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Revision 0

Thermal Energy Delivery System Design Basis Report

Carl Stoots
Alexander Duenas
Piyush Sabharwall
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Jun Soo Yoo
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September 2018

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Thermal Energy Delivery System Design Basis Report

1. Introduction

Nuclear power plants operate most efficiently and economically when they operate at a constant power output. However, with the current dynamics of the electrical grid, including the introduction and growth of renewable energy sources (such as wind and solar), nuclear generation facilities across the U.S. are finding it difficult to maintain constant power output and provide for baseload generation capacities. As a result, most nuclear plants are finding it hard to compete with other power generation sources, most notably natural gas [1]. Finding a solution to this intermittent demand dynamic could help U.S. nuclear power plants to economically compete with other generation sources, such as natural gas, wind, and solar.

A Dynamic Energy Transport and Integration Laboratory (DETAIL) is being designed for installation within the Energy Systems Laboratory at Idaho National Laboratory (INL) to demonstrate integrated system operation. The overall objective for the DETAIL facility is to demonstrate simultaneous, coordinated, and efficient transient distribution of electricity and heat for power generation, energy storage, and industrial end uses. A dynamically controlled, electrically heated thermal energy production and distribution system has been designed in which heat production from nuclear fuel will be simulated using electrical heating and sophisticated control algorithms to provide simulation of system dynamics within a hardware system. The combined DETAIL facility will provide demonstration of real-time integration with the electrical grid, renewable energy inputs, thermal and electrical energy storage, and energy delivery to an end user. As such, an integrated energy network can be simulated to improve our understanding of how to optimize energy flows while maintaining system stability and efficient operation of all assets in the system.

A Thermal Energy Delivery System (TEDS) is needed within the DETAIL facility to test heat transfer components, distribution systems, instruments, and controls that can be monitored and controlled for hybrid generation of electrical power and/or non-electrical products. As is the case for other subsystems within DETAIL, TEDS is designed to operate as a part of an integrated system or independently to demonstrate the operation of TEDS unit components, to develop and validate thermal energy transport models and control systems, and to study thermal energy inertia and storage. Within the integrated system, TEDS will be connected to the INL Real Time Power Simulation test platform to develop and demonstrate monitoring and control systems and to investigate real-time, hardware-in-the-loop response characteristics relative to grid operations. The system can be used to characterize thermal energy inertia and thermal energy management relative to the interoperability of a nuclear plant, power generation, and industrial heat applications. TEDS operation will additionally provide data to validate computational models such as RELAP, Modelica, and other transient physics-based models that can be used to support scale-up of hybrid energy systems for demonstration with operating (fueled) nuclear plants. TEDS can also be used to support cyber-informed engineering of controls and hardware systems.

This report and the corresponding Functional and Operational Requirements (F&OR, included as Appendix A) document the current TEDS design. Before the design is finalized and sent out for procurement, a design review will be conducted with both internal and external stakeholders to ensure that all intended operational capabilities can be met via the current design.

2. Design

TEDS is designed to allow for modulation of the flow rate and temperature of the heat transfer medium and will be capable of diverting thermal energy as required by multiple heat customers. The heat transfer medium selected for use in TEDS is a high-performance, highly stable synthetic heat transfer oil (Therminol 66). A schematic of the TEDS loop is provided in Figure 1. The TEDS facility will be located within the Energy Systems Laboratory (ESL) in the D100 northwest high bay.

TEDS is designed to deliver process heat supply to heat consumers/customers and to demonstrate associated transport/transmission characteristics and performance in a flexible and dynamic manner, such that the envisioned operational modes can be tested and performance verified. Data acquired using TEDS will support improved modeling of integrated systems and provide data for validation of computational models. Data acquired will include information on time constants, which will aid in the conduct of parametric studies that enable further design improvements and system operational optimization. This test facility will allow researchers to develop an increased understanding of the cyclic behavior (charging and discharging characteristic) of an integrated energy storage system and the system dynamic behavior with integrated industrial applications. The facility will also provide much-needed feedback for control systems to support DETAIL test/demonstration operations.

The overall Nuclear-Renewable Hybrid Energy Systems (N-R HES) program and the planned experimental demonstrations supported by the program will enhance existing DOE and INL core research capabilities, including design of thermal capacitors that can optimize high-temperature thermal energy utilization, thus assisting research in the nuclear industry and heat transport/delivery systems. DETAIL, and TEDS specifically, will support systems integration, demonstration of flexible operation, dynamic model validation, and technical performance characterization of envisioned operational scenarios. The facility can be further expanded in the future to integrate additional systems (e.g. additional energy users) with minimal disruption to TEDS operation by establishing a control strategy to divert the flow as required (based on various demand conditions, control signals, etc.) and adjust the temperature and flow rate accordingly.

2.1 Design and Operating Conditions

TEDS will have design and operating conditions as shown in Table 1. The limiting design pressure of 100 psig was selected to accommodate the pressure ratings of the vendor-acquired components, including the heater system, oil pump, expansion tank, and filtration system. Because Therminol 66 has a low vapor pressure (10.3 psi at 340°C), the system does not need to be pressurized and does not drive the design pressure selection. Establishing the design pressure as 100 psig allows the components acquired from vendors to be procured without pressure modification, which would have substantially driven up costs. Additionally, this design parameter provides flexibility with pump operation to provide enough total pressure head without concern of over pressurizing the system. The design temperature was selected because the pump, heater, and Therminol 66 are only rated to 343°C. This design point prevents the system from reaching this temperature, thereby preventing oil, heater, and pump degradation.

The planned operating conditions are lower than the specified design limits to provide operational margin and to allow TEDS to properly interface with other facilities. The 325°C maximum operating temperature was selected because it matches the maximum temperature of the pressurized water reactor (PWR) emulation loop, which will interface with the TEDS loop via a heat exchanger.[1] The nominal flowrate is based on a heat transfer analysis of the required flowrate to heat the oil from 225 to 325°C using 200 kW heat input from either the PWR heat exchanger interface or a supplemental heater system, or a total 400 kW heat input from both heat sources.

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[1] J. O'Brien, S-J. Yoon, P. Sabharwall, and S. Bragg-Sitton, *High-Pressure High-Temperature Thermal Hydraulic Test Facility for Nuclear-Renewable Hybrid Energy System Studies; Facility Design Description and Status Report*, INL/EXT-17-43269, September 2017.

Table 1. TEDS operating and design conditions.

Condition	Value
Design Pressure	100 [psig]
Design Temperature	340[°C]
Maximum Oil Operating Temperature	325[°C]
Return Oil Operating Temperature	225[°C]
Maximum Operating Pressure	14 [psig]
Nominal flow rate	0.8-1.62 [kg/s] (14-33 [gpm])
Nominal Pipe Size (NPS)	2 [in.]

2.2 Piping & Instrumentation Diagram (P&ID)

The TEDS loop process layout is shown in Figure 1. This layout is broken down into four different subsystems. The baseline system is indicated by instruments and valves with the numbering scheme of (type, XXX), the future PWR loop interface is indicated by (1XX) numbering, the thermal energy storage (TES) system is indicated by (2XX) numbering, and the interface with the High Temperature Steam Electrolysis (HTSE) test stand is indicated by (3XX) numbering. Note that the HTSE system is the initial energy user to be demonstrated in DETAIL, but other energy users may be integrated via TEDS in the future.

Looking at Figure 1, the flow path starts from the Mid-Size Hot Oil System (MOS) pump at State Point 1. The flow can be split and heated at the PWR interface, which will be a heat exchanger, or go directly to the MOS heater system to have its temperature increased from 225 to 325°C. The valve labeled as GBV-004 is a variable position valve to allow varying flowrates into either piping leg. After the heat transfer fluid (HTF) has been heated to the maximum operating temperature (State Point 2), it can be diverted to the TES system for charging mode (State Point 2a) or to either the HTSE (State Point 4) or oil-to-air heat exchanger (State Point 5) before entering the suction side of the pump. Dashed lines in Figure 1 indicate future components that will be added to the baseline configuration. This includes the PWR interface heat exchanger and the connection to the HTSE. These subsystems will be installed with valved off blind flanges, which will allow flexibility in design of those systems and provide an additional point in the system to drain the HTF.

Valves used in TEDS include check, ball, globe, and gate valves. Globe valves are used in locations to provide variable position control. This will allow variable flowrates into multiple components, which is necessary to meet the loop's function as a distribution system. Check valves are used to prevent flow reversal in critical locations. A check valve is on the discharge side of the pump to prevent flow reversal into the pump, which would cause severe damage. Another check valve is used upstream of the TES discharge outlet piping to prevent flow reversal towards the heater system. The third check valve is used on the expansion tank vent line to prevent air from entering into the expansion tank during venting. The TES tank will have four main valves—GBV-201, GBV-202, GBV-203, and GBV-204—to support two modes of operation, charging and discharging. The thermal storage system is described in detail in Section 2.5.3. Flow to the oil-to-air heat exchanger and HTSE interface is controlled with ball valves BV-008 and BV-009. The piping for BV-009 can act as a bypass line to the oil-to-air heat exchanger to decrease heat-up time when heating the system and when heat removal is not needed.

Pressure in the system is controlled with an expansion tank, which will also be used to vent dissolved gases from components and oil from pressure relief valves in the system. High points in the piping and components will be capable of venting to the storage tank either through the expansion tank or directly to the vent line. The expansion tank is connected to the suction side of the pump to provide net positive suction head. The TES tank's charging outlet piping is connected upstream of the filtration system to filter and sample the oil to determine if it is carrying small pieces of the alumina particles from the packed bed.

The instrumentation layout uses thermocouples before and after a component to observe temperature changes, as well as pressure transmitters on the high-temperature side to monitor pressure drop and system conditions. This allows the oil's thermophysical properties to be determined at each component. Flowmeters are preferentially placed on the cold legs of the loop to reduce exposure to the higher system temperatures. Flowmeters were positioned downstream of valves GBV-203 and GBV-204 to provide researchers with accurate flowrate and to allow operators to monitor for leaks from the valves. Instrumentation shown around the TES tank are used to provide bulk fluid properties and are connected to piping surrounding the tank. More detailed instrumentation of the TES tank is beyond the scope of current work. National Instrument's LabVIEW software will be used to control the flow loop. This software will communicate with the actuators equipped on the valves to control their positions, collect instrumentation data with a data acquisition system, control heater power, adjust pump motor speed with a variable frequency drive (VFD), and have built-in alarms to prevent damage to the flow loop and personnel.

