pump	Water Recycle @TPL3 Swp Wtr Rcy Pmp Pwr @TPL	21 @TPL3	No	500.0 *
Process Water Recycle Pump	Pump	10 @TPL3 PWRP Pwr @TPL3	11 @TPL3	No	500.0 *
Inlet Water Pump @TPL3	Pump	Electrolysis Water In @TPL3 Inlet Water Pmp Pwr @TPL3	1 @TPL3	No	500.0 *
Recycle Pump 2 @TPL3	Pump	23 @TPL3 Rcyc Pmp 2 PWR @TPL3	22 @TPL3	No	500.0 *
M2 @TPL3	Mixer	Sweep Water @TPL3 21 @TPL3	14 @TPL3	No	500.0 *
M1 @TPL3	Mixer	13 @TPL3 11 @TPL3 Process Water @TPL3 22 @TPL3	2 @TPL3	No	500.0 *
M3 @TPL3	Mixer	Return Sweep Side @TPL3 Return H2 Side @TPL3	Process Return @TPL3	No	500.0 *
RCY-1 @TPL3	Recycle	14 @TPL3	15 @TPL3	No	3500 *
RCY-2 @TPL3	Recycle	2 @TPL3	3 @TPL3	No	3500 *
H2 Circulator @TPL3	Compressor	12 @TPL3 H2 Circ Pwr @TPL3	13 @TPL3	No	500.0 *
T2 @TPL3	Tee	9 @TPL3	24 @TPL3 12 @TPL3	No	500.0 *
T1 @TPL3	Tee	1 @TPL3	Sweep Water @TPL3 Process Water @TPL3	No	500.0 *
T3 @TPL3	Tee	Process Heat In @TPL3	Process Heat In H2 Side @TF Process Heat In Sweep Side (	No	500.0 *
HTE Calcs @TPL3	Spreadsheet			No	500.0 *
LTHR Tb dP @TPL3	Set			No	500.0 *
PHSH Tb dP @TPL3	Set			No	500.0 *
HTHR Tb dP @TPL3	Set			No	500.0 *
HTH dP @TPL3	Set			No	500.0 *
HTHR Sh dP @TPL3	Set			No	500.0 *
LTSR Sh dP @TPL3	Set			No	500.0 *
LTSR Tb dP @TPL3	Set			No	500.0 *
PHSH Sh dP @TPL3	Set			No	500.0 *
SET-1 @TPL3	Set			No	500.0 *
SET-2 @TPL3	Set			No	500.0 *
HTSR Sh dP @TPL3	Set			No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Workbook: High Temperature Steam Electrolysis (TPL3) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level

Spreadsheet: HTE Calcs @TPL3

Units Set: NuScale

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
B1	Material Stream:	Residual Water from H2 @	Mass Flow	1.948e-002 kg/s
B2	Material Stream:	Residual Water from O2 @	Mass Flow	7.216e-002 kg/s
B3	Material Stream:	H2O/H2 In @TPL3	Master Comp Mass Flow (H2O)	43259.1010 kg/h
B4	Material Stream:	H2/H2O Out @TPL3	Master Comp Mass Flow (H2O)	18540.8507 kg/h
D1	Energy Stream:	Rcyc Pmp 2 PWR @TPL3	Power	8.859e-004 MW
D2	Energy Stream:	H2 Circ Pwr @TPL3	Power	0.1892 MW
D3	Energy Stream:	PWRP Pwr @TPL3	Power	5.054e-003 MW
D4	Energy Stream:	Inlet Water Pmp Pwr @TP	Power	7.060e-002 MW
D5	Energy Stream:	Swp Wtr Rcy Pmp Pwr @	Power	4.201e-003 MW
D7	Energy Stream:	STH Q @TPL3	Heat Flow	1.620 MW
D8	Energy Stream:	SGT Q @TPL3	Heat Flow	4.956e-002 MW
D10	Energy Stream:	Electrolysis Power @TPL3	Power	-94.99 MW
B6	Heat Exchanger:	Process Heat Steam/H2 H	Exchanger Cold Duty	20.58 MW
B7	Heat Exchanger:	Process Heat Sweep HX @	Exchanger Cold Duty	2.413 MW
B10	Energy Stream:	Electricity Generated @TP	Power	96.98 MW
E1	Energy Stream:	Q-100 @TPL3	Heat Flow	-6.815 MW
E2	Energy Stream:	Q-Amb 1 @TPL3	Heat Flow	-3.002 MW
E3	Energy Stream:	Q-Amb 2 @TPL3	Heat Flow	-4.492e-002 MW
E4	Energy Stream:	Q-Amb 4 @TPL3	Heat Flow	-0.4490 MW
F6	Heat Exchanger:	Condenser @TPL1	Exchanger Cold Duty	129.4 MW
F7	Energy Stream:	Total Cooling Tower Powe	Power	0.5878 MW
F8	Material Stream:	Make Up Water @TPL2	Mass Flow	61.94 kg/s
F1	Material Stream:	Hydrogen Product @TPL3	Mass Higher Heating Value	1.404e+005 kJ/kg
F2	Material Stream:	Hydrogen Product @TPL3	Mass Flow	0.7684 kg/s
F3	Energy Stream:	Reactor Heat	Heat Flow	250.0 MW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
F11	Total Water for HTSE @TPL3	Mass Flow	11.89 kg/s

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B5	B5: Water Loss	Water Loss	Mass Flow	6.958 kg/s
D6	D6: Total Power for flow	Total Power for flow	Power	0.2699 MW
D9	D9: Total Topping Heat	Total Topping Heat	Energy	1.669 MW
B8	B8:		Energy	23.00 MW
B9	B9:		Power	96.98 MW
B11	B11:		Power	2.993e-003 MW
C11	C11:		Power	2.993 MW
F5	F5:		Energy	10.31 MW
F9	F9:		Power	4.682e-002 MW
F10	F10:		Mass Flow	4.934 kg/s
F11	F11: Mass Flow	Mass Flow	Mass Flow	11.89 kg/s
D11	D11:		Power	8.075e-002 MW
F4	F4:		---	43.14

User Variables

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Spreadsheet: HTE Calcs @TPL3 (continued)

Units Set: NuScale

FORMULAS

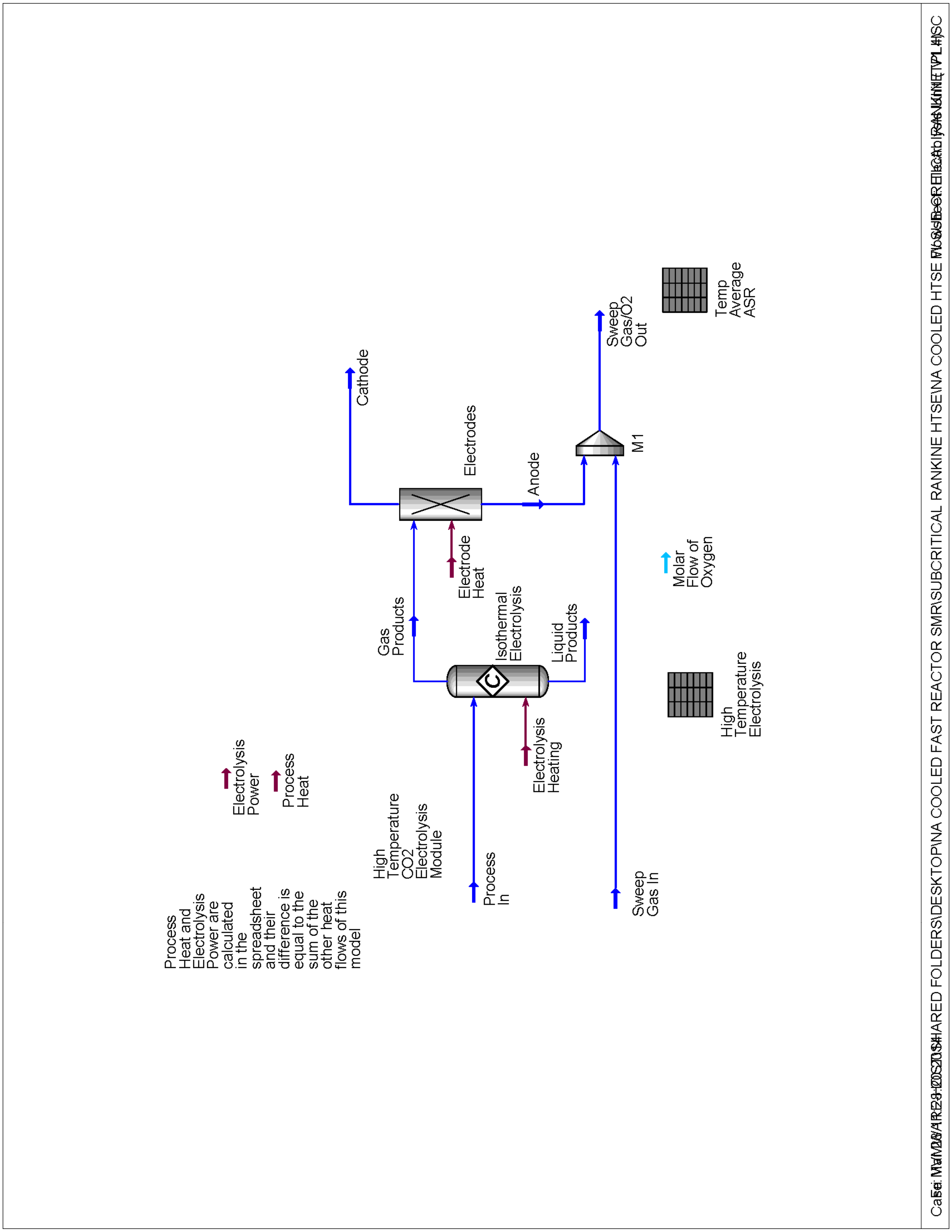
Cell	Formula	Result
B5	=B1+B2+(B3-B4)/3600	6.958 kg/s
B8	=B6+B7	23.00 MW
B9	=D6+D9-D10+F9	96.98 MW
B11	=B10-B9	2.993e-003 MW
C11	=B11*1000	2.993 MW
D6	=D1+D2+D3+D4+D5	0.2699 MW
D9	=D7+D8	1.669 MW
D11	=D1+D3+D4+D5	8.075e-002 MW
F4	=F1*F2/F3*100/1000	43.14
F5	=-(E1+E2+E3+E4)	10.31 MW
F9	=F5/F6*F7	4.682e-002 MW
F10	=F5/F6*F8	4.934 kg/s
F11	=B5+F10	11.89 kg/s

Spreadsheet

	A	B	C	D
1	Resid H2O from H2 *	1.948e-002 kg/s *	Rcyc Pmp 2 PWR *	8.859e-004 MW *
2	Resid H2O from O2 *	7.216e-002 kg/s *	H2 Circ Pwr *	0.1892 MW *
3	Water into Cells *	43259.1010 kg/h *	PWR Pwr *	5.054e-003 MW *
4	Water out of Cells *	18540.8507 kg/h *	Inlet Water Pmp Pwr *	7.060e-002 MW *
5	Water loss *	6.958 kg/s *	Swp Wtr Pmp Pwr *	4.201e-003 MW *
6	Process Heat Steam/H2 HX Duty *	20.58 MW *	Total Power for flow *	0.2699 MW *
7	Process Heat Sweep HX Duty *	2.413 MW *	STH Q *	1.620 MW *
8	Total Heat from Reactor *	23.00 MW *	SGT Q *	4.956e-002 MW *
9	Power Needed for Electrolysis *	96.98 MW *	Total Topping Heat *	1.669 MW *
10	Electricity Generated *	96.98 MW *	Electrolysis Power *	-94.99 MW *
11	Excess Electricity *	2.993e-003 MW *	2.993 MW *	8.075e-002 MW *

	E	F		
1	-6.815 MW *	1.404e+005 kJ/kg *		
2	-3.002 MW *	0.7684 kg/s *		
3	-4.492e-002 MW *	250.0 MW *		
4	-0.4490 MW *	43.14 *		
5	Total HTSE Ambient Heat *	10.31 MW *		
6	Condenser Heat *	129.4 MW *		
7	Cooling Tower Power *	0.5878 MW *		
8	Cooling Tower Make up Water *	61.94 kg/s *		
9	HTSE Cooling Power *	4.682e-002 MW *		
10	Water Needed to cool HTSE *	4.934 kg/s *		
11	Total Water for HTSE *	11.89 kg/s *		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.



Process Heat and Electrolysis Power are calculated in the spreadsheet and their difference is equal to the sum of the other heat flows of this model
Electrolysis Power
Process Heat
High Temperature CO2 Electrolysis Module
Process In
Electrolysis Heating
Isothermal Electrolysis
Gas Products
Liquid Products
Electrode Heat
Electrodes
Cathode
Anode
M1
Sweep Gas/O2 Out
Sweep Gas In
Molar Flow of Oxygen
High Temperature Electrolysis
Temp Average ASR
HARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\SUBCRITICAL RANKINE HTSE\NA COOLED HTSE

aspentech	BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED HTSE W SUB CRITICAL RANKINE V1.HSC Unit Set: AFR Date/Time: Fri Mar 28 11:35:17 2014

Workbook: Electrolysis Unit (TPL4)

Streams

Fluid Pkg: All

Name		Process In @TPL4	Sweep Gas In @TPL4	Cathode @TPL4	Sweep Gas/O2 Out @	Gas Products @TPL4
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	800.0	800.0	800.0 *	800.0	800.0
Pressure	(MPa)	7.185	7.185	7.185	7.185	7.185
Molar Flow	(kgmole/h)	3431	687.2	3431	1373	4117
Mass Flow	(kg/s)	12.59	3.441	6.495	9.539	12.59
Liquid Volume Flow	(m3/h)	73.06	12.41	87.88	31.71	107.2
Heat Flow	(MW)	-135.7	-40.71	-45.57	-35.84	-40.74
Molar Enthalpy	(kJ/kgmole)	-1.424e+005	-2.133e+005	-4.781e+004	-9.396e+004	-3.563e+004

Name		Liquid Products @TPL	Anode @TPL4	Molar Flow of Oxygen	Electrolysis Heating @	Electrode Heat @TPL4
Vapour Fraction		0.0000	1.0000	---	---	---
Temperature	(C)	800.0	807.2	---	---	---
Pressure	(MPa)	7.185	7.185	---	---	---
Molar Flow	(kgmole/h)	0.0000	686.0	686.0	---	---
Mass Flow	(kg/s)	0.0000	6.098	6.098	---	---
Liquid Volume Flow	(m3/h)	0.0000	19.30	19.30	---	---
Heat Flow	(MW)	0.0000	4.874	---	94.94	4.541e-002
Molar Enthalpy	(kJ/kgmole)	-3.412e+004	2.558e+004	---	---	---

Name		Process Heat @TPL4	Electrolysis Power @T			
Vapour Fraction		---	---			
Temperature	(C)	---	---			
Pressure	(MPa)	---	---			
Molar Flow	(kgmole/h)	---	---			
Mass Flow	(kg/s)	---	---			
Liquid Volume Flow	(m3/h)	---	---			
Heat Flow	(MW)	-1.050e-002	-94.99			
Molar Enthalpy	(kJ/kgmole)	---	---			

Conversion Reactors

Fluid Pkg: All

Name		Isothermal Electrolysis				
Separator Type		---				
Vessel Temperature	(C)	800.0				
Vessel Pressure	(MPa)	7.185				
Vapour Molar Flow	(kgmole/h)	4117				
Liquid Molar Flow	(kgmole/h)	0.0000				
Heat Flow	(MW)	94.94				

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Isothermal Electrolysis @TPL4	Conversion Reactor	Process In @TPL4 Electrolysis Heating @TPL4	Liquid Products @TPL4 Gas Products @TPL4 Electrolysis Heating @TPL4	No	500.0 *
Electrodes @TPL4	Component Splitter	Gas Products @TPL4 Electrode Heat @TPL4	Cathode @TPL4 Anode @TPL4	No	500.0 *
Gas Product Temperature @T	Set			No	500.0 *
Outlet Temperature @TPL4	Set			No	500.0 *
Inlet Temperature @TPL4	Set			No	500.0 *
SET-1 @TPL4	Set			No	500.0 *
High Temperature Electrolysis	Spreadsheet			No	500.0 *
Temp Average ASR @TPL4	Spreadsheet			No	500.0 *
M1 @TPL4	Mixer	Anode @TPL4 Sweep Gas In @TPL4	Sweep Gas/O2 Out @TPL4	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.

Workbook: Electrolysis Unit (TPL4) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
ADJ-1 @TPL4	Adjust			No	3500 *

Spreadsheet: High Temperature Electrolysis @TPL4

Units Set: Electrolysis_

CONNECTIONS

Imported Variables

Cell	Object		Variable Description	Value
D2	Material Stream:	Process In @TPL4	Temperature	1073 K
D3	Material Stream:	Cathode @TPL4	Temperature	1073 K
A8	Material Stream:	Sweep Gas/O2 Out @TPL	Pressure	7.185e+006 N/m2
E2	Material Stream:	Process In @TPL4	Master Comp Mole Frac (H2O)	0.6999
F2	Material Stream:	Process In @TPL4	Master Comp Mole Frac (Hydrogen)	0.3001
G2	Material Stream:	Sweep Gas In @TPL4	Master Comp Mole Frac (Oxygen)	0.0008
E3	Material Stream:	Cathode @TPL4	Master Comp Mole Frac (H2O)	0.3000
F3	Material Stream:	Cathode @TPL4	Master Comp Mole Frac (Hydrogen)	0.7000
G3	Material Stream:	Sweep Gas/O2 Out @TPL	Master Comp Mole Frac (Oxygen)	0.5000
B16	SpreadSheetCell:	Temp Average ASR@B2	B2: Temp Aver ASR	0.4000
D11	Energy Stream:	Electrolysis Heating @TPL	Heat Flow	9.494e+004 kW
D12	Energy Stream:	Electrode Heat @TPL4	Heat Flow	45.41 kW