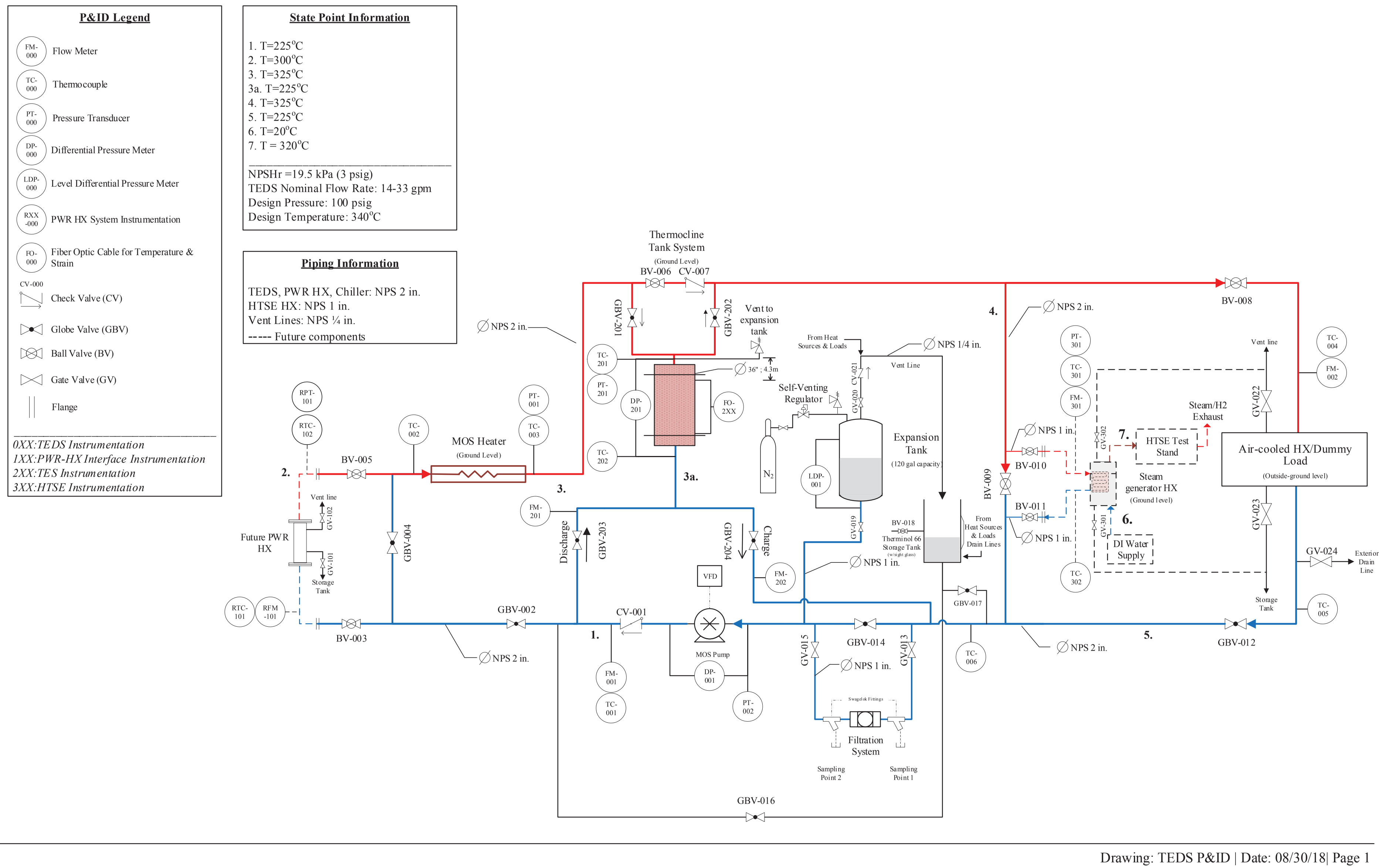
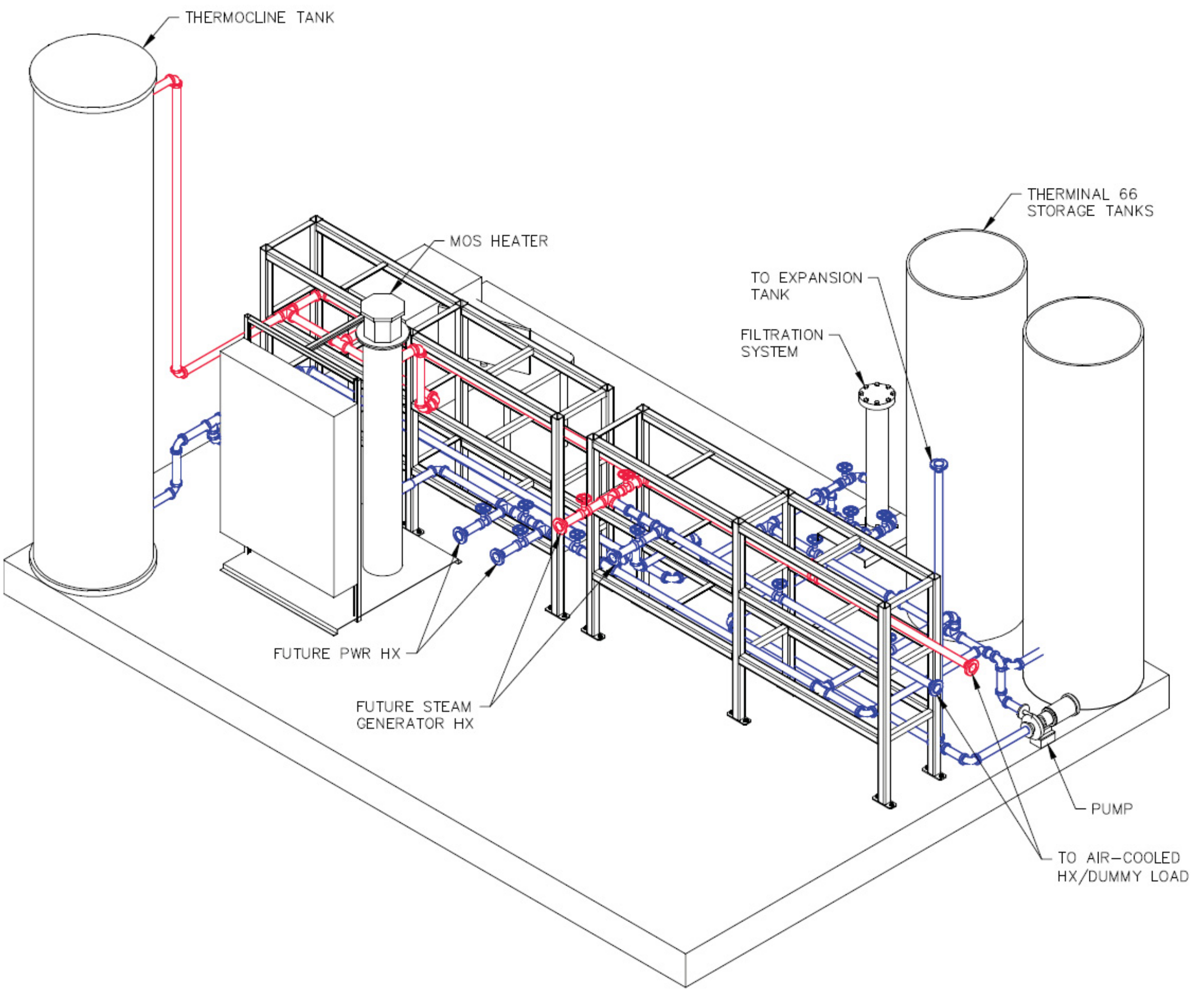


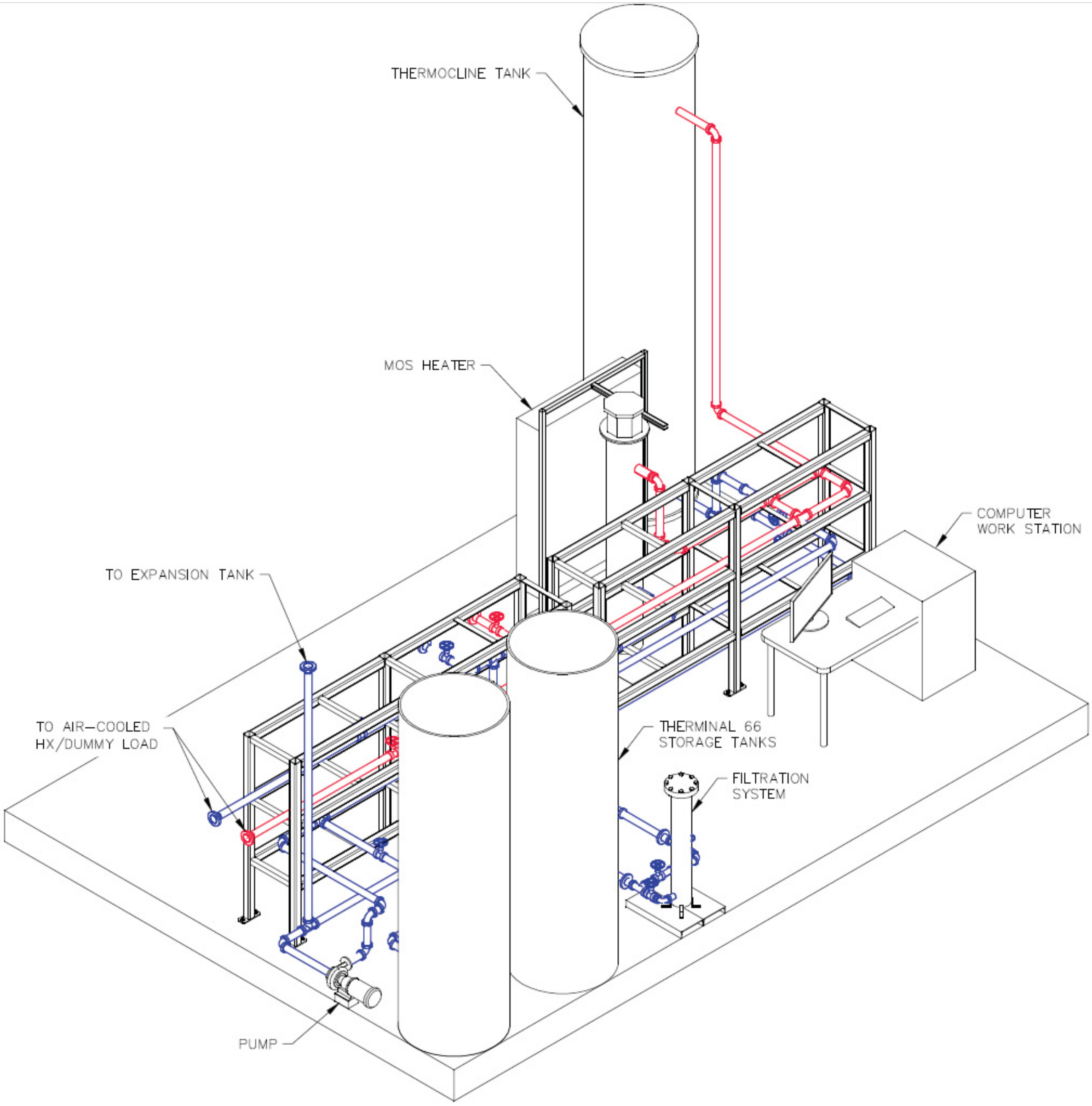
Figure 1. TEDS P&ID.

2.3 TEDS Equipment Layout

The preliminary equipment layout for TEDS is shown in Figure 2 via two isometric views. This layout uses the 2-inch pipe runs configured per the P&ID.



(a) Northwest view.



(b) Southwest view.

Figure 2. Isometric Views of the TEDS equipment layout.

2.4 Oil Selection

Therminol 66 was selected as the heat transfer fluid because of its wide operating temperature range (-3 to 343°C), low vapor pressure at high temperatures (10.3 psi at 340°C), and material compatibility. Therminol 66 is a commonly used heat transfer fluid. Figure and Figure show comparisons of vapor pressure and volumetric heat capacity versus temperature for Therminol 66, Therminol VP-1, and Xceltherm. It can be seen that, of these oils, Therminol 66 has the largest volumetric heat capacity and lowest vapor pressure in the operating and design conditions. Parameters such as thermal conductivity and viscosity were comparable between the oils. Other oils, such as Dowtherm A, Dowtherm G, and Drakeol5, were considered, but Therminol 66 had the most preferred properties (vapor pressure, freezing point, boiling point, material compatibility, corrosion, viscosity, etc.) that made it the ideal heat transfer fluid for the TEDS loop.

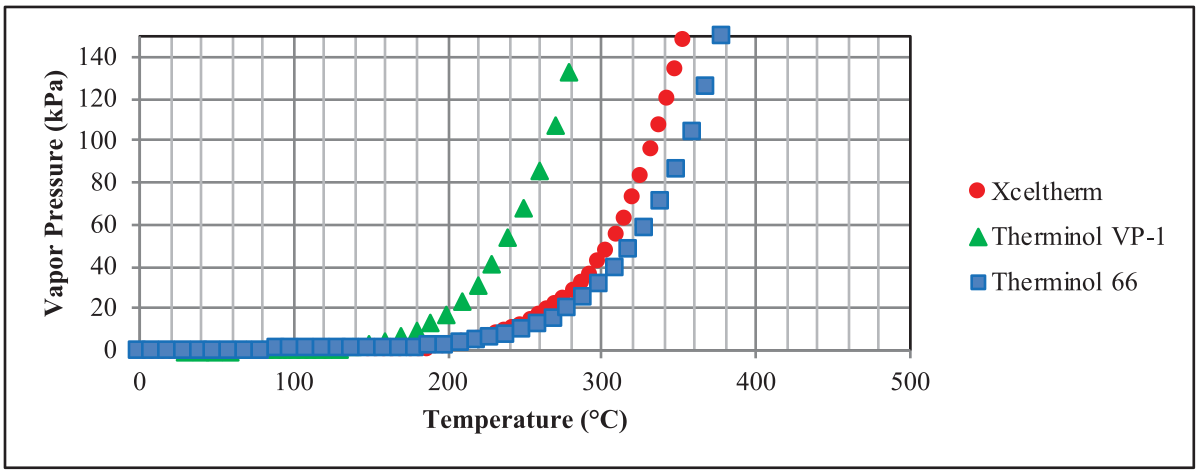


Figure 3. Comparison of oil vapor pressures.

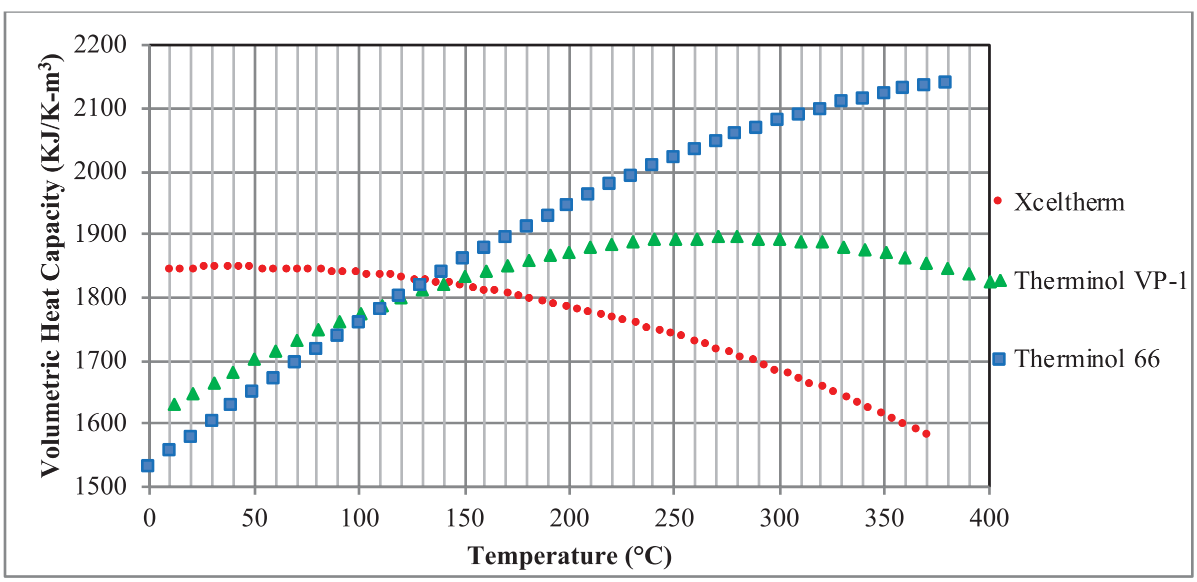


Figure 4. Comparison of oil volumetric heat capacity.

2.5 Loop Components

The TEDS loop consists of a baseline configuration composed of the heater system, oil pump, thermal energy storage system, expansion and storage tanks, and an oil-to-air heat exchanger. Listed below are the requirements and specifications identified for these components, which are based on the design and operating requirements outline in Section 2.1.

2.5.1 Heater System

A 200 kW oil heater system provided by Chromalox has been identified as the oil heater to supplement heat from the PWR heat exchanger interface. This heater system will initially be the heat source for the loop and bring the oil temperature to its maximum 325°C operating temperature. The heater is rated up to 343°C (650°F) and will be designed per American Society of Mechanical Engineers (ASME) standards and certified up to the design pressure.