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
B15	Molar Flow of Oxygen @TPL4	Molar Flow	190.6 gmole/s
B19	Electrolysis Power @TPL4	Power	-9.499e+004 kW
B20	Process Heat @TPL4	Heat Flow	-10.50 kW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A1	A1: A1 for Gibbs Formation Energy	A1 for Gibbs Formation Energy	Gibbs. Coeff. CA	2.382e+005 J/gmole
A2	A2: A2 for Gibbs Formation Energy	A2 for Gibbs Formation Energy	Gibbs. Coeff. CB	39.95 J/gmole-K
A3	A3: A3 for Gibbs Formation Energy	A3 for Gibbs Formation Energy	Gibbs. Coeff. CC	3.319e-003 kJ/gmol-K^2
A4	A4: A4 for Gibbs Formation Energy (kJ/gmol-K^3)	A4 for Gibbs Formation Energy (kJ/gmol-K^3)	---	-3.532e-008
A5	A5: A5 for Gibbs Formation Energy	A5 for Gibbs Formation Energy	Gibbs. Coeff. CB	-12.85 J/gmole-K
A6	A6: Fa Faraday Number (J/Volt-gmole)	Fa Faraday Number (J/Volt-gmole)	---	9.649e+004
A7	A7: R Universal Gas Constant	R Universal Gas Constant	Entropy	8.314 J/gmole-K
A9	A9: Standard Pressure	Standard Pressure	Pressure	1.013e+005 N/m2
H2	H2:		---	5.658e-002
B11	B11: B2: Number of Cells	B2: Number of Cells	---	5.140e+005
B12	B12: B3: Cell Area	B3: Cell Area	Small Area	225.0 cm2
B13	B13: B4: Current Density (Amperes/cm^2)	B4: Current Density (Amperes/cm^2)	---	0.6359
B14	B14:		---	143.1
B15	B15: Molar Flow	Molar Flow	Molar Flow	190.6 gmole/s
D4	D4:		Temperature	0.0000 K
D6	D6:		Temperature	1073 K
I2	I2:		Molar Enthalpy	1.887e+005 J/gmole
I3	I3:		Molar Enthalpy	1.887e+005 J/gmole
I6	I6:		Molar Enthalpy	1.887e+005 J/gmole
E4	E4:		Vapour Fraction	-0.3999
F4	F4:		Vapour Fraction	0.3999
G4	G4:		Vapour Fraction	0.4992
H3	H3:		---	35.45
H4	H4:		---	35.40
E5	E5:		Vapour Fraction	0.2885
F5	F5:		Vapour Fraction	-0.2884

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
G5	G5:		Vapour Fraction	-0.8401
H5	H5:		---	91.27
J2	J2:		Entropy	2.321e+008 J/gmole-K
J3	J3:		Entropy	2.321e+008 J/gmole-K
K2	K2:		---	0.8721
K3	K3:		---	1.099
B17	B17:		Vapour Fraction	1.0373
K6	K6:		Vapour Fraction	1.0373
K7	K7:		---	<empty>
B18	B18:		Vapour Fraction	1.2916
D8	D8:		---	3.661e-007
D9	D9:		---	<empty>
B19	B19: Power	Power	Power	-9.499e+004 kW
B20	B20: Heat Flow	Heat Flow	Energy	-10.50 kW
I11	I11:		---	<empty>
E9	E9:		---	<empty>
C20	C20:		Energy	<empty>
E8	E8:		Temperature	<empty>
F10	F10:		Vapour Fraction	<empty>
C18	C18:		---	<empty>
F20	F20:		---	<empty>

User Variables

FORMULAS

Cell	Formula	Result
B14	=B12*B13	143.1
B15	=B11*B14/(4*A6)	190.6 gmole/s
B17	@IF(@ABS(D4)<1e-3,K6,K7)	1.0373
B18	=B17+B13*B16	1.2916
B19	=-B11*B18*B14/1000	-9.499e+004 kW
B20	=B19+D11+D12	-10.50 kW
D4	=D2-D3	0.0000 K
D6	=(D2+D3)/2	1073 K
D8	=1/(2*A6*H4*F4)	3.661e-007
D9	=-1/(2*A6*H4*F4*D4)	<empty>
E4	=E3-E2	-0.3999
E5	=(E3*@LN(E3)-E3) - (E2*@LN(E2)-E2)	0.2885
F4	=F3-F2	0.3999
F5	=(F3*@LN(F3)-F3) - (F2*@LN(F2)-F2)	-0.2884
G4	=G3-G2	0.4992
G5	=(G3*@LN(G3)-G3) - (G2*@LN(G2)-G2)	-0.8401
H2	=G2*A8/A9	5.658e-002
H3	=G3*A8/A9	35.45
H4	=H3-H2	35.40
H5	=(H3*@LN(H3)-H3) - (H2*@LN(H2)-H2)	91.27
I2	=A1 + A2*D2+ A3*D2^2 + A4*D2^3 + A5*D2*@LN(D2)	1.887e+005 J/gmole
I3	=A1 + A2*D3+ A3*D3^2 + A4*D3^3 + A5*D3*@LN(D3)	1.887e+005 J/gmole
I6	=A1 + A2*D6+ A3*D6^2 + A4*D6^3 + A5*D6*@LN(D6)	1.887e+005 J/gmole

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
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
J3	= A1*D3 + A2/2*D3^2 + A3/3*D3^3 + A4/4*D3^4 + A5/2*D3^2*(@LN(D3)-0.5)	2.321e+008 J/gmole-K
K2	=1/(2*A6)*(I2-A7*D2*@LN(E2/(F2*H2^0.5)))	0.8721
K3	=1/(2*A6)*(I3-A7*D3*@LN(E3/(F3*H3^0.5)))	1.099
K6	=D8*(I6*F4*H4 + A7*D6*((E5+F5)*H4 + H5/2*F4))	1.0373
K7	=D9*(A7/2*(D3^2-D2^2)*((E5+F5)*H4 + H5/2*F4) + F4*H4*(J3-J2))	<empty>

Spreadsheet

	A	B	C	D
1	2.382e+005 J/gmole *	A1 for Gibbs Formation Energy *		Temperature *
2	39.95 J/gmole-K *	A2 for Gibbs Formation Energy *	in *	1073 K *
3	3.319e-003 kJ/gmol-K^2 *	A3 for Gibbs Formation Energy *	out *	1073 K *
4	-3.532e-008 *	ibbs Formation Energy (kJ/gmol-K^3) *	Delta *	0.0000 K *
5	-12.85 J/gmole-K *	A5 for Gibbs Formation Energy *	Integration Coeff *	
6	9.649e+004 *	Fa Faraday Number (J/Volt-gmole) *	Average *	1073 K *
7	8.314 J/gmole-K *	R Universal Gas Constant *		
8	7.185e+006 N/m2 *	Pressure *	C isothermal *	3.661e-007 *
9	1.013e+005 N/m2 *	Standard Pressure *	C average *	<empty> *
10				
11	Number of Cells *	5.140e+005 *	Electrolysis Heating *	9.494e+004 kW *
12	Cell Area *	225.0 cm2 *	Electrode Heat *	45.41 kW *
13	Current Density (Amperes/cm^2) *	0.6359 *		
14	Current (Amperes) *	143.1 *		
15	Molar Flow of Oxygen *	190.6 gmole/s *		
16	Area Specific Resistance (ohm*cm^2) *	0.4000 *		
17	Nernst Potential (Volts) *	1.0373 *		
18	Operating Voltage (Volts) *	1.2916 *	<empty> *	
19	Electrolysis Power *	-9.499e+004 kW *		
20	Process Heat *	-10.50 kW *	<empty> *	

	E	F	G	H
1	y H2O *	y H2 *	y O2 *	y A *
2	0.6999 *	0.3001 *	0.0008 *	5.658e-002 *
3	0.3000 *	0.7000 *	0.5000 *	35.45 *
4	-0.3999 *	0.3999 *	0.4992 *	35.40 *
5	0.2885 *	-0.2884 *	-0.8401 *	91.27 *
6				
7				
8	<empty> *			
9	<empty> *			
10		<empty> *		
11				
12				
13				
14				
15				
16				
17				
18				
19				
20		<empty> *		

	I	J	K

Spreadsheet: High Temperature Electrolysis @TPL4 (

Units Set: Electrolysis_

Spreadsheet

1	Delta G *	Integral Delta G dT *	Nernst Voltage *	
2	1.887e+005 J/gmole *	2.321e+008 J/gmole-K *	0.8721 *	
3	1.887e+005 J/gmole *	2.321e+008 J/gmole-K *	1.099 *	
4				
5				
6	1.887e+005 J/gmole *	Isothermal *	1.0373 *	
7		Average *	<empty> *	
8				
9				
10				
11	<empty> *			
12				
13				
14				
15				
16				
17				
18				
19				
20				

* Specified by user.

Spreadsheet: Temp Average ASR @TPL4

Units Set: Electrolysis_

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A3	Material Stream: Process In @TPL4	Temperature	1073 K
E15	Material Stream: Cathode @TPL4	Temperature	1073 K

Exported Variables' Formula Results

Cell	Object	Variable Description	Value

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
B1	B1: B5: ASR @ 1100 K (ohms*cm^2)	B5: ASR @ 1100 K (ohms*cm^2)	---	0.2776
B2	B2: Temp Aver ASR	Temp Aver ASR	---	0.4000
B3	B3:		---	0.4000
B4	B4:		---	0.4000
B5	B5:		---	0.4000
B6	B6:		---	0.4000
B7	B7:		---	0.4000
B8	B8:		---	0.4000
B9	B9:		---	0.4000
B10	B10:		---	0.4000
B11	B11:		---	0.4000
B12	B12:		---	0.4000
B13	B13:		---	0.4000
B14	B14:		---	0.4000
B15	B15:		---	0.4000
B16	B16:		---	0.4000
B17	B17:		---	0.4000
B18	B18:		---	0.4000
B19	B19:		---	0.4000
E1	E1:		Temperature	1073 K
E2	E2:		Temperature	1073 K
F2	F2:		---	0.4000
C1	C1:		Temperature	1073 K
D1	D1:		---	0.4000
C2	C2:		Temperature	1073 K
D2	D2:		---	0.4000
C3	C3:		Temperature	1073 K
D3	D3:		---	0.4000
C4	C4:		Temperature	1073 K
D4	D4:		---	0.4000
C5	C5:		Temperature	1073 K
D5	D5:		---	0.4000
C6	C6:		Temperature	1073 K
D6	D6:		---	0.4000
C7	C7:		Temperature	1073 K
D7	D7:		---	0.4000
C8	C8:		Temperature	1073 K
D8	D8:		---	0.4000
C9	C9:		Temperature	1073 K

Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
D9	D9:		---	0.4000
C10	C10:		Temperature	1073 K
D10	D10:		---	0.4000
C11	C11:		Temperature	1073 K
D11	D11:		---	0.4000
C12	C12:		Temperature	1073 K
D12	D12:		---	0.4000
C13	C13:		Temperature	1073 K
D13	D13:		---	0.4000
C14	C14:		Temperature	1073 K
D14	D14:		---	0.4000
C15	C15:		Temperature	1073 K
D15	D15:		---	0.4000
C16	C16:		Temperature	1073 K
D16	D16:		---	0.4000
C17	C17:		Temperature	1073 K
D17	D17:		---	0.4000
C18	C18:		Temperature	1073 K
D18	D18:		---	0.4000
C19	C19:		Temperature	1073 K
D19	D19:		---	0.4000
A4	A4:		Temperature	1073 K
A5	A5:		Temperature	1073 K
A6	A6:		Temperature	1073 K
A7	A7:		Temperature	1073 K
A8	A8:		Temperature	1073 K
A9	A9:		Temperature	1073 K
A10	A10:		Temperature	1073 K
A11	A11:		Temperature	1073 K
A12	A12:		Temperature	1073 K
A13	A13:		Temperature	1073 K
A14	A14:		Temperature	1073 K
A15	A15:		Temperature	1073 K
A16	A16:		Temperature	1073 K
A17	A17:		Temperature	1073 K
A18	A18:		Temperature	1073 K
A19	A19:		Temperature	1073 K
A20	A20:		---	40.00
E3	E3:		Temperature	1073 K
E4	E4:		Temperature	1073 K
E5	E5:		Temperature	1073 K
E6	E6:		Temperature	1073 K
E7	E7:		Temperature	1073 K
E8	E8:		Temperature	1073 K
E9	E9:		Temperature	1073 K
E10	E10:		Temperature	1073 K
E11	E11:		Temperature	1073 K
E12	E12:		Temperature	1073 K
E13	E13:		Temperature	1073 K

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
E14	E14:		Temperature	1073 K
F15	F15:		---	0.4000
F16	F16:		Temperature	0.0000 K
F1	F1:		---	0.4000
F3	F3:		---	0.4000
F4	F4:		---	0.4000
F5	F5:		---	0.4000
F6	F6:		---	0.4000
F7	F7:		---	0.4000
F8	F8:		---	0.4000
F9	F9:		---	0.4000
F10	F10:		---	0.4000
F11	F11:		---	0.4000
F12	F12:		---	0.4000
F13	F13:		---	0.4000
F14	F14:		---	0.4000
B20	B20:		---	19.20

User Variables

FORMULAS

Cell	Formula	Result
A4	=A3+F16	1073 K
A5	=A4+F16	1073 K
A6	=A5+F16	1073 K
A7	=A6+F16	1073 K
A8	=A7+F16	1073 K
A9	=A8+F16	1073 K
A10	=A9+F16	1073 K
A11	=A10+F16	1073 K
A12	=A11+F16	1073 K
A13	=A12+F16	1073 K
A14	=A13+F16	1073 K
A15	=A14+F16	1073 K
A16	=A15+F16	1073 K
A17	=A16+F16	1073 K
A18	=A17+F16	1073 K
A19	=A18+F16	1073 K
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
B2	@if(E15==A3,F15,(1/3*F16*(B3+A20+B20+F15))/(E15-A3))	0.4000
B3	@EXP(10300/A3)*0.00003973+(B1-0.463)	0.4000
B4	@EXP(10300/A4)*0.00003973+(B1-0.463)	0.4000
B5	@EXP(10300/A5)*0.00003973+(B1-0.463)	0.4000
B6	@EXP(10300/A6)*0.00003973+(B1-0.463)	0.4000
B7	@EXP(10300/A7)*0.00003973+(B1-0.463)	0.4000
B8	@EXP(10300/A8)*0.00003973+(B1-0.463)	0.4000
B9	@EXP(10300/A9)*0.00003973+(B1-0.463)	0.4000
B10	@EXP(10300/A10)*0.00003973+(B1-0.463)	0.4000
B11	@EXP(10300/A11)*0.00003973+(B1-0.463)	0.4000

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
B12	@EXP(10300/A12)*0.00003973+(B1-0.463)	0.4000
B13	@EXP(10300/A13)*0.00003973+(B1-0.463)	0.4000
B14	@EXP(10300/A14)*0.00003973+(B1-0.463)	0.4000
B15	@EXP(10300/A15)*0.00003973+(B1-0.463)	0.4000
B16	@EXP(10300/A16)*0.00003973+(B1-0.463)	0.4000
B17	@EXP(10300/A17)*0.00003973+(B1-0.463)	0.4000
B18	@EXP(10300/A18)*0.00003973+(B1-0.463)	0.4000
B19	@EXP(10300/A19)*0.00003973+(B1-0.463)	0.4000
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
C1	=A19+F16	1073 K
C2	=C1+F16	1073 K
C3	=C2+F16	1073 K
C4	=C3+F16	1073 K
C5	=C4+F16	1073 K
C6	=C5+F16	1073 K
C7	=C6+F16	1073 K
C8	=C7+F16	1073 K
C9	=C8+F16	1073 K
C10	=C9+F16	1073 K
C11	=C10+F16	1073 K
C12	=C11+F16	1073 K
C13	=C12+F16	1073 K
C14	=C13+F16	1073 K
C15	=C14+F16	1073 K
C16	=C15+F16	1073 K
C17	=C16+F16	1073 K
C18	=C17+F16	1073 K
C19	=C18+F16	1073 K
D1	@EXP(10300/C1)*0.00003973+(B1-0.463)	0.4000
D2	@EXP(10300/C2)*0.00003973+(B1-0.463)	0.4000
D3	@EXP(10300/C3)*0.00003973+(B1-0.463)	0.4000
D4	@EXP(10300/C4)*0.00003973+(B1-0.463)	0.4000
D5	@EXP(10300/C5)*0.00003973+(B1-0.463)	0.4000
D6	@EXP(10300/C6)*0.00003973+(B1-0.463)	0.4000
D7	@EXP(10300/C7)*0.00003973+(B1-0.463)	0.4000
D8	@EXP(10300/C8)*0.00003973+(B1-0.463)	0.4000
D9	@EXP(10300/C9)*0.00003973+(B1-0.463)	0.4000
D10	@EXP(10300/C10)*0.00003973+(B1-0.463)	0.4000
D11	@EXP(10300/C11)*0.00003973+(B1-0.463)	0.4000
D12	@EXP(10300/C12)*0.00003973+(B1-0.463)	0.4000
D13	@EXP(10300/C13)*0.00003973+(B1-0.463)	0.4000
D14	@EXP(10300/C14)*0.00003973+(B1-0.463)	0.4000
D15	@EXP(10300/C15)*0.00003973+(B1-0.463)	0.4000
D16	@EXP(10300/C16)*0.00003973+(B1-0.463)	0.4000
D17	@EXP(10300/C17)*0.00003973+(B1-0.463)	0.4000
D18	@EXP(10300/C18)*0.00003973+(B1-0.463)	0.4000
D19	@EXP(10300/C19)*0.00003973+(B1-0.463)	0.4000
E1	=C19+F16	1073 K
E2	=E1+F16	1073 K
E3	=E2+F16	1073 K
E4	=E3+F16	1073 K

Spreadsheet: Temp Average ASR @TPL4 (continued)

Units Set: Electrolysis_

FORMULAS

Cell	Formula	Result
E5	=E4+F16	1073 K
E6	=E5+F16	1073 K
E7	=E6+F16	1073 K
E8	=E7+F16	1073 K
E9	=E8+F16	1073 K
E10	=E9+F16	1073 K
E11	=E10+F16	1073 K
E12	=E11+F16	1073 K
E13	=E12+F16	1073 K
E14	=E13+F16	1073 K
F1	@EXP(10300/E1)*0.00003973+(B1-0.463)	0.4000
F2	@EXP(10300/E2)*0.00003973+(B1-0.463)	0.4000
F3	@EXP(10300/E3)*0.00003973+(B1-0.463)	0.4000
F4	@EXP(10300/E4)*0.00003973+(B1-0.463)	0.4000
F5	@EXP(10300/E5)*0.00003973+(B1-0.463)	0.4000
F6	@EXP(10300/E6)*0.00003973+(B1-0.463)	0.4000
F7	@EXP(10300/E7)*0.00003973+(B1-0.463)	0.4000
F8	@EXP(10300/E8)*0.00003973+(B1-0.463)	0.4000
F9	@EXP(10300/E9)*0.00003973+(B1-0.463)	0.4000
F10	@EXP(10300/E10)*0.00003973+(B1-0.463)	0.4000
F11	@EXP(10300/E11)*0.00003973+(B1-0.463)	0.4000
F12	@EXP(10300/E12)*0.00003973+(B1-0.463)	0.4000
F13	@EXP(10300/E13)*0.00003973+(B1-0.463)	0.4000
F14	@EXP(10300/E14)*0.00003973+(B1-0.463)	0.4000
F15	@EXP(10300/E15)*0.00003973+(B1-0.463)	0.4000
F16	=(E15-A3)/50	0.0000 K

Spreadsheet

	A	B	C	D
1	ASR @ 1100 K *	0.2776 *	1073 K *	0.4000 *
2	Temp Average ASR *	0.4000 *	1073 K *	0.4000 *
3	1073 K *	0.4000 *	1073 K *	0.4000 *
4	1073 K *	0.4000 *	1073 K *	0.4000 *
5	1073 K *	0.4000 *	1073 K *	0.4000 *
6	1073 K *	0.4000 *	1073 K *	0.4000 *
7	1073 K *	0.4000 *	1073 K *	0.4000 *
8	1073 K *	0.4000 *	1073 K *	0.4000 *
9	1073 K *	0.4000 *	1073 K *	0.4000 *
10	1073 K *	0.4000 *	1073 K *	0.4000 *
11	1073 K *	0.4000 *	1073 K *	0.4000 *
12	1073 K *	0.4000 *	1073 K *	0.4000 *
13	1073 K *	0.4000 *	1073 K *	0.4000 *
14	1073 K *	0.4000 *	1073 K *	0.4000 *
15	1073 K *	0.4000 *	1073 K *	0.4000 *
16	1073 K *	0.4000 *	1073 K *	0.4000 *
17	1073 K *	0.4000 *	1073 K *	0.4000 *
18	1073 K *	0.4000 *	1073 K *	0.4000 *
19	1073 K *	0.4000 *	1073 K *	0.4000 *
20	40.00 *	19.20 *		

	E	F		
1	1073 K *	0.4000 *		

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Temp Average ASR @TPL4 (continued)

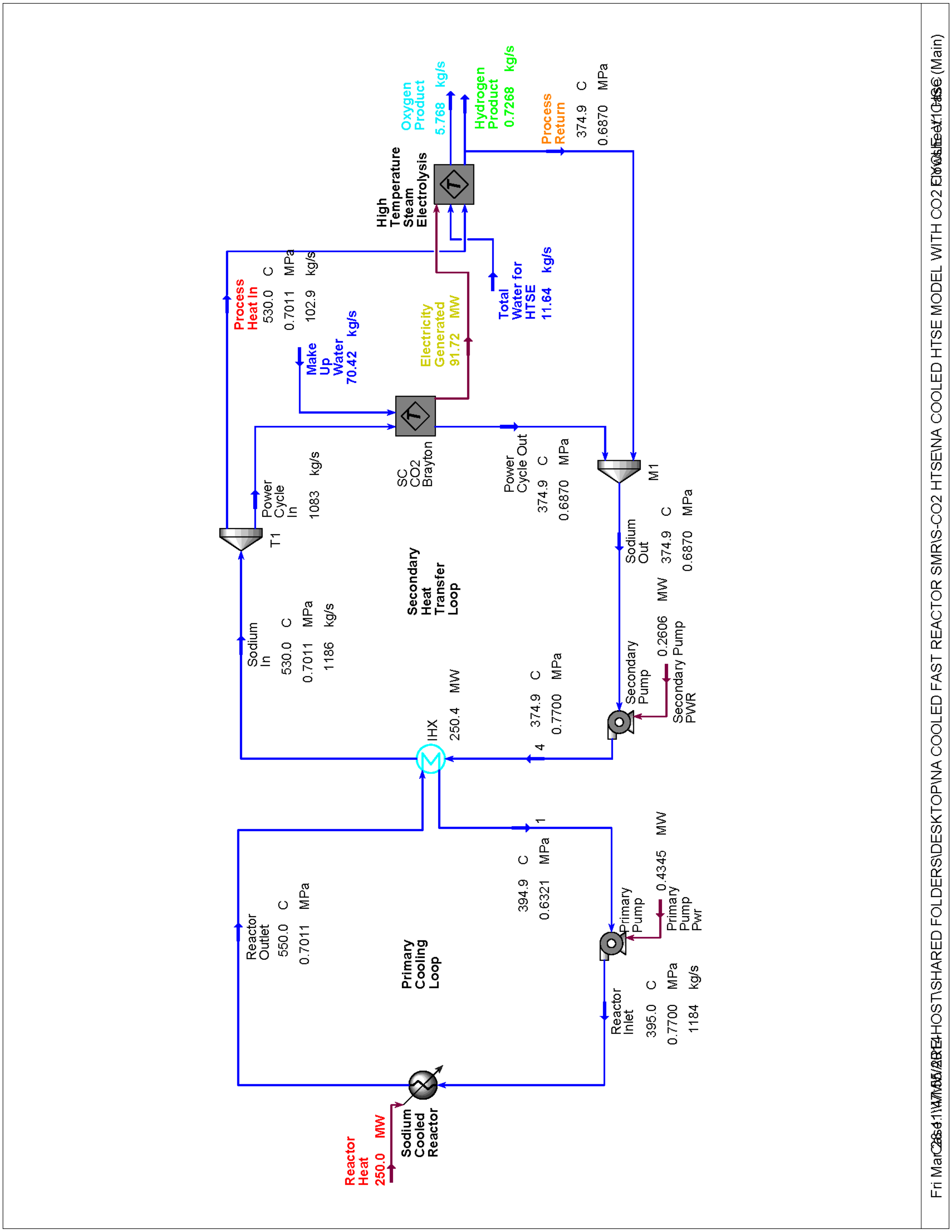
Units Set: Electrolysis_

Spreadsheet

2	1073 K *	0.4000 *		
3	1073 K *	0.4000 *		
4	1073 K *	0.4000 *		
5	1073 K *	0.4000 *		
6	1073 K *	0.4000 *		
7	1073 K *	0.4000 *		
8	1073 K *	0.4000 *		
9	1073 K *	0.4000 *		
10	1073 K *	0.4000 *		
11	1073 K *	0.4000 *		
12	1073 K *	0.4000 *		
13	1073 K *	0.4000 *		
14	1073 K *	0.4000 *		
15	1073 K *	0.4000 *		
16	delta T *	0.0000 K *		
17				
18				
19				
20				

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

6.6 Supercritical CO_2 Brayton HTSE



aspentech

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:57:05 2014

Workbook: Case (Main)

Material Streams

Fluid Pkg: All

Name		Hydrogen Product	Oxygen Product	Total Water for HTSE	Sodium In	Process Heat In
Vapour Fraction		1.0000	1.0000	0.0000	0.0000	0.0000
Temperature	(C)	54.44	54.44	21.11	530.0	530.0
Pressure	(MPa)	6.901	6.901	0.1013	0.7011	0.7011
Molar Flow	(kgmole/h)	1298	648.9	2325	1.857e+005	1.612e+004
Mass Flow	(kg/s)	0.7268	5.768	11.64	1186	102.9
Liquid Volume Flow	(m3/h)	37.46	18.25	41.98	4544	394.3
Heat Flow	(MW)	0.3069	6.293e-002	-184.3	818.8	71.05

Name		Process Return	4	Reactor Outlet	Reactor Inlet	1
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	374.9	374.9	550.0 *	395.0	394.9 *
Pressure	(MPa)	0.6870	0.7700 *	0.7011	0.7700 *	0.6321
Molar Flow	(kgmole/h)	1.612e+004	1.857e+005	1.854e+005	1.854e+005	1.854e+005
Mass Flow	(kg/s)	102.9	1186	1184	1184	1184
Liquid Volume Flow	(m3/h)	394.3	4544	4537	4537	4537
Heat Flow	(MW)	49.30	568.3	849.9	599.9	599.5

Name		Sodium Out	Power Cycle In	Power Cycle Out	Make Up Water	
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	
Temperature	(C)	374.9	530.0	374.9	20.00	
Pressure	(MPa)	0.6870	0.7011	0.6870	0.1013	
Molar Flow	(kgmole/h)	1.857e+005	1.696e+005	1.696e+005	1.407e+004	
Mass Flow	(kg/s)	1186	1083	1083	70.42	
Liquid Volume Flow	(m3/h)	4544	4149	4149	254.0	
Heat Flow	(MW)	568.1	747.7	518.8	-1116	

Compositions

Fluid Pkg: All

Name	Hydrogen Product	Oxygen Product	Total Water for HTSE	Sodium In	Process Heat In
Comp Mole Frac (H2O)	0.0000	0.0000	1.0000	***	***
Comp Mole Frac (Nitrogen)	0.0000	0.0000	***	***	***
Comp Mole Frac (Oxygen)	0.0000	1.0000	***	***	***
Comp Mole Frac (Hydrogen)	1.0000	0.0000	***	***	***
Comp Mole Frac (CO2)	0.0000	0.0000	***	***	***
Comp Mole Frac (CO)	0.0000	0.0000	***	***	***
Comp Mole Frac (Sodium)	***	***	***	1.0000	1.0000
Comp Mole Frac (Air)	***	***	***	***	***

Name	Process Return	4	Reactor Outlet	Reactor Inlet	1
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	1.0000 *	1.0000	1.0000 *	1.0000
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

aspentech

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:57:05 2014

Workbook: Case (Main) (continued)

Compositions (continued)

Fluid Pkg: All

Name	Sodium Out	Power Cycle In	Power Cycle Out	Make Up Water	
Comp Mole Frac (H2O)	***	***	***	1.0000	
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	1.0000	1.0000	***	
Comp Mole Frac (Air)	***	***	***	***	