2.5.2 Main Oil Pump

A hot oil pump provided by Chromalox will drive flow through the system and supply the necessary nominal flowrate range listed in Table 1. The oil pump will be capable of meeting the loop design temperature and pressure. The pump will also be used to fill and drain the oil to the storage tanks. The MP Pumps HTO 80 model has been identified for the oil pump because it is rated up to 343°C and 150 psig, provides flowrates up to 85 gpm and pressure head between 10-60 psi, and has a motor compatible with a variable frequency drive (VFD). This VFD will be used to control the pump's flowrate and will be adjusted with LabVIEW software.

2.5.3 Thermal Energy Storage System

The TES system used in TEDS is a single packed bed thermocline tank with 1/8-inch diamter alumina beads as the filler material. The preliminary dimensions range from a 13−14.5-foot height with an outer diameter of 36-inches. The tank will be an ASME designed and certified Section 8 Division 1 vessel. To reduce manufacturing costs and simplify design, the main body of the vessel will be a 36-inch pipe with an appropriate pipe schedule to meet the loop's design pressure limits. Inside of the tank there will be an upper and lower plenum, which will allow for sufficient mixing of the oil before traveling through the packed pebble bed. These plenums are formed by flow distribution plates located at the top and bottom of the tank. These plates will also prevent the alumina beads from leaving the tank with the lower flow distribution plate supporting the weight of the alumina beads. Preliminary dimensions and a diagram of the thermocline tank are shown in Table 2 and Figure 5, respectively. It is important to note that the height of the tank will depend on which pipe schedule is selected for the final design. Figure 5 provides an example based on the application of schedule 40 dimensions to the tank. Since TEDS is a low-pressure system, the pipe schedule will likely be smaller, on the order of schedule 10 or 20.

The thermocline tank will be capable of operating in either a charging or discharging mode. During charging mode, the tank will behave as a heat sink. Valves BV-006, GBV-202, and GBV-203 will be closed, with GBV-201 and GBV-204 remaining open. This will allow the hot oil to transfer its heat to the alumina beads until an equilibrium temperature has been reached and the system has reached its storage capacity. Similarly, during discharging mode, the TES can act as a heat source by having valves GBV-202 and GBV 203 opened, with GBV-201 and GBV-204 closed and with BV-006 being either opened or closed. This will cause the cooler oil to flow from the bottom to the top of the tank. This will continue until the outlet temperature at the top of the tank reaches 325°C and starts to decrease until a cutoff temperature is reached. This cutoff temperature will vary based on testing performed with the TES.

Table 2. Potential thermocline tank heights.

Thermocline Tank Dimensions					
NPS [in]	*Schedule*				
36	10	STD	20	30	40
D_o [in]	36	36	36	36	36
t [in]	0.312	0.375	0.50	0.625	0.75
D_i [in]	35.38	35.25	35.00	34.75	34.50
Area [in^2]	982.90	975.91	962.11	948.42	934.82
Alumina Section Volume [m^3]	2.14				
Total Volume [m^3]	2.68				
Distribution Plate Distance [in]	16.61	16.73	16.97	17.21	17.46
Total Height [in]	**166.08**	**167.27**	**169.67**	**172.12**	**174.62**

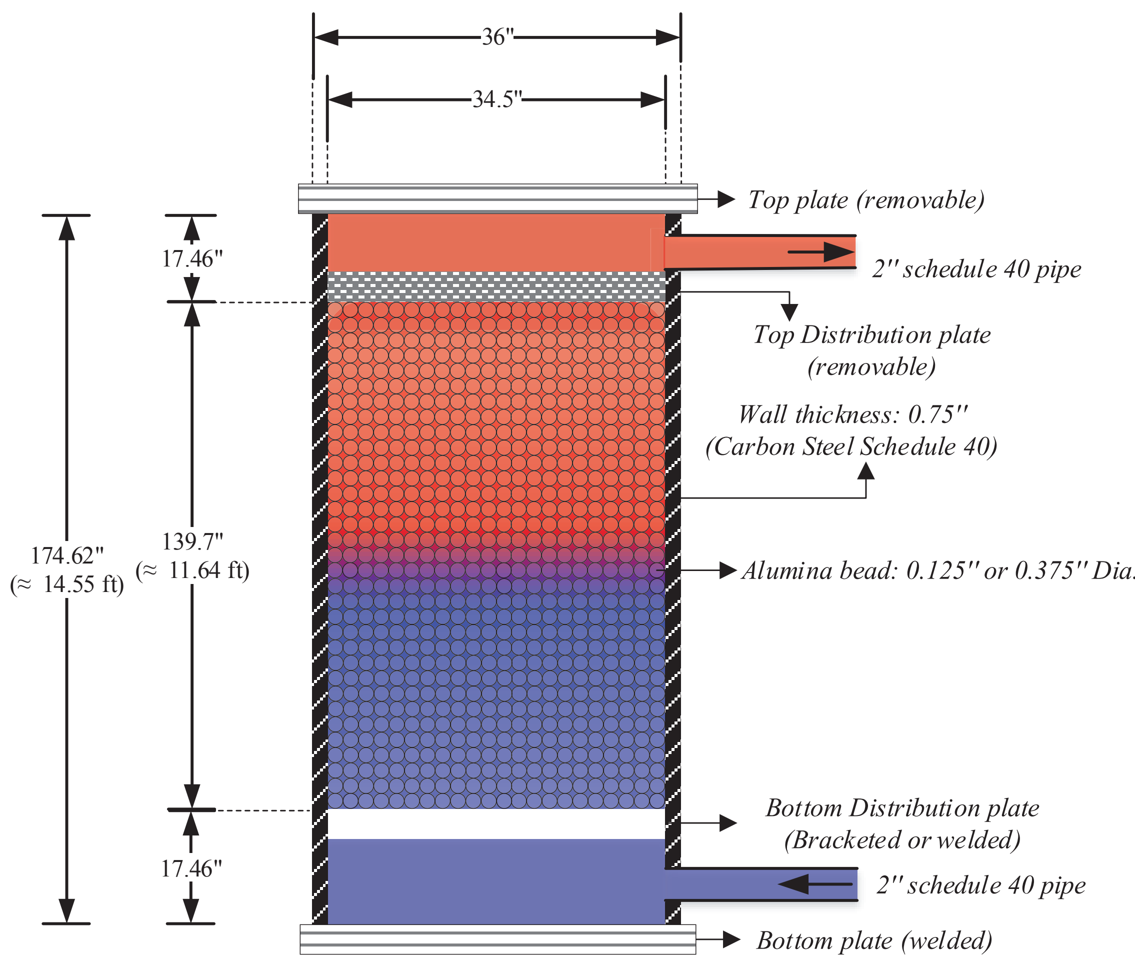


Figure 5. Potential thermocline tank dimensions.

2.5.4 Piping and Insulation

Piping in the TEDS loop will be constructed of carbon steel, which is compatible with Therminol 66 and can meet the design conditions. This pipe size was selected based on a comparison of pressure drop, fluid velocity, and loop time constant for various nominal pipe sizes (NPS). Possible sizes range from 1 to 3-inches. A NPS of 2-inches had optimal values for all parameters and offered a reduced pressure drop (≈ 2–7 psi) while maintaining an adequate loop time constant (≈ 2–4 minutes). These parameters are compared with values calculated for other pipe sizes in Table 3 and Table 4. These parameters were calculated for flowrates needed to heat the oil from 225 to 325°C from either 200 kW or 400 kW heat input into the system (with properties averaged over the temperature range), respectively. The specific pipe schedule will be decided by INL engineering services, which is designing the piping system between the loop's components.

Table 3. Pipe size information for 200 kW heat input.

Heat Input 200 [kW] | Volume Flow Rate: 15.48 [gpm]					
NPS [in]	1	1 1/2	2	2 1/2	3
D [m]	0.0254	0.0381	0.0508	0.0635	0.0762
A [m^2]	5.1E-04	1.1E-03	2.0E-03	3.2E-03	4.6E-03
v [m/s]	1.9	0.9	0.5	0.3	0.2
Re	84,305	56,203	42,152	33,722	28,102
t [s]	62	141	250	390	562
t [min]	1.04	2.34	4.16	6.51	9.37
ΔP [psi]	**56.87**	**6.91**	**1.61**	**0.53**	**0.22**

Table 4. Pipe size information for 400 kW heat input.

Heat Input 400 [kW] | Volume Flow Rate: 30.96 [gpm]					
NPS [in]	1	1 1/2	2	2 1/2	3
D [m]	0.0254	0.0381	0.0508	0.0635	0.0762
A [m^2]	5.1E-04	1.1E-03	2.0E-03	3.2E-03	4.6E-03
v [m/s]	3.9	1.7	1.0	0.6	0.4
Re	168,610	112,406	84,305	67,444	56,203
t [s]	31	70	125	195	281
t [min]	0.52	1.17	2.08	3.25	4.68
ΔP [psi]	**226.16**	**27.33**	**6.33**	**2.06**	**0.84**

2.5.5 Oil-to-Air Heat Exchanger/Dummy Load

An oil-to-air heat exchanger will act as a heat sink/heat control unit for the loop. For the first phase/shakedown testing of the loop, this heat exchanger will act as a "dummy load," which is meant to act as a heat consumer for TEDS. This heat exchanger will be installed outside of the ESL D100 high bay with an air blower to remove the heat. It will require a 200 kW heat duty to remove heat input by the MOS heater system. Because Therminol 66 has a freezing point of -3°C, heat tracing will be implemented on the piping to prevent potential freezing of the oil during the winter.

2.5.6 Expansion Tank

A 120-gallon expansion tank will be used to accommodate Therminol 66 expansion, function as a knock-out tank to remove dissolved gases (such as air) from the oil, and maintain system pressure. This will require the tank to be located at the highest elevation point in the system, which is recommended by Chromalox to be at least 15 feet from the bottom of the tank to the pump. This will provide adequate net positive suction head due to its location on the suction side of the pump.

2.5.7 Storage Tanks

The oil will be stored in two 500-gallon tanks that are unpressurized and open to atmosphere. These tanks will be used as a reservoir for any oil vented from high points in the piping and components. The system will be filled from and drained to these tanks. Similar to the manufacturing of the thermocline tank, a pipe of 36-inch NPS will be used to construct the main body of the tanks. Preliminary diagrams and dimensions of the thermocline tank have been determined and are shown in Table 5 and Figure , respectively. It is important to note that the height of the tank will depend on which pipe schedule is selected for the final design. Figure shows what the dimensions from Table 5 would look like when schedule 40 is applied to the tank and is just an example. Because the storage tanks are not sealed vessels, are unpressurized, and are open to atmosphere, the pipe schedule would likely be schedule 10. The various schedules and corresponding dimensions are for reference purposes when obtaining manufacturing quotes.

Table 5. Potential storage tank heights.

Storage Tank Dimension					
NPS [in]	*Schedule*				
36	10	STD	20	30	40
D_o [in]	36	36	36	36	36
t [in]	0.312	0.375	0.500	0.625	0.750
D_i [in]	35.38	35.25	35.00	34.75	34.50
Area [in^2]	982.90	975.91	962.11	948.42	934.82
Tank Vol [gal]	500				
Volume [m^3]	1.89				
Height [in]	**117.51**	**118.35**	**120.05**	**121.78**	**123.55**

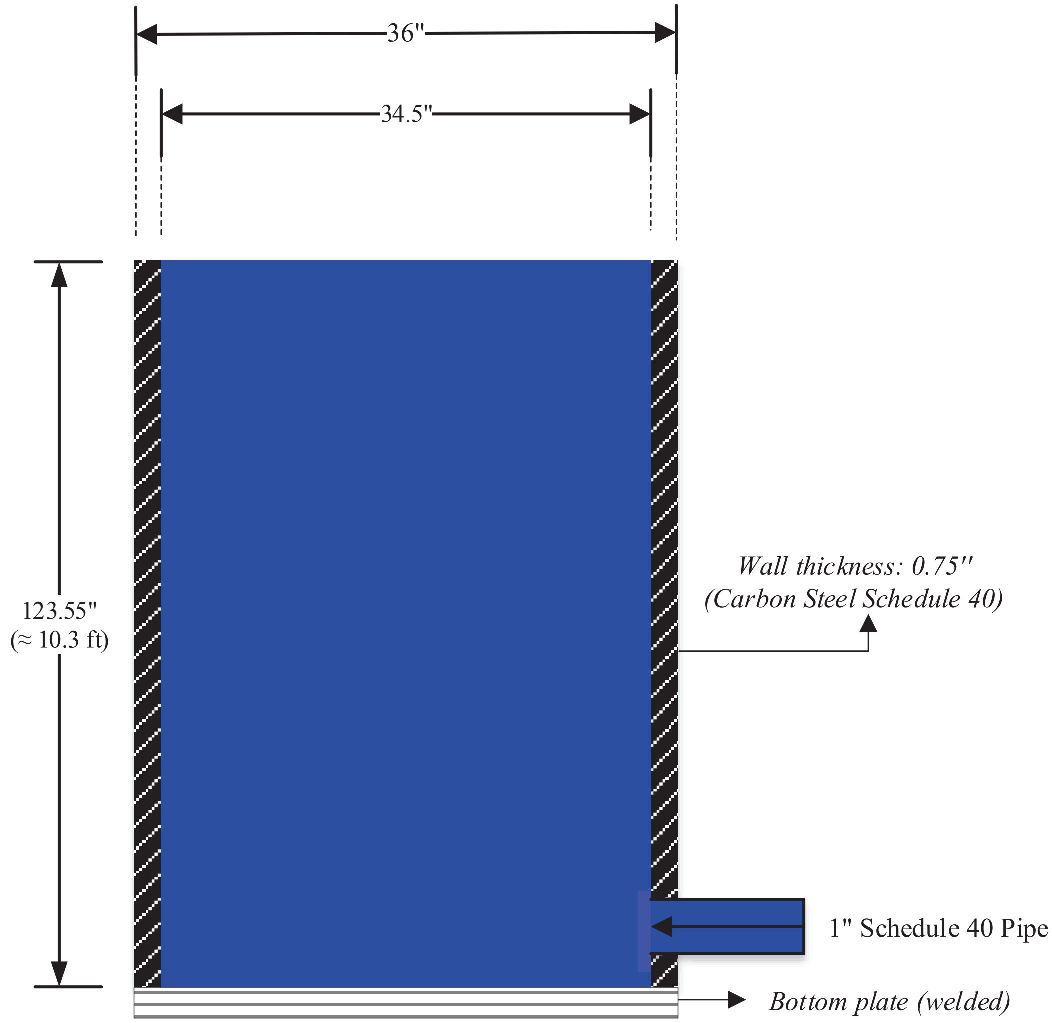


Figure 6. Potential storage tank dimensions.