Energy Streams

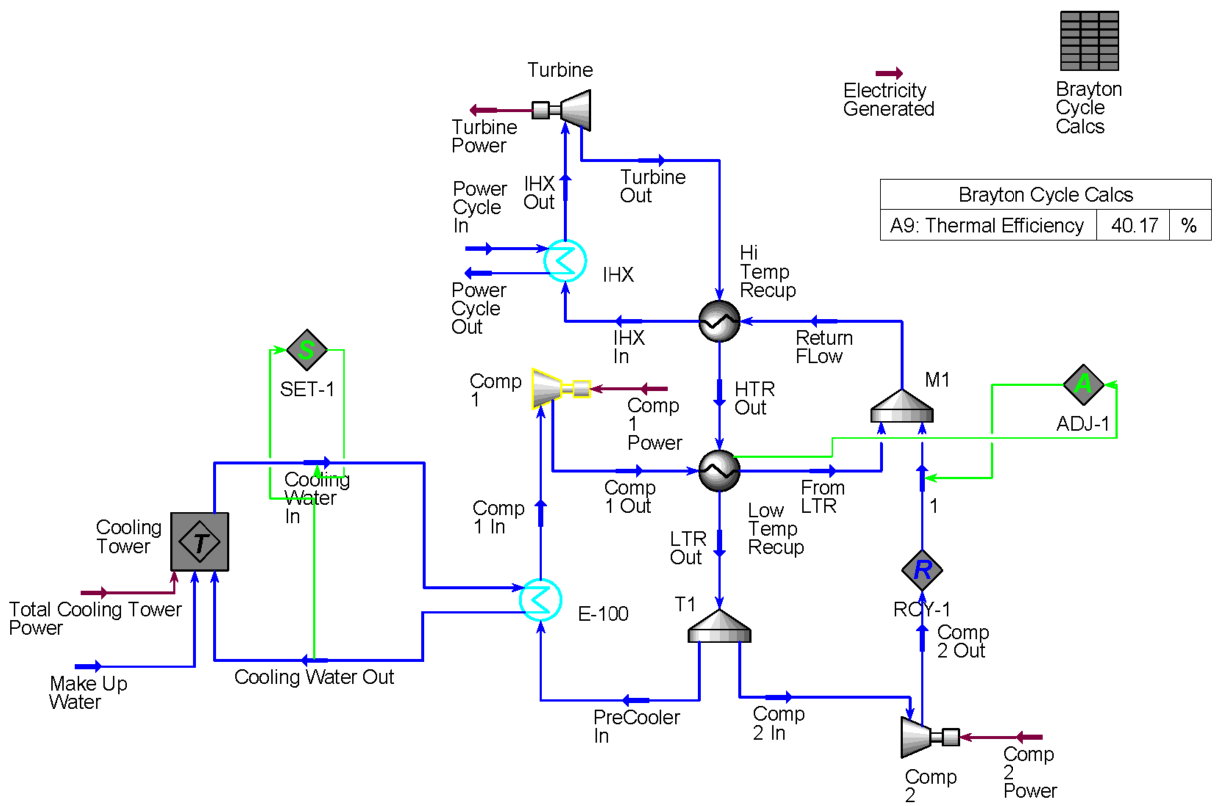
Fluid Pkg: All

Name	Reactor Heat	Electricity Generated	Primary Pump Pwr	Secondary Pump PWR	
Heat Flow (MW)	250.0 *	91.72	0.4345	0.2606	

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
Sodium Cooled Reactor	Heater	Reactor Inlet Reactor Heat	Reactor Outlet	No	500.0 *
High Temperature Steam Elec	Standard Sub-Flowsheet	Process Heat In Total Water for HTSE Electricity Generated	Hydrogen Product Oxygen Product Process Return	No	2500 *
SC CO2 Brayton	Standard Sub-Flowsheet	Power Cycle In Make Up Water	Power Cycle Out Electricity Generated	No	2500 *
Efficiency Calcs	Spreadsheet			No	500.0 *
IHX	Heat Exchanger	Reactor Outlet 4	1 Sodium In	No	500.0 *
Primary Pump	Pump	1 Primary Pump Pwr	Reactor Inlet	No	500.0 *
Secondary Pump	Pump	Sodium Out Secondary Pump PWR	4	No	500.0 *
T1	Tee	Sodium In	Power Cycle In Process Heat In	No	500.0 *
M1	Mixer	Power Cycle Out Process Return	Sodium Out	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.



Brayton Cycle Calcs		
A9: Thermal Efficiency	40.17	%

Fri Mar 28 11:48:33 2014 Case: \\VMWARE-HOST\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\S-CO2 HTSE\NA COOLED HTSE MODEL WITH CO2 CYCLE 3 HSC Flowsheet: Brayton (TPL1)

Workbook: SC CO2 Brayton (TPL1)

Material Streams

Fluid Pkg: All

Name		Power Cycle In @TPL	Power Cycle Out @TF	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1
Vapour Fraction		0.0000	0.0000	1.0000	1.0000	1.0000
Temperature	(C)	530.0	374.9	510.0	354.9	403.8
Pressure	(MPa)	0.7011	0.6870	19.60	20.00	7.866 *
Molar Flow	(kgmole/h)	1.696e+005	1.696e+005	9.818e+004	9.818e+004	9.818e+004
Mass Flow	(kg/s)	1083	1083	1200	1200	1200
Liquid Volume Flow	(m3/h)	4149	4149	5236	5236	5236
Heat Flow	(MW)	747.7	518.8	-1.017e+004	-1.040e+004	-1.031e+004

Name		HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	0.0000	0.0000
Temperature	(C)	139.3	133.7	74.28	30.56	68.74
Pressure	(MPa)	7.709	20.41	7.555	7.404	20.83
Molar Flow	(kgmole/h)	9.818e+004	9.818e+004	9.818e+004	6.816e+004	6.816e+004
Mass Flow	(kg/s)	1200	1200	1200	833.2	833.2
Liquid Volume Flow	(m3/h)	5236	5236	5236	3635	3635
Heat Flow	(MW)	-1.067e+004	-1.076e+004	-1.077e+004	-7610	-7590

Name		From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1 @TPL1
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	120.2	74.28	74.28	168.3	168.4 *
Pressure	(MPa)	20.41	7.555	7.555	20.41 *	20.41 *
Molar Flow	(kgmole/h)	6.816e+004	6.816e+004	3.002e+004	3.002e+004	3.002e+004 *
Mass Flow	(kg/s)	833.2	833.2	367.0	367.0	367.0
Liquid Volume Flow	(m3/h)	3635	3635	1601	1601	1601
Heat Flow	(MW)	-7490	-7475	-3293	-3270	-3270

Name		Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL		
Vapour Fraction		0.0000	0.0000	0.0000		
Temperature	(C)	28.69	25.00 *	20.00		
Pressure	(MPa)	0.1015	0.1035	0.1013		
Molar Flow	(kgmole/h)	1.705e+006	1.705e+006	1.407e+004		
Mass Flow	(kg/s)	8532	8532	70.42		
Liquid Volume Flow	(m3/h)	3.078e+004	3.078e+004	254.0		
Heat Flow	(MW)	-1.354e+005	-1.355e+005	-1120		

Compositions

Fluid Pkg: All

Name	Power Cycle In @TPL	Power Cycle Out @TF	IHX Out @TPL1	IHX In @TPL1	Turbine Out @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	***	***	1.0000 *	1.0000	1.0000
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	1.0000	1.0000	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	HTR Out @TPL1	Return FLow @TPL1	LTR Out @TPL1	Comp 1 In @TPL1	Comp 1 Out @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	1.0000	1.0000	1.0000	1.0000	1.0000
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: SC CO2 Brayton (TPL1) (continued)

Compositions (continued)

Fluid Pkg: All

Name	From LTR @TPL1	PreCooler In @TPL1	Comp 2 In @TPL1	Comp 2 Out @TPL1	1 @TPL1
Comp Mole Frac (H2O)	***	***	***	***	***
Comp Mole Frac (Nitrogen)	***	***	***	***	***
Comp Mole Frac (Oxygen)	***	***	***	***	***
Comp Mole Frac (Hydrogen)	***	***	***	***	***
Comp Mole Frac (CO2)	1.0000	1.0000	1.0000	1.0000	1.0000 *
Comp Mole Frac (CO)	***	***	***	***	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	Cooling Water Out @T	Cooling Water In @TF	Make Up Water @TPL		
Comp Mole Frac (H2O)	1.0000	1.0000	1.0000		
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000		
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000		
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000		
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000		
Comp Mole Frac (CO)	0.0000	0.0000	0.0000		
Comp Mole Frac (Sodium)	***	***	***		
Comp Mole Frac (Air)	***	***	***		

Energy Streams

Fluid Pkg: All

Name	Turbine Power @TPL1	Comp 1 Power @TPL	Comp 2 Power @TPL	Electricity Generated (	Total Cooling Tower P
Heat Flow (MW)	136.8	20.87	22.88	91.72	0.6364

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
IHX @TPL1	Heat Exchanger	Power Cycle In @TPL1 IHX In @TPL1	Power Cycle Out @TPL1 IHX Out @TPL1	No	500.0 *
Hi Temp Recup @TPL1	Heat Exchanger	Return FLow @TPL1 Turbine Out @TPL1	IHX In @TPL1 HTR Out @TPL1	No	500.0 *
Low Temp Recup @TPL1	Heat Exchanger	Comp 1 Out @TPL1 HTR Out @TPL1	From LTR @TPL1 LTR Out @TPL1	No	500.0 *
E-100 @TPL1	Heat Exchanger	Cooling Water In @TPL1 PreCooler In @TPL1	Cooling Water Out @TPL1 Comp 1 In @TPL1	No	500.0 *
IHX tb dP @TPL1	Set			No	500.0 *
IHX sh dP @TPL1	Set			No	500.0 *
HTR tb dP @TPL1	Set			No	500.0 *
HTR sh dP @TPL1	Set			No	500.0 *
LTR sh dP @TPL1	Set			No	500.0 *
LTR tb dP @TPL1	Set			No	500.0 *
Pre Cooler tb dP @TPL1	Set			No	500.0 *
Pre Cooler sh dP @TPL1	Set			No	500.0 *
SET-1 @TPL1	Set			No	500.0 *
Turbine @TPL1	Expander	IHX Out @TPL1	Turbine Out @TPL1 Turbine Power @TPL1	No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Workbook: SC CO2 Brayton (TPL1) (continued)

Unit Ops (continued)