2.6 Instrumentation

To monitor system parameters, a combination of flow sensors, pressure sensors, and thermocouples will be utilized. RTDs were considered but were not selected due to cost. Table 6 shows potential thermocouples, flowmeters, and pressure transmitters capable of functioning with the TEDS loop. Omega brand thermocouples were selected due to availability, familiarity, short lead time, and their widespread use. For the TEDS loop, the Quick Disconnect—Standard Size Molded Connector thermocouple will be used. This is because of the low-cost, durability, and versatility when compared with similar thermocouples. The 12-inch length was selected to allow the probe tip to reach the centerline of the 3-inch NPS diameter. The stainless steel construction will allow the probe to operate up to 1,250°C. This is more than capable of handling the maximum 325°C operating temperature. Because the connector body is rated to 180°C, the 12-inch length will provide enough distance from the operating temperature that the connector body will not overheat and exceed its 180°C rating.

Note: Sheath diameters were quoted at 1/8-inch because this diameter is common and various sheath diameters did not change pricing.

Parameters considered for flow meter selection included process temperatures, maximum pressure, cost, turn-down ratio, and instrument accuracy. Because flow meters need to be installed in-line with the piping, the biggest selection criteria was identifying flow meters capable of handling the high 325°C temperatures. Since the facility is low pressure, maximum pressure was not a key criteria in evaluating different meters. Both flow meters from Flow Technology and General Electric (GE) are capable of functioning in the operating condition range. Both have high burst pressures and similar turndown ratios, and provide a 4–20 mA output. The FT series flowmeter offered by Flow Technology has superior accuracy compared with the Panaflow MV-80 meter from GE and comes calibrated for Therminol-66. The Panaflow meter can be ordered with calibration for Therminol-66 for an additional cost. An advantage to using the Panaflow meter is its included transmitter, which is separate for the FT series meter. Additionally, the MV80 transmitter is a 4–20 mA output with a HART protocol, which will enable in-field communication with the device to verify if the instrument is within its calibration specification or out of tolerance.

The Flow Technology FT series meter is a turbine flow meter, while the GE Panaflow MV80-V is a vortex flow meter. Typically, turbine meters are susceptible to decreased accuracy when the flow is not completely clean. Considering that Therminol-66 will flow through a thermocline system, there is a chance that debris from the alumina beads will be carried throughout the system, potentially decreasing meter performance. Because the MV80-V is a vortex meter, it is less susceptible to flow debris. Additionally, the MV80-V vortex meter has no moving parts. Due to the lower cost, lack of moving parts, and HART protocol, the GE Panaflow MV80 Vortex flow meter was selected for use in the TEDS facility.

Selection of the pressure meters applied the decision criteria of maximum pressure, accuracy, operating temperature limits, signal output, and cost. There are three types of pressure transmitters used throughout the TEDS loop: differential pressure, static gauge pressure, and level differential pressure. The differential pressure transmitters evaluated are shown in Table 6. The transmitters need to be capable of handling operating temperatures in the facility of 225 to 325°C. Typically, transmitters are not capable of directly handling these high temperatures without incurring a large cost for the instrument materials. Sensing lines, also known as impulse lines, are used to distance the transmitter from the process temperature. This allows the fluid to cool by roughly 100°F (~38°C) per foot, which allows the Therminol-66 to cool within the transmitters' operating range. The length of the sensing lines will be long enough to reduce the temperature, but short enough to prevent damping of the pressure signal.

Differential transmitters from Rosemount and Omega were considered because of their similar capability to meet the pressure range, accuracy, and signal output requirements. Due to the reduced cost, the Omega PX81 transmitter was selected for the differential pressure meters. Honeywell was selected for the gauge pressure meter because of its cost, accuracy, and pressure range. While this meter has the lowest operating range and would require longer sensing lines, the cost of longer tubing would be far less than the increased cost of the Rosemount. A piezoelectric pressure meter from PCB Electronics was also considered. Piezoelectric pressure meters have difficulty operating in steady-state conditions and are better for systems with fast transients, such as shock tubes. TEDS is not expected to operate under such small time scales that the Honeywell meter would be incapable of accurately capturing pressure changes. The Omega PX81 pressure transmitter was selected for the level differential pressure meter because of its use for the differential meter and the limited selection for level differential meters.

The thermocline tank will be further instrumented with strain gauges to monitor the vessel for thermal ratcheting resulting from thermal expansion of the vessel and shifting of the packed pebble bed. Multi-junction thermocouples will be installed from radial instrumentation ports at various heights to provide both radial and axial temperature profiles in the pebble bed. A fiber optic temperature measurement system will be installed to demonstrate a more novel, advanced instrumentation system.

Table 6. Preliminary instrumentation specifications.

Manufacturer	Part Name	Part Description	Model Number	Operating Range	Unit Cost ($)	Quantity	Total Cost ($)	Electrical Requirement
Thermocouples								
Omega	Type K Thermocouples	1/8" Sheath Diameter, Grounded, 12" Length	KQSS-18G-12	-270 to 1,372°C Tolerance value 2.2°C or 0.75% (0 to 1,250°C) Connector Body Rated to 180°C (356°F)	$29.50	12	$354.00	Powered by NI Module
Omega	Standard Mating Connector	-	OSTW-K-F	Connector	$4.00	12	$48.00	
Omega	Cable Clamp Standard Connector	-	PCLM	Cable clamp	$1.10	12	$13.20	
Pressure Meters								
Differential Pressure Transmitter								
Omega	Wet/Wet Differential Pressure Transducers	High Accuracy Wet/Wet Differential Pressure Transmitter	PX81D0-100DI	0 to 100 psi difference -46 to 121°C ±0.25% of span 4 to 20 mA Output 1/4-18 FNPT	$755.00	2	$1,510.00	10 to 40 VDC
Gauge Pressure Transmitter								
Omega	High-Performance Thin-Film Transmitter	Pressure Transducer	PX5500C1-050GI	0 to 50 psig -40 to 85°C ±0.1% of full span 4 to 20 mA Output 1/4-18 FNPT	$765.00	5	$3,825.00	10 to 40 VDC
Level Differential Pressure Transmitter								
Omega	Wet/Wet Differential Pressure Transducers	High Accuracy Wet/Wet Differential Pressure Transmitter	PX81D0-100DI	0 to 100 psi difference -46 to 121°C ±0.25% of span	$755.00	1	$755.00	10 to 40 VDC

				4 to 20 mA Output				
				1/4-18 FNPT				
Flow Meter								
GE	Panaflow MV80 Meter	Volume Flow Vortex Meter	MV80-V-08-C-300-L-DD-DC2-1AHL-HT-PE-CC-NC	2.2 to 67 gpm	$4,032.00	6	$24,192.00	12-36 VDC
				Up to 750°F (400C)				
				±0.7% of rate				
				Max 300 psia				
				Turn-down up to 100:1				
				4-20 mA output HART Protocol				
				1" 300lb Flange Connection				
						Total Cost:	**$30,697.20**	

3. Project Status

Preliminary design of the TEDS loop has been completed, with instrumentation specifications and system component requirements identified. Chromalox has been identified as the vendor for the heater system and oil pump. A visit to Chromalox occurred on July 31, 2018, during which a MOS heater was shown to visiting members of the TEDS project, as shown in Figure 7. The team held a meeting with Chromalox representatives to discuss requirements for the heater.

Figure 7. MOS heater from Chromalox tour.

The operating conditions and design requirements have been identified and documented in functional and operational document FOR-415, which has been through a review process in the electronic change request (eCR) system (see Appendix A). Comments from this review process were incorporated into the final version of FOR-415 and entered into the INL Electronic Document Management System (EDMS). The functional and operational document was submitted to engineering services and is being used to design the piping, necessary support structures, and utilities needed for the operation of the TEDS loop. A design review including both internal and external stakeholders will be held for the TEDS design prior to finalizing the design and moving forward with procurement.

4. Summary

A preliminary design for the Thermal Energy Delivery System has been completed. A finalized P&ID has been developed to allow the loop to flexibly operate between charging/discharging modes of a thermal energy storage system and delivering process heat for high-temperature steam electrolysis and a heat sink/simulated heat load. Instrumentation to observe the system dynamics has been specified and will be used with a LabVIEW data acquisition system to record data and implement a control system.

Appendix A

Functional & Operational Requirements

Document ID: FOR-415
Revision ID: 1
Effective Date: 08/30/18

Functional and Operational Requirements

Thermal Energy Delivery System

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

Idaho National Laboratory

CONTENTS

1. INTRODUCTION

1.1 Description of Engineering Task

The Thermal Energy Delivery System (TEDS) will be a thermal hydraulic flow loop with a stand-alone dedicated control system to support test/demonstration operations for DETAIL and Nuclear-Renewable Hybrid Energy System (N-R HES) applications. This Functional and Operational Requirements document is requesting the design of piping/insulation between flow loop equipment, necessary support structures, and utilities needed for the operation of TEDS.

1.2 Description of the End-Use for the Engineered Item or Activity

TEDS will have the capability of modulating the flow rate and temperature of the heat transfer medium and be able to divert thermal energy as required by heat customers. The heat transfer medium used in TEDS will be a high-performance, highly stable synthetic heat transfer oil (Therminol 66). A schematic of the TEDS loop is shown in Figure 1. Further information on the functional and operational requirements is described in Section 3. The TEDS facility will be located within the Energy Systems Laboratory (ESL) D100 northwest high bay.

TEDS will be able to deliver required process heat supply to heat consumers/customers, demonstrate associated transport/transmission characteristics and performance in a flexible and dynamic manner, such that envisioned operational modes can be tested and performance verified. Experimental performance of TEDS will allow for better modeling of integrated systems and provide experimental data for validation of computational models. This would include providing information on time constants, which would aid in parametric studies for further improvements and optimization. The outcomes of this project will help understand the cyclic behavior (charging and discharging characteristic) of an energy storage system and the system dynamic behavior with integrated industrial applications, and provide much-needed feedback for control systems to support DETAIL test/demonstration operations.

This facility will enhance the existing INL core research capability of being able to design thermal capacitors that would optimize high-temperature thermal energy utilization, thus assisting research in nuclear reactor industry and heat transport/delivery systems. The project will support systems integration, flexible operation, dynamic model validation, and technical performance characterization of envisioned scenarios to support DETAIL test/demonstration operations. The loop can be further expanded to integrate additional future systems with minimal disruptions to TEDS operation by having a control strategy in place to divert the flow as required and adjust the temperature and flow rate, accordingly.

2. OVERVIEW

2.1 Ownership of the F&OR

Dr. James O'Brien is the principle investigator/principal researcher and owner of the functional and operational requirements document.

2.2 End-User of Engineered Item or Activity

The end user of the facility will be Dr. James O'Brien. The ESL building is maintained by Facilities and Site Services.

3. ENGINEERING INPUTS

The designed TEDS facility shall be capable of meeting the following functional and operational requirements.

3.1 Functional Requirements

- The 200 kW thermal energy delivery system shall include a 200 kW oil heating unit, which shall supplement future heat delivery from the PWR water loop when available, with similar heat duty.
- The oil heating system shall allow for monitoring/control of heater electrical power level.
- The system shall be designed to support unattended operation with remote alarm capability.
- An air-to-oil heat exchanger shall be used as a heat sink/heat control unit for TEDS and shall be located outside.
- An appropriately sized oil circulation pump with a variable frequency drive shall provide flow through the system.
- An expansion tank shall be used to accommodate the Therminol 66's expansion, function as a knock-out tank to remove dissolved gases such as air from the oil, and maintain system pressure. This requires the expansion tank to be located at the highest elevation point in the system.
- The expansion tank shall be capable of venting to the storage tank.
- Piping and components shall have capability to vent highpoints to the storage tank.
- Piping shall have instrumentation ports to accommodate thermocouples and pressure sensing lines. Flowmeters shall be installed in-line as flanged components with appropriate gaskets.
- Thermocouple instrumentation ports shall be able to accommodate multiple thermocouples in each port.
- Piping shall have sufficient insulation to prevent heat loss to the environment and protect personnel.
- Pressure sensing lines shall have isolation valves and bleed valves to isolate pressure instrumentation and allow lines to be drained.
- Valved-off blind flanges shall be designed to accommodate a future interface with potential systems with minimal disruptions to TEDS operation.
- Valves should be configured on piping as shown in Figure 1 and Table 2.
- Valves shall be capable of remote control as described in Table 2.
- System shall be capable of filling and draining the oil with the oil pump.
- Wire ways shall be installed to allow wiring paths for instrumentation and valve controls.
- Flow analysis of the system shall be performed upon completion of physical layout and design.
- Loop shall be capable of being completely drained to the storage tank.
- TEDS loop shall be placed on a skid with a no-slip material.
- System shall be analyzed and designed to accommodate thermal stresses in the piping system.