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

Spreadsheet: Brayton Cycle Calcs @TPL1

Units Set: NuScale2

CONNECTIONS

Imported Variables

Cell	Object	Variable Description	Value
A1	Energy Stream: Turbine Power @TPL1	Power	136.8 MW
A2	Energy Stream: Comp 1 Power @TPL1	Power	20.87 MW
A3	Energy Stream: Comp 2 Power @TPL1	Power	22.88 MW
A4	Energy Stream: Total Cooling Tower Powe	Power	0.6364 MW
A5	Energy Stream: Primary Pump Pwr	Power	0.4345 MW
A6	Energy Stream: Secondary Pump PWR	Power	0.2606 MW
A8	Energy Stream: Reactor Heat	Heat Flow	250.0 MW
A10	Tee: T1	Flow Ratio (Flow Ratio_1)	0.9132

Exported Variables' Formula Results

Cell	Object	Variable Description	Value
A7	Electricity Generated @TPL1	Power	91.72 MW

PARAMETERS

Exportable Variables

Cell	Visible Name	Variable Description	Variable Type	Value
A7	A7: Power	Power	Power	91.72 MW
A9	A9: Thermal Efficiency	Thermal Efficiency	Percent	40.17

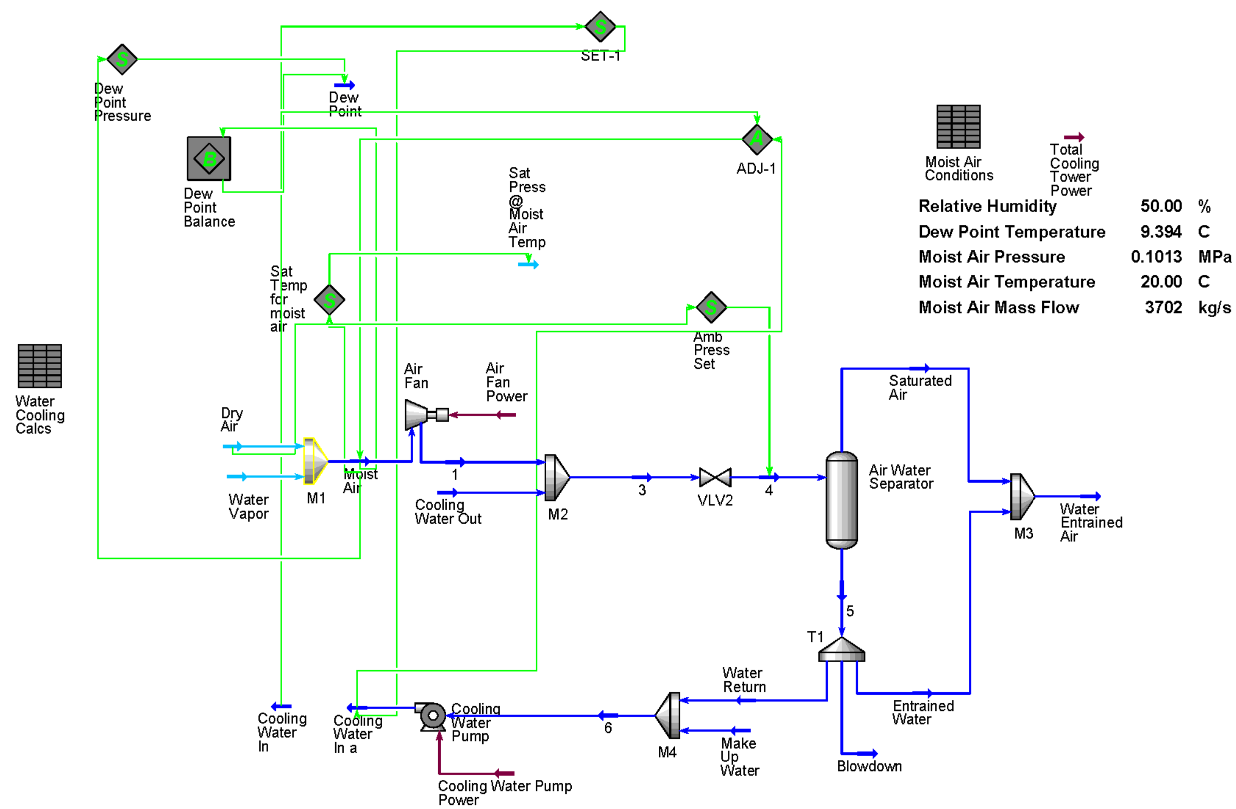
User Variables

FORMULAS

Cell	Formula	Result
A7	=A1-A2-A3-A4-A5-A6	91.72 MW
A9	=A7/(A8*A10)*100	40.17

Spreadsheet

	A	B	C	D
1	136.8 MW *			
2	20.87 MW *			
3	22.88 MW *			
4	0.6364 MW *			
5	0.4345 MW *			
6	0.2606 MW *			
7	91.72 MW *			
8	250.0 MW *			
9	40.17 *			
10	0.9132 *			



Fri Mar 28 11:42:17 2024 Case: \\MAC\HOME\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\S-CO2 HTSE\NA COOLED HTSE MODEL WITH SCO2 CYCLE VT.HSC Flowsheet: Cooling Tower (TPL4)

BATTELLE ENERGY ALLIANCE
Burlington, MA
USA

Case Name:	NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC
Unit Set:	AFR
Date/Time:	Fri Mar 28 11:57:05 2014

Workbook: Cooling Tower (TPL4)

Material Streams

Fluid Pkg: All

Name		Cooling Water Out @T	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air
Vapour Fraction		0.0000	0.0000	---	---	1.0000 *
Temperature	(C)	28.69	25.00	---	---	20.00
Pressure	(MPa)	0.1015	0.1035	0.1013	0.1013	2.339e-003
Molar Flow	(kgmole/h)	1.705e+006	1.705e+006	4.586e+005	5336	---
Mass Flow	(kg/s)	8532	8532	3675	26.70	---
Liquid Volume Flow	(m3/h)	3.078e+004	3.078e+004	1.530e+004	96.33	---
Heat Flow	(MW)	-1.354e+005	-1.355e+005	---	---	---
Name		**1 @TPL4**	**3 @TPL4**	**Dew Point @TPL4**	**4 @TPL4**	**Saturated Air @TPL4**
Vapour Fraction		1.0000	0.2183	1.0000 *	0.2183	1.0000
Temperature	(C)	20.16	25.05	9.394	25.04	25.04
Pressure	(MPa)	0.1015	0.1015	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	4.640e+005	2.169e+006	4.640e+005	2.169e+006	4.734e+005
Mass Flow	(kg/s)	3702	1.223e+004	3702	1.223e+004	3749
Liquid Volume Flow	(m3/h)	1.539e+004	4.617e+004	1.539e+004	4.617e+004	1.556e+004
Heat Flow	(MW)	-377.8	-1.358e+005	-418.4	-1.358e+005	-992.5
Name		**5 @TPL4**	**Entrained Water @TP**	**Blowdown @TPL4**	**Water Return @TPL4**	**Water Entrained Air @**
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.9964
Temperature	(C)	25.04	25.04	25.04	25.04	25.04
Pressure	(MPa)	0.1013	0.1013	0.1013	0.1013	0.1013
Molar Flow	(kgmole/h)	1.695e+006	1705	2951	1.691e+006	4.751e+005
Mass Flow	(kg/s)	8484	8.532	14.77	8461	3758
Liquid Volume Flow	(m3/h)	3.061e+004	30.78	53.28	3.052e+004	1.559e+004
Heat Flow	(MW)	-1.348e+005	-135.5	-234.6	-1.344e+005	-1128
Name		**Make Up Water @TPL**	**Cooling Water In a @T**	**6 @TPL4**	**Moist Air @TPL4**	
Vapour Fraction		0.0000	0.0000	0.0000	1.0000	
Temperature	(C)	20.00 *	25.00	25.00	20.00 *	
Pressure	(MPa)	0.1013	0.1035	0.1013	0.1013 *	
Molar Flow	(kgmole/h)	1.407e+004	1.705e+006	1.705e+006	4.640e+005	
Mass Flow	(kg/s)	70.42	8532	8532	3702 *	
Liquid Volume Flow	(m3/h)	254.0	3.078e+004	3.078e+004	1.539e+004	
Heat Flow	(MW)	-1120	-1.355e+005	-1.355e+005	-378.5	

Compositions

Fluid Pkg: All

Name	Cooling Water Out @T	Cooling Water In @TF	Dry Air @TPL4	Water Vapor @TPL4	Sat Press @ Moist Air
Comp Mole Frac (H2O)	1.0000	1.0000 *	0.0000 *	1.0000 *	1.0000 *
Comp Mole Frac (Nitrogen)	0.0000	0.0000 *	0.7900 *	0.0000 *	***
Comp Mole Frac (Oxygen)	0.0000	0.0000 *	0.2100 *	0.0000 *	***
Comp Mole Frac (Hydrogen)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (CO2)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (CO)	0.0000	0.0000 *	0.0000 *	0.0000 *	***
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***
Name	**1 @TPL4**	**3 @TPL4**	**Dew Point @TPL4**	**4 @TPL4**	**Saturated Air @TPL4**
Comp Mole Frac (H2O)	0.0115	0.7885	0.0115	0.7885	0.0312
Comp Mole Frac (Nitrogen)	0.7809	0.1671	0.7809	0.1671	0.7654
Comp Mole Frac (Oxygen)	0.2076	0.0444	0.2076	0.0444	0.2035
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Licensed to: BATTELLE ENERGY ALLIANCE
* Specified by user.