3.2 Operational Requirements

- Design Pressure: 100 psig
- Design Temperature: 340°C
- Nominal operation requirements for TEDS are provided below and in Table 1.
- Maximum Oil Operating Temperature: 325°C
- Return Oil Operating Temperature: 225°C
- Maximum Operating Pressure: 14 psig
- Nominal flow rate in TEDS: 0.8-1.62 kg/s (14-33 gpm)
- Nominal Pipe Size: 2 in.
- Electrical Requirement: 120/208/480 VAC as required for the process equipment

Table 1: TEDS Operating Requirements

Components	Rating	Suggested Equipment/Notes
Heater	200 kW Output	Chromalox MOS Hot Oil System, T_{max}=343°C
	Electrical Requirement: 480V (3 Phase)	
Expansion Tank	120 Gallons (sized for 200 kW heater)	Chromalox provided expansion tank rated for MOS Hot Oil System
Oil Pump	3 HP motor	MP Pumps: HTO 80 model Class 150 Flanges
	Motor Requirement: 0-50 gpm	
	Head pressure to be determined by fluid flow analysis	
	Controller: Variable Frequency Drive (VFD)	
Packed Bed Thermal Energy Storage	NPS: 36 in Height: 166-175 in	Height depends on use of pipe schedules such as 10 thru 40 for carbon steel.
Heat Load (Air-to-Oil HX/Dummy Load)	200 kW Heat Duty	Located outside, air blower will need electrical power.
Oil Storage Tank(s)	Total capacity of 1000 gallons	Open to atmosphere tank(s)
Filtration System	Rated up to 343°C and 150 psig	1-1/2” Class 300 Flanges
		Liquid Process Systems, Inc. Model # VC15C-BP-F
Data Acquisition System	Electrical Requirement: 9-40 VDC Input	Access to 110 V outlets required.
Computer Station	Electrical Requirement: 110 V Outlet	Access to 110 V outlets required.

Table 2 shows each valve listed in Figure 1 and includes the valve number, desired control method, and precision required for opening/closing each valve. Check valves are listed as uni-directional because they open with flow in one direction and prevent flow reversal, and is why they are listed as flow controlled. The only valves that are manually controlled are the isolation and bleed valves on the pressure sensing lines (not shown in Figure 1) and BV-018 is attached to the oil storage tank(s).

Table 2: Valve Description and Control Method

Valve Number	Valve Type	Position(s)	Control Method
TEDS Valves			
CV-001	Check Valve	Uni-directional	Flow controlled
GBV-002	Globe Valve	Variable	Pneumatic actuator
BV-003	Ball Valve	On/Off	Pneumatic actuator
GBV-004	Globe Valve	Variable	Pneumatic actuator
BV-005	Ball Valve	On/Off	Pneumatic actuator
BV-006	Ball Valve	On/Off	Pneumatic actuator
CV-007	Check Valve	Uni-directional	Flow controlled
BV-008	Ball Valve	On/Off	Pneumatic actuator
BV-009	Ball Valve	On/Off	Pneumatic actuator
BV-010	Ball Valve	On/Off	Pneumatic actuator
BV-011	Ball Valve	On/Off	Pneumatic actuator
GBV-012	Globe Valve	Variable	Pneumatic actuator
GV-013	Gate Valve	On/Off	Pneumatic actuator
GBV-014	Globe Valve	Variable	Pneumatic actuator
GV-015	Gate Valve	On/Off	Pneumatic actuator
GBV-016	Globe Valve	Variable	Pneumatic actuator
GBV-017	Globe Valve	Variable	Pneumatic actuator
BV-018	Ball Valve	On/Off	Manual
GV-019	Gate Valve	On/Off	Pneumatic actuator
GV-020	Gate Valve	On/Off	Pneumatic actuator
CV-021	Check Valve	Uni-directional	Flow controlled
GV-022	Gate Valve	On/Off	Pneumatic actuator
GV-023	Gate Valve	On/Off	Pneumatic actuator
GV-024	Gate Valve	On/Off	Pneumatic actuator
PWR HX Valves			
GV-101	Gate Valve	On/Off	Electrical actuator
GV-102	Gate Valve	On/Off	Electrical actuator
Thermocline Tank Valves			
GBV-201	Globe Valve	Variable	Pneumatic actuator
GBV-202	Globe Valve	Variable	Pneumatic actuator
GBV-203	Globe Valve	Variable	Pneumatic actuator
GBV-204	Globe Valve	Variable	Pneumatic actuator
HTSE SG Valves			
GV-301	Gate Valve	On/Off	Electrical actuator
GV-302	Gate Valve	On/Off	Electrical actuator

3.3 Owner Specified Technical Requirements

- An expansion tank shall be located at the highest elevation point in the system which is assumed to be at least 15ft elevation from bottom of tank to the pump. It is preferred to locate the tank on the existing utility support structure for the High Temperature Steam Electrolysis while considering design of the system.
- Air-to-Oil heat exchanger needs to be rated to a heat duty of 200 kW, located outside, and not allow the Therminol 66 to freeze.
- Piping, flanges, and tank material are assumed to be carbon steel.
- Piping shall comply with ASME 31.3 Process Piping Code
- Thermal Energy Storage tank shall be an ASME BVPC Section 8 Division 1 vessel.
- The electrical system shall be designed to the current National Electric Code
- Layout of flow loop equipment should reference Figure 3.
- Configuration of valves should reference Figure 1.
- Pressure drop through Thermocline tank system for flow analysis will be performed/provided by the researchers.
- Project researchers shall be responsible for instrumentation and valve control wiring.

3.4 Supporting Information

3.4.1 Need for Configuration Management

The TEDS project will require some configuration management as described in LWP-10500, and will require as built drawings.

3.4.2 Sensitive Information

Not applicable

3.4.3 Export Control

Not applicable

3.4.4 Need for Engineering Change Control

Not applicable

3.4.5 Level of Verification Needed

The TEDS project will require an electronic design review with project stakeholders.

3.4.6 Technical Integrator

Not applicable

4. APPENDIX

Appendix A: Charts, Diagrams, and Lists

Appendix B: Instrumentation Specifications

Appendix A
Charts, Diagrams, and Lists

P&ID Legend

- FM-000 Flow Meter
- TC-000 Thermocouple
- PT-000 Pressure Transducer
- DP-000 Differential Pressure Meter
- LDP-000 Level Differential Pressure Meter
- RXX-000 PWR HX System Instrumentation
- FO-000 Fiber Optic Cable for Temperature & Strain
- CV-000 Check Valve (CV)
- Globe Valve (GBV)
- Ball Valve (BV)
- Gate Valve (GV)
- Flange

0XX:TEDS Instrumentation
1XX:PWR-HX Interface Instrumentation
2XX:TES Instrumentation
3XX:HTSE Instrumentation

State Point Information

1. T=225°C
2. T=300°C
3. T=325°C
3a. T=225°C
4. T=325°C
5. T=225°C
6. T=20°C
7. T = 320°C

NPSHr =19.5 kPa (3 psig)
TEDS Nominal Flow Rate: 14-33 gpm
Design Pressure: 100 psig
Design Temperature: 340°C

Piping Information

TEDS, PWR HX, Chiller: NPS 2 in.
HTSE HX: NPS 1 in.
Vent Lines: NPS ¼ in.
----- Future components

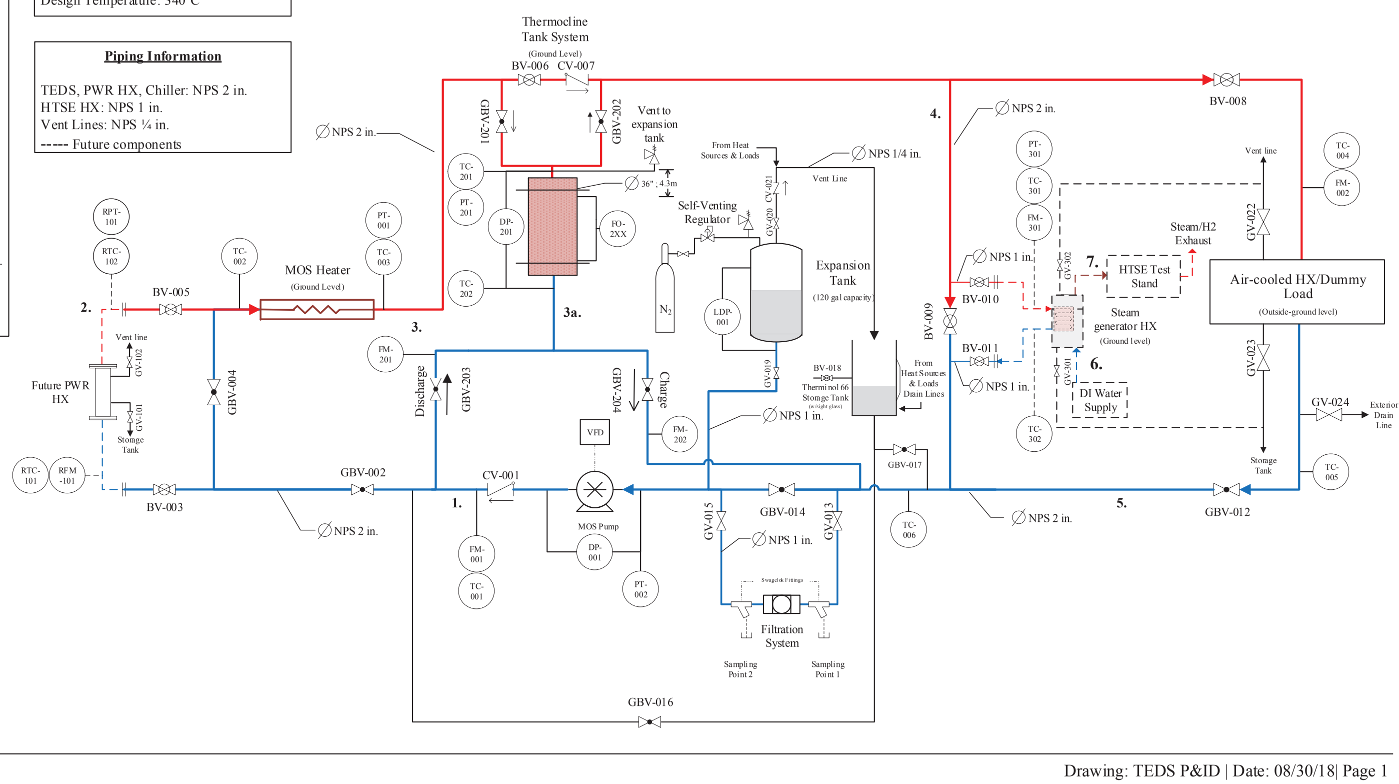
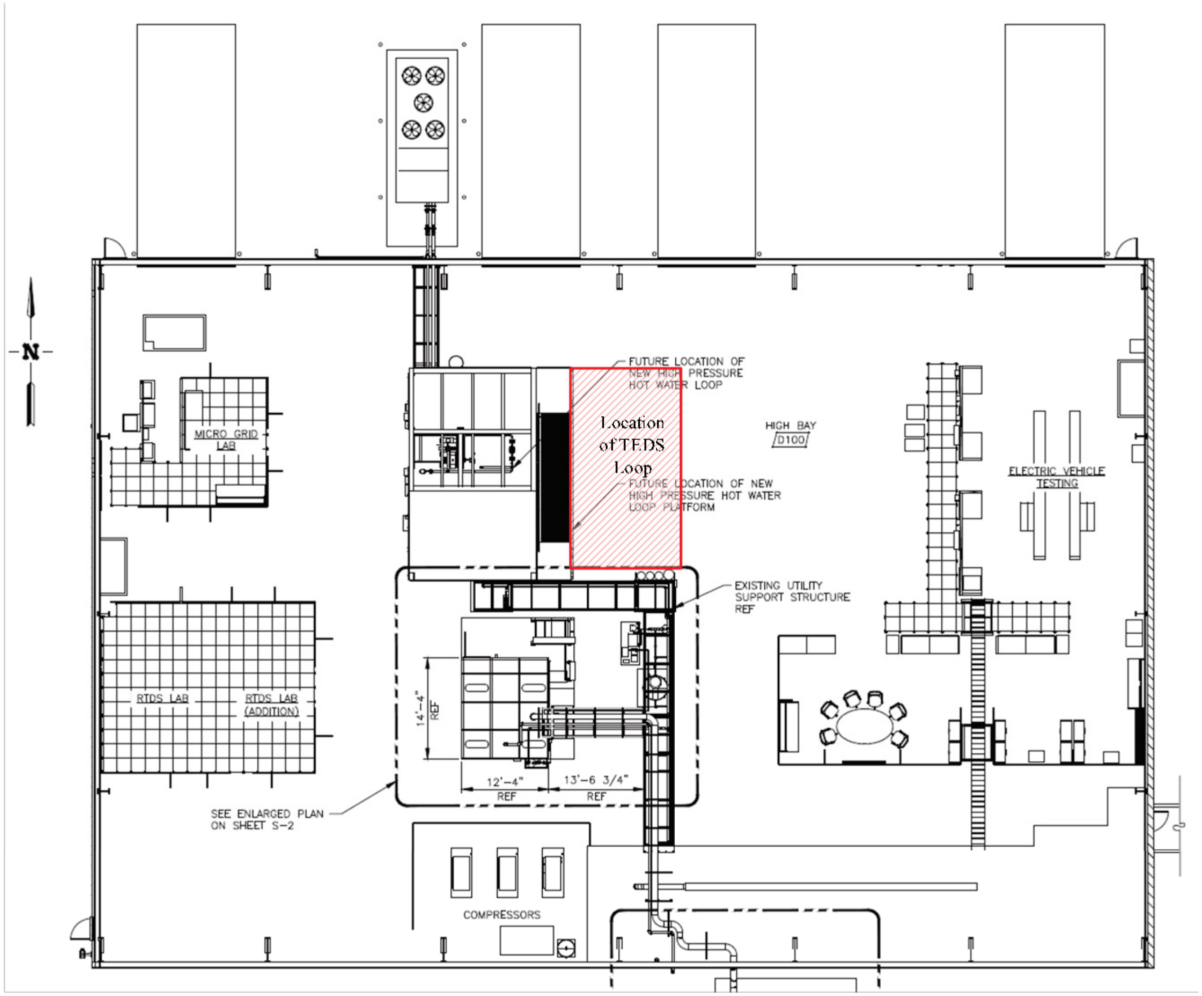


Figure 1: TEDS P&ID



TEDS Floor Plan and Equipment Layout | 08/22/18 | Page 1

Figure 2: TEDS Floorplan Location

Appendix A

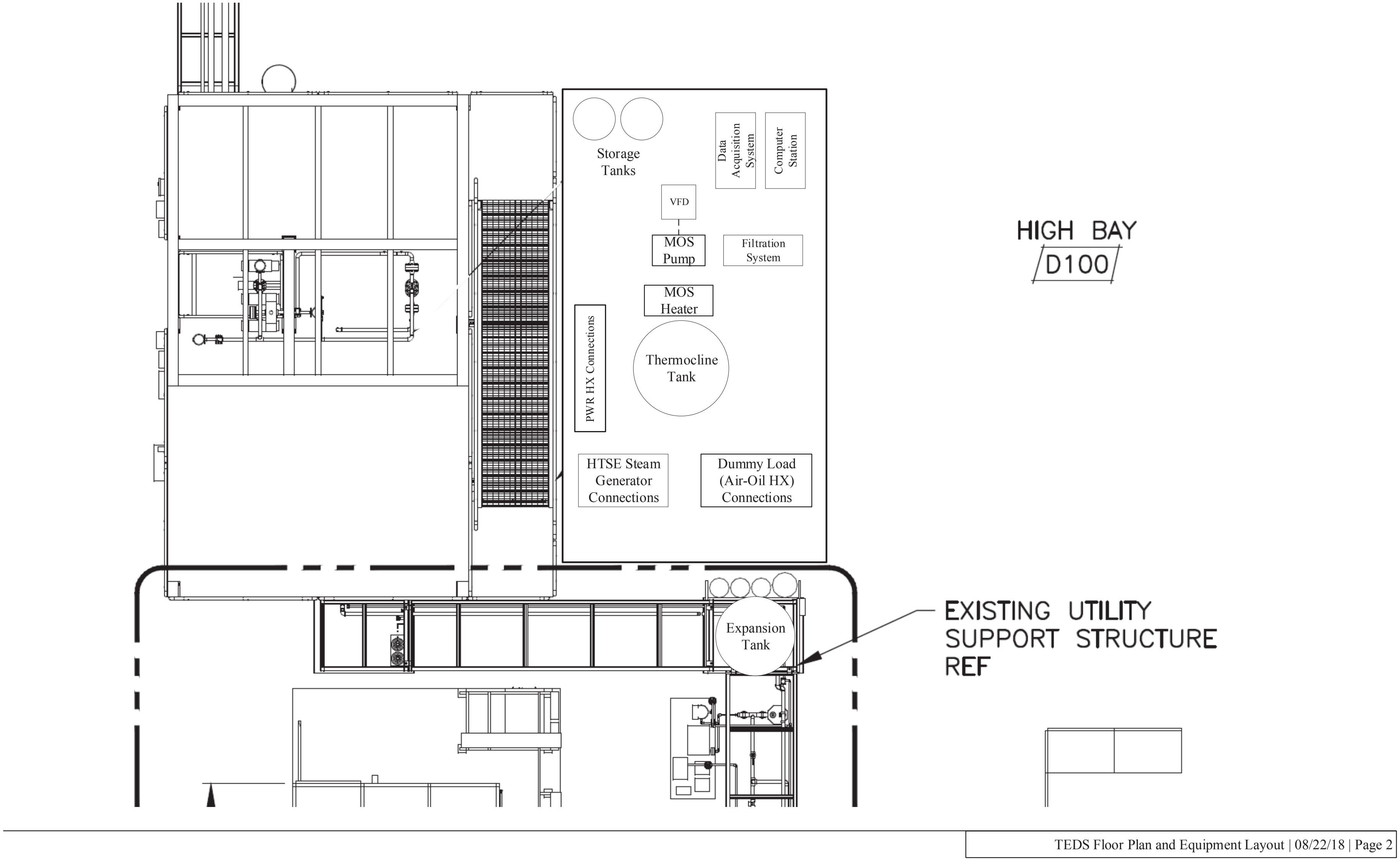


Figure 3: TEDS Equipment Layout

Appendix A

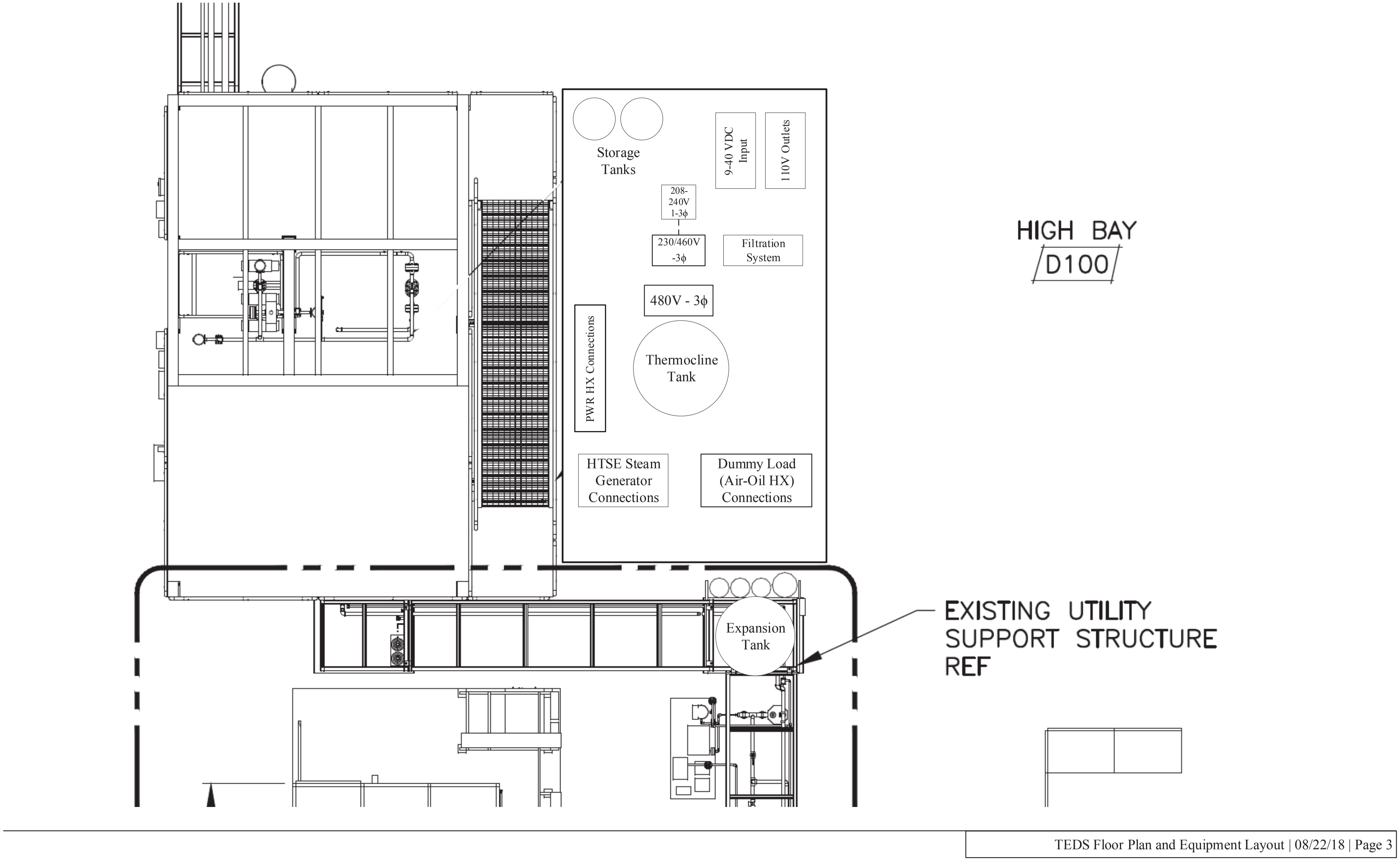
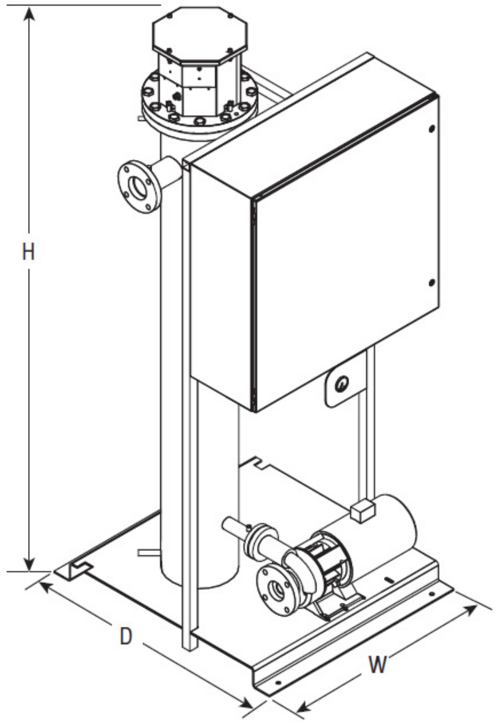


Figure 4: TEDS Equipment Electrical Requirement

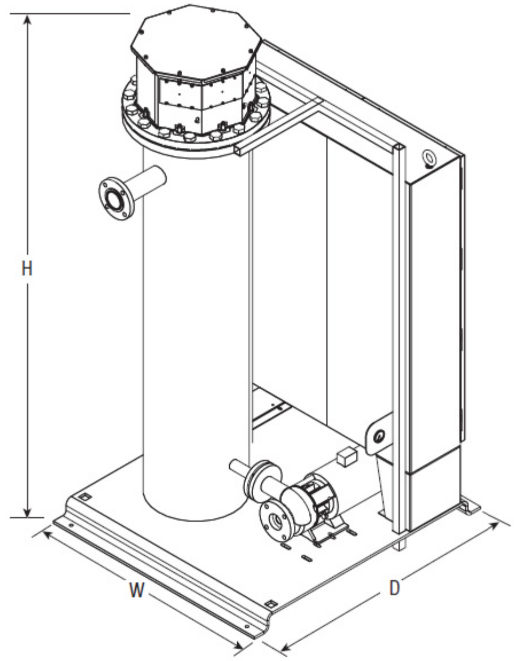
Appendix A

MOS Heater System Drawings:

See attached drawings detailing dimensions of the MOS heater system.



MOS 50-150 kW Unit (Front View)



MOS 175-500 kW Unit (Rear View)

Unit Proportions

Unit Size	Dry Weight (Lbs.)	Width (In.)	Depth (In.)	Height[1] (In.)	Flow Rate[2] GPM	Pressure[2] TDH (Ft.)	Motor HP	Inlet/Outlet Connection ANSI	System Capacity (Gal.)
50 & 75 kW	900	36	42	96	80	130	5	2”, 150#	24
100-150 kW	1400	36	42	96	120	130	7.5	3”, 150#	35
175-300 kW	2600	48	54	96	200	130	10	3”, 150#	65
350-500 kW	3500	48	54	96	200[3]	130	10[3]	3”, 150#[3]	85

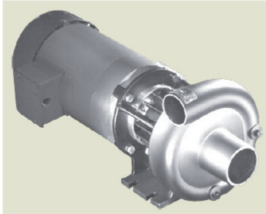
Potential MOS Pump Curves and Datasheet

HTO™ 80

1-1/2" x 1-1/4" End Suction Centrifugal Hot Oil Pump

HTO80 is a patented, unique centrifugal pump designed for high temperature applications, such as the plastics, chemical, food and processing industries. The pump can be used in horizontal or vertical positions and is available with or without an electric motor. It is designed to greatly reduce the temperature at the seal by utilizing ambient air temperature which greatly increases seal life.

Want to learn more about using pumps with heat transfer fluids? Click here to view "Using Pumps with Heat Transfer Fluids" an article featured in Process Heating Magazine written by MP Pumps' Chief Engineer.



SPECIFICATIONS:

Suction And Discharge	1-1/2" x 1-1/4" NPT or flat flange option
Materials Of Construction	Ductile iron
Flow	Up to 85 GPM
Head Feet	Up to 130'
Impeller	5.9" steel, enclosed
Motor	Up to 3 HP
Drive Options	Close coupled 56C, Close coupled 145TC, Pedestal, PumPAK® (without motor)
Seal	Carbon / silicon carbide / Viton
Temperature	650°F max