BATTELLE ENERGY ALLIANCE Burlington, MA USA	Case Name: NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC Unit Set: AFR Date/Time: Fri Mar 28 11:57:05 2014

Workbook: Cooling Tower (TPL4) (continued)

Compositions (continued)

Fluid Pkg: All

Name	5 @TPL4	Entrained Water @TP	Blowdown @TPL4	Water Return @TPL4	Water Entrained Air @
Comp Mole Frac (H2O)	1.0000	1.0000	1.0000	1.0000	0.0347
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.7626
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.2027
Comp Mole Frac (Hydrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO2)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Sodium)	***	***	***	***	***
Comp Mole Frac (Air)	***	***	***	***	***

Name	Make Up Water @TPL	Cooling Water In a @T	6 @TPL4	Moist Air @TPL4	
Comp Mole Frac (H2O)	1.0000 *	1.0000	1.0000	0.0115	
Comp Mole Frac (Nitrogen)	0.0000 *	0.0000	0.0000	0.7809	
Comp Mole Frac (Oxygen)	0.0000 *	0.0000	0.0000	0.2076	
Comp Mole Frac (Hydrogen)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (CO)	0.0000 *	0.0000	0.0000	0.0000	
Comp Mole Frac (Sodium)	***	***	***	***	
Comp Mole Frac (Air)	***	***	***	***	

Energy Streams

Fluid Pkg: All

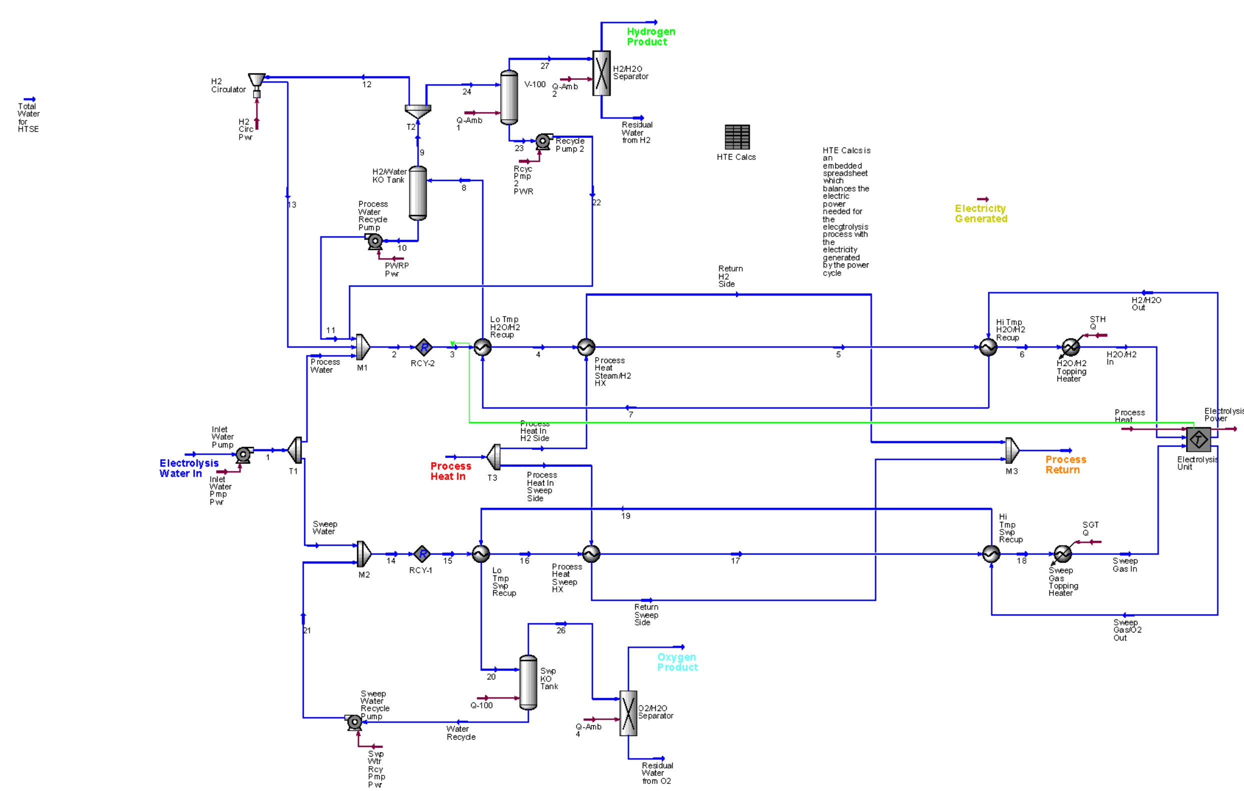
Name	Air Fan Power @TPL4	Cooling Water Pump F	Total Cooling Tower P		
Heat Flow (MW)	0.6118	2.459e-002	0.6364		

Unit Ops

Operation Name	Operation Type	Feeds	Products	Ignored	Calc Level
M1 @TPL4	Mixer	Dry Air @TPL4 Water Vapor @TPL4	Moist Air @TPL4	No	500.0 *
M2 @TPL4	Mixer	1 @TPL4 Cooling Water Out @TPL4	3 @TPL4	No	500.0 *
M3 @TPL4	Mixer	Saturated Air @TPL4 Entrained Water @TPL4	Water Entrained Air @TPL4	No	500.0 *
M4 @TPL4	Mixer	Water Return @TPL4 Make Up Water @TPL4	6 @TPL4	No	500.0 *
Moist Air Conditions @TPL4	Spreadsheet			No	500.0 *
Water Cooling Calcs @TPL4	Spreadsheet			No	500.0 *
Sat Temp for moist air @TPL4	Set			No	500.0 *
Dew Point Pressure @TPL4	Set			No	500.0 *
Amb Press Set @TPL4	Set			No	500.0 *

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.



Fri Mar 28 11:57:55 2014 Case: \\VBOXSVR\...HOST\SHARED FOLDERS\DESKTOP\NA COOLED FAST REACTOR SMR\S-CO2 HTSE\NA COOLED HTSE MODEL WITH CO2 CYCLE V1.HSC Flowsheet: High Temperature Steam Electrolysis (TPL3)

Workbook: High Temperature Steam Electrolysis (TPL3)

Material Streams

Fluid Pkg: All

Name		H2O/H2 In @TPL3	H2/H2O Out @TPL3	Sweep Gas/O2 Out @	Sweep Gas In @TPL3	7 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	800.0 *	800.0	800.0	800.0 *	515.6
Pressure	(MPa)	7.185	7.185	7.185	7.185	7.042
Molar Flow	(kgmole/h)	3245	3245	1299	650.1	3245
Mass Flow	(kg/s)	11.91	6.144	9.023	3.255	6.144
Liquid Volume Flow	(m3/h)	69.11	83.13	29.99	11.74	83.13
Heat Flow	(MW)	-128.3	-43.10	-33.90	-38.51	-51.75

Name		6 @TPL3	5 @TPL3	18 @TPL3	19 @TPL3	17 @TPL3
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	(C)	757.2	510.0 *	794.4	641.3	510.0 *
Pressure	(MPa)	7.332	7.482	7.332	7.042	7.482
Molar Flow	(kgmole/h)	3245	3245	650.1	1299	650.1
Mass Flow	(kg/s)	11.91	11.91	3.255	9.023	3.255
Liquid Volume Flow	(m3/h)	69.11	69.11	11.74	29.99	11.74
Heat Flow	(MW)	-129.9	-138.5	-38.56	-36.13	-40.79

Name		Process Heat In H2 Si	Return H2 Side @TPL	Process Heat In Swee	Return Sweep Side @	4 @TPL3
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.6276
Temperature	(C)	530.0	374.9 *	530.0	374.9 *	244.5
Pressure	(MPa)	0.7011	0.6870	0.7011	0.6870	7.634
Molar Flow	(kgmole/h)	1.442e+004	1.442e+004	1692	1692	3245
Mass Flow	(kg/s)	92.11	92.11	10.80	10.80	11.91
Liquid Volume Flow	(m3/h)	352.9	352.9	41.39	41.39	69.11
Heat Flow	(MW)	63.59	44.12	7.459	5.175	-158.0

Name		20 @TPL3	26 @TPL3	Water Recycle @TPL3	Sweep Water @TPL3	21 @TPL3
Vapour Fraction		0.8417	1.0000	0.0000	0.0000	0.0000
Temperature	(C)	222.7	100.0 *	100.0	21.77	100.1
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	1299	662.6	636.4	13.64	636.4
Mass Flow	(kg/s)	9.023	5.836	3.187	6.826e-002	3.187
Liquid Volume Flow	(m3/h)	29.99	18.50	11.49	0.2462	11.49
Heat Flow	(MW)	-43.64	-0.5882	-49.50	-1.085	-49.50

Name		14 @TPL3	15 @TPL3	16 @TPL3	8 @TPL3	9 @TPL3
Vapour Fraction		0.0000	0.0000	0.9076	0.7769	1.0000
Temperature	(C)	98.49	98.46 *	290.8	158.5	158.5
Pressure	(MPa)	7.790	7.790 *	7.634	6.901	6.901
Molar Flow	(kgmole/h)	650.1	650.1	650.1	3245	2521
Mass Flow	(kg/s)	3.255	3.255 *	3.255	6.144	2.524
Liquid Volume Flow	(m3/h)	11.74	11.74	11.74	83.13	70.05
Heat Flow	(MW)	-50.58	-50.58	-43.07	-69.51	-14.16

Name		10 @TPL3	12 @TPL3	24 @TPL3	13 @TPL3	11 @TPL3
Vapour Fraction		0.0000	1.0000	1.0000	1.0000	0.0000
Temperature	(C)	158.5	158.5	158.5	178.6	158.6
Pressure	(MPa)	6.901	6.901	6.901	7.790	7.790
Molar Flow	(kgmole/h)	724.0	1080	1441	1080	724.0
Mass Flow	(kg/s)	3.620	1.082	1.443	1.082	3.620
Liquid Volume Flow	(m3/h)	13.08	30.01	40.04	30.01	13.08
Heat Flow	(MW)	-55.35	-6.065	-8.091	-5.886	-55.34

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.