Application

- Industrial
- OEM

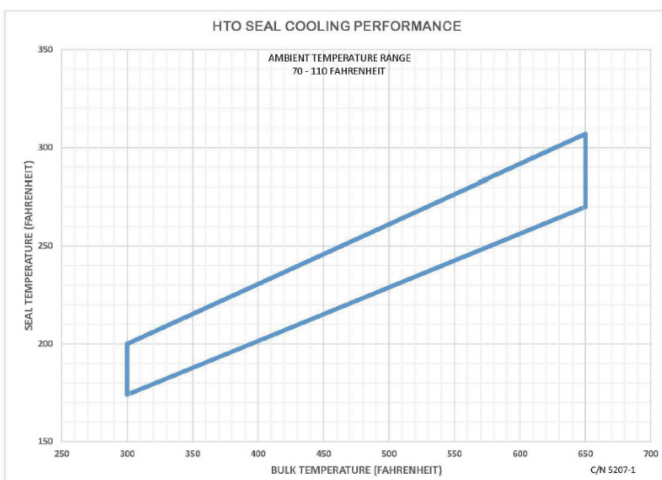
Drive Sleeve

- Hardened 303 stainless steel

Features

- Isolated air cooled seal chamber

HTO™ 80



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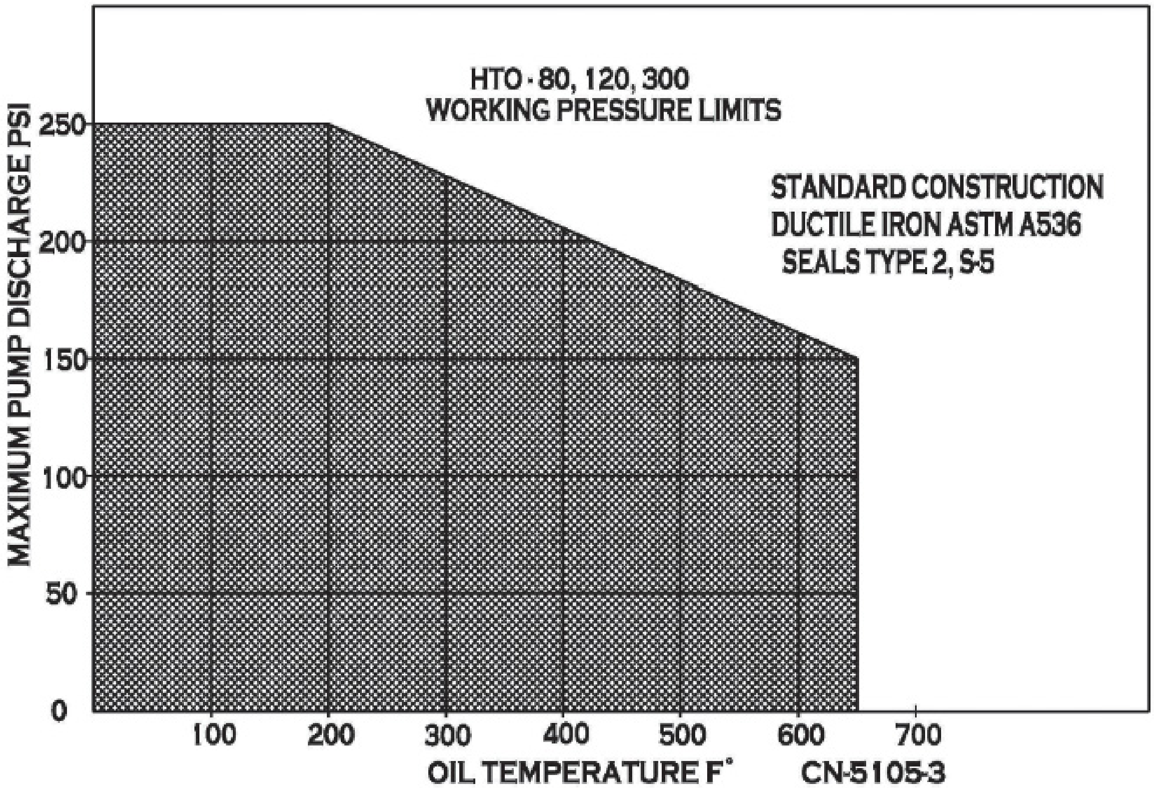
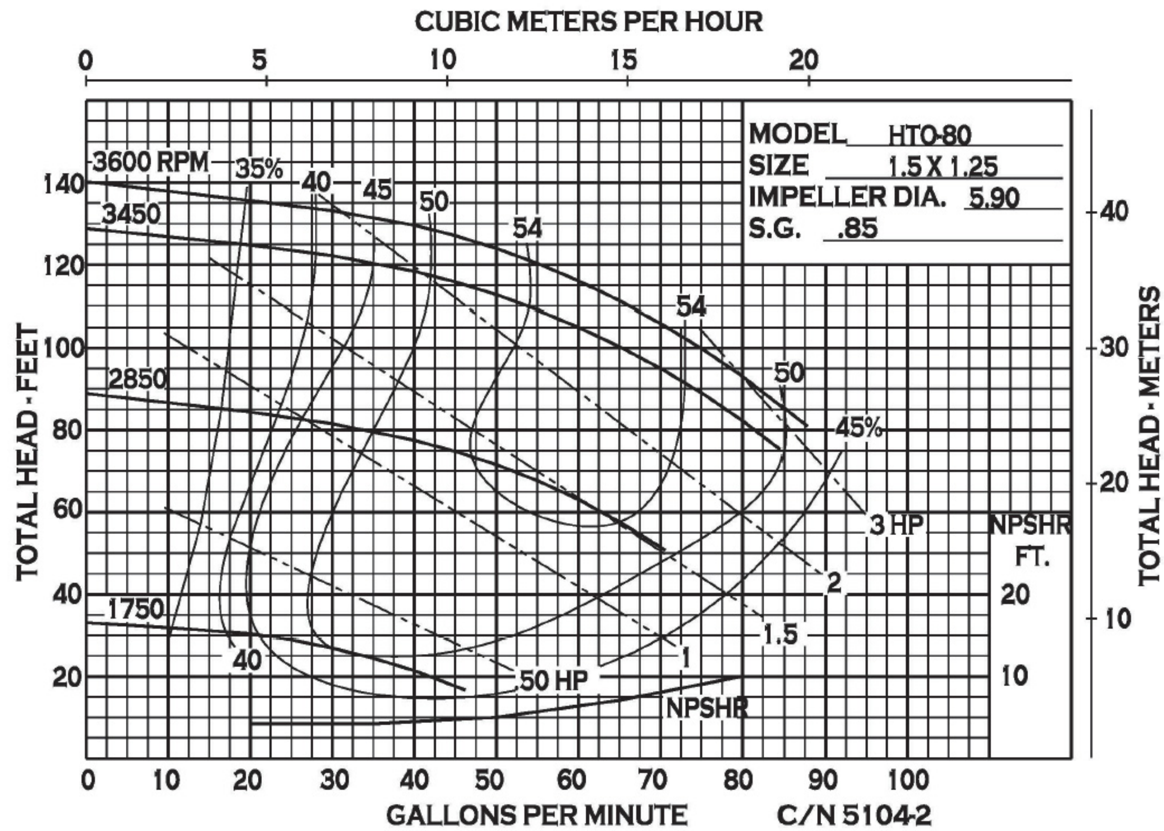
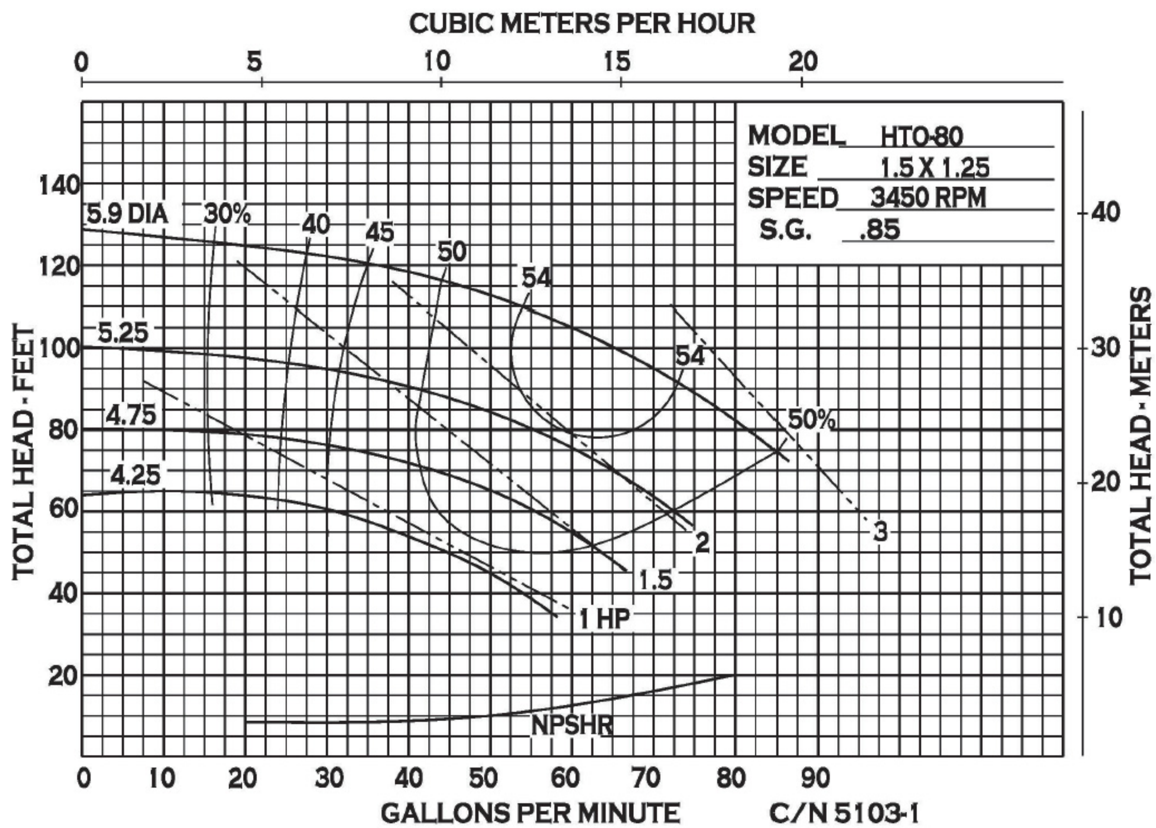

HTO - 80, 120, 300
WORKING PRESSURE LIMITS
STANDARD CONSTRUCTION
DUCTILE IRON ASTM A536
SEALS TYPE 2, S-5
MAXIMUM PUMP DISCHARGE PSI
250
200
150
100
50
0
100
200
300
400
500
600
700
OIL TEMPERATURE F°
CN-5105-3

HTO™ 80



CUBIC METERS PER HOUR
0
5
10
15
20
MODEL HTO-80
SIZE 1.5 X 1.25
IMPELLER DIA. 5.90
S.G. .85
3600 RPM
3450
2850
1750
35%
40
45
50
54
54
50
45%
40
3 HP
2
1.5
1
.50 HP
NPSHR
NPSHR FT.
20
10
TOTAL HEAD - FEET
140
120
100
80
60
40
20
TOTAL HEAD - METERS
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
GALLONS PER MINUTE
C/N 5104-2

HTO™ 80


CUBIC METERS PER HOUR
0
5
10
15
20
MODEL HTO-80
SIZE 1.5 X 1.25
SPEED 3450 RPM
S.G. .85
140
120
100
80
60
40
20
5.9 DIA
30%
40
45
50
54
54
50%
5.25
4.75
4.25
2
3
1.5
1 HP
NPSHR
TOTAL HEAD - FEET
TOTAL HEAD - METERS
40
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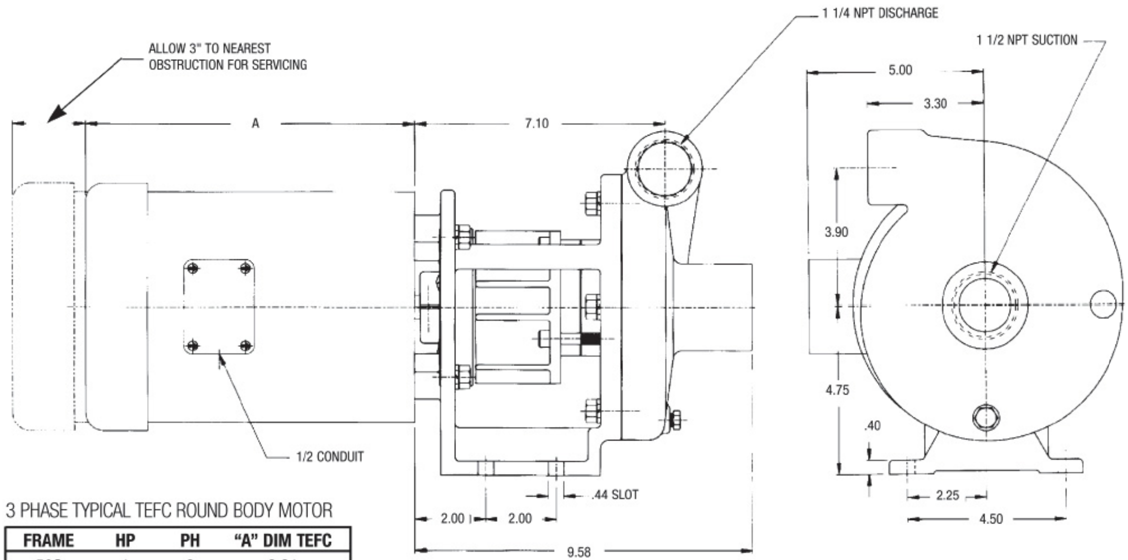
C/N 5103-1

HTO™ 80

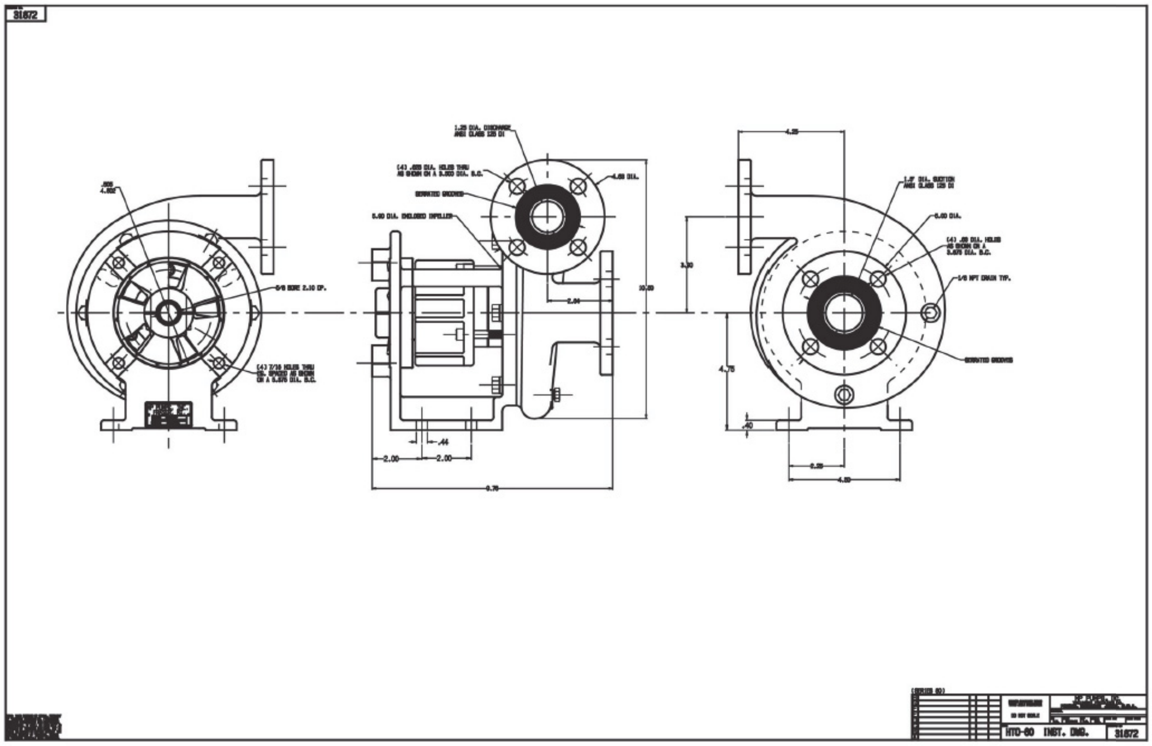


3 PHASE TYPICAL TEFC ROUND BODY MOTOR

FRAME	HP	PH	"A" DIM TEFC
56C	1	3	9.31
56C	1.5	3	9.94
56C	2	3	11.25
56C	3	3	12.12

Pump dimensions certifiable for construction purposes.
Motor dimensions dependent upon motor manufacturer.

HTO™ 80



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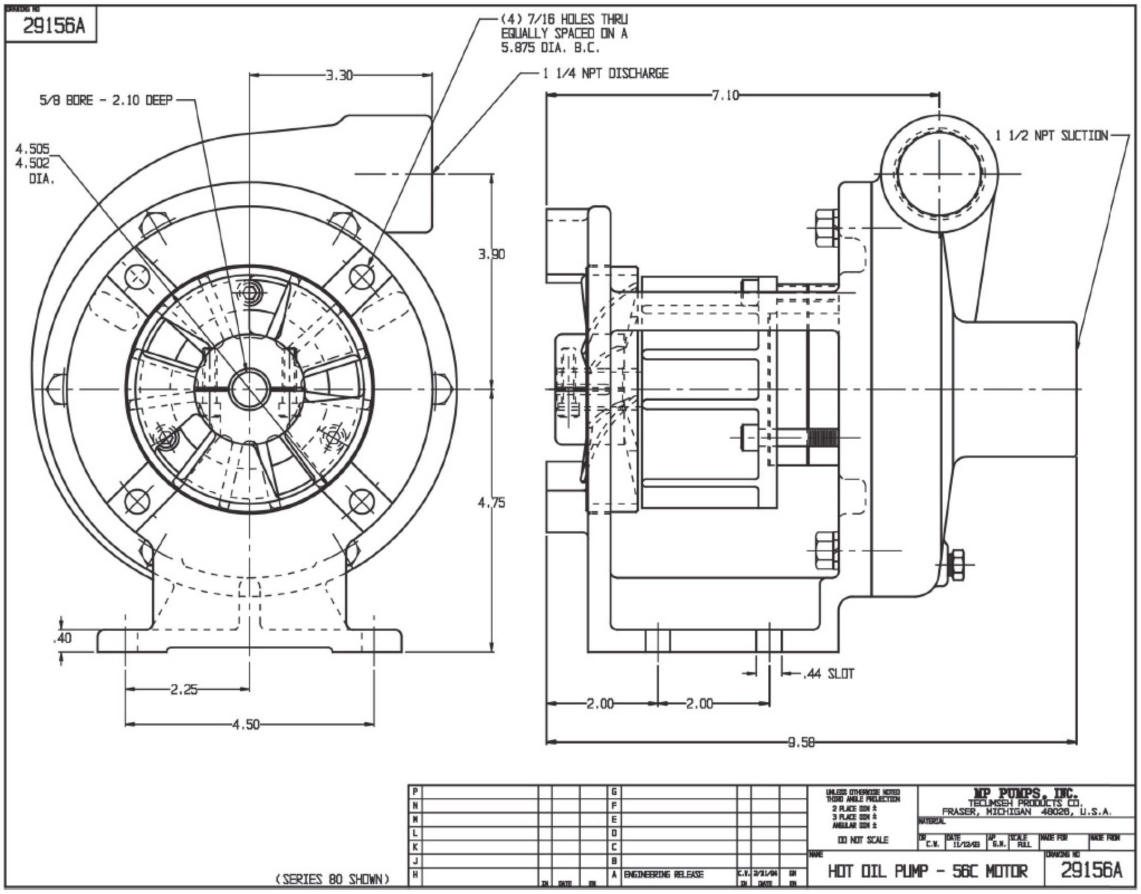
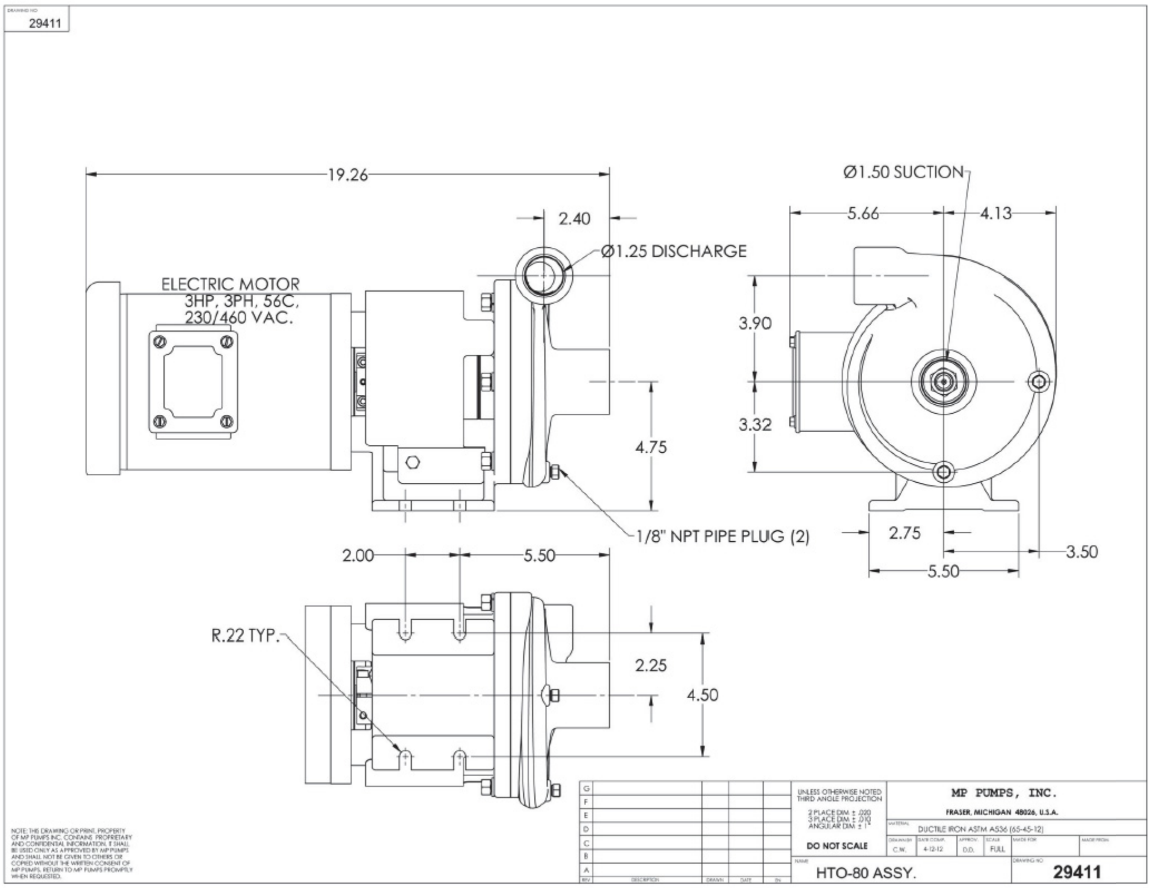
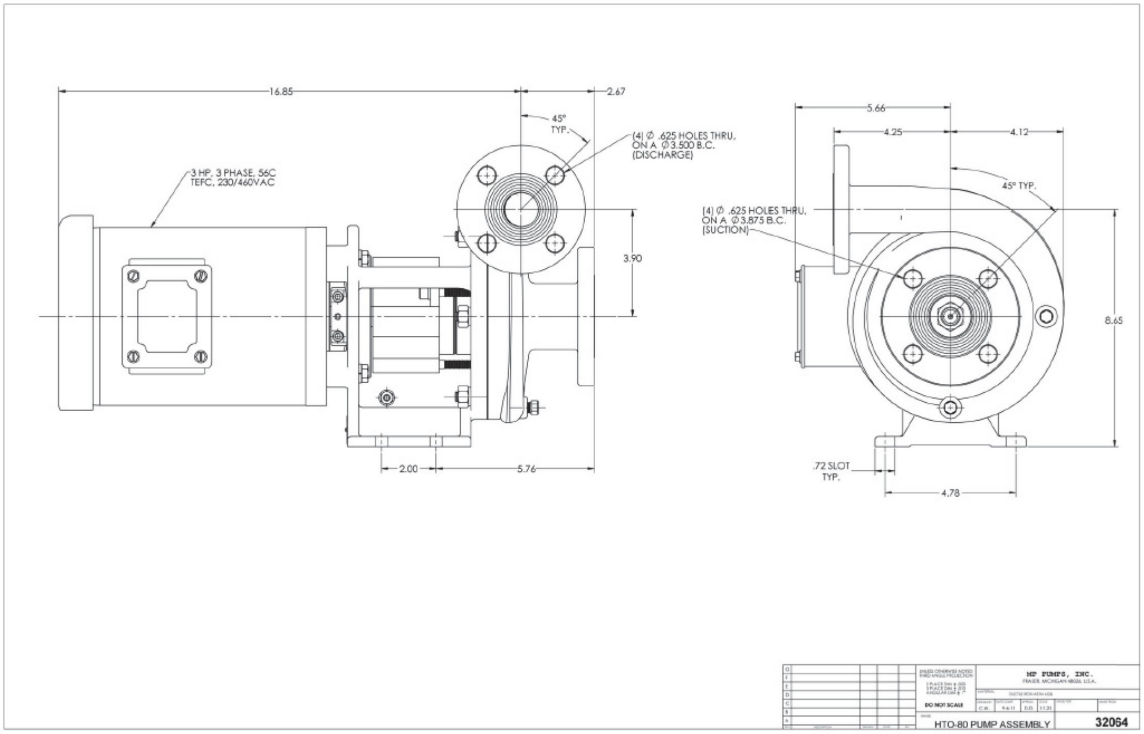

29156A
(4) 7/16 HOLES THRU EQUALLY SPACED ON A 5.875 DIA. B.C.
1 1/4 NPT DISCHARGE
3.30
5/8 BORE - 2.10 DEEP
4.505
4.502
DIA.
7.10
1 1/2 NPT SUCTION
3.90
4.75
.40
2.25
4.50
.44 SLOT
2.00
2.00
9.58
(SERIES 80 SHOWN)
ENGINEERING RELEASE
DO NOT SCALE
MP PUMPS, INC.
TECUMSEH PRODUCTS CO.
FRASER, MICHIGAN 48026, U.S.A.
HOT OIL PUMP - 56C MOTOR
29156A

HTO™ 80

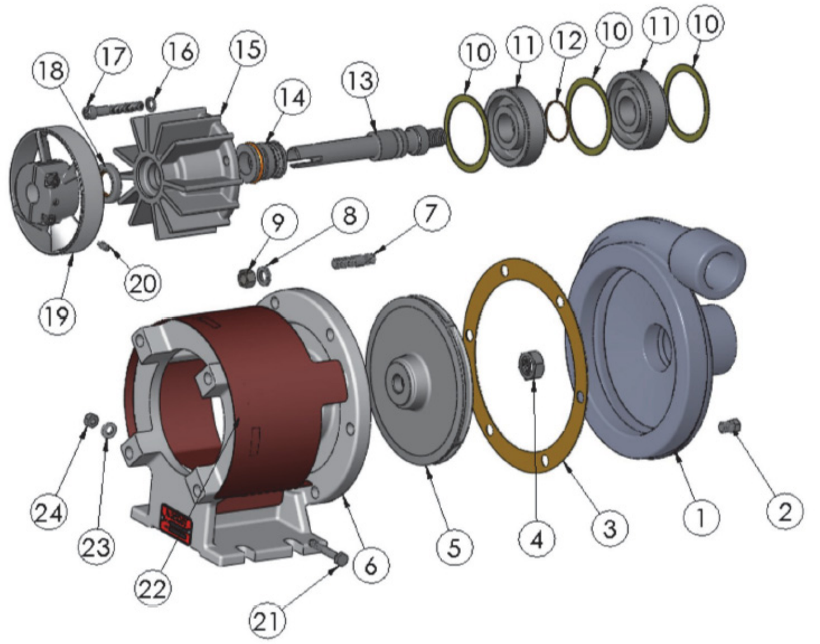

29411
19.26
2.40
Ø1.25 DISCHARGE
ELECTRIC MOTOR
3HP, 3PH, 56C,
230/460 VAC.
4.75
1/8" NPT PIPE PLUG (2)
Ø1.50 SUCTION
5.66
4.13
3.90
3.32
2.75
5.50
3.50
2.00
5.50
R.22 TYP.
2.25
4.50
DO NOT SCALE
MP PUMPS, INC.
FRASER, MICHIGAN 48026, U.S.A.
DUCTILE IRON ASTM A536 (65-45-12)
C.W.
4-12-12
D.D.
FULL
HTO-80 ASSY.
29411

HTO™ 80


16.85
2.67
45° TYP.
(4) Ø .625 HOLES THRU, ON A Ø 3.500 B.C. (DISCHARGE)
3 HP, 3 PHASE, 56C TEFC, 230/460VAC
3.90
2.00
5.76
5.66
4.25
4.12
45° TYP.
(4) Ø .625 HOLES THRU, ON A Ø 3.875 B.C. (SUCTION)
8.65
.72 SLOT TYP.
4.78
MP PUMPS, INC.
DO NOT SCALE
HTO-80 PUMP ASSEMBLY
32064

HTO™ 80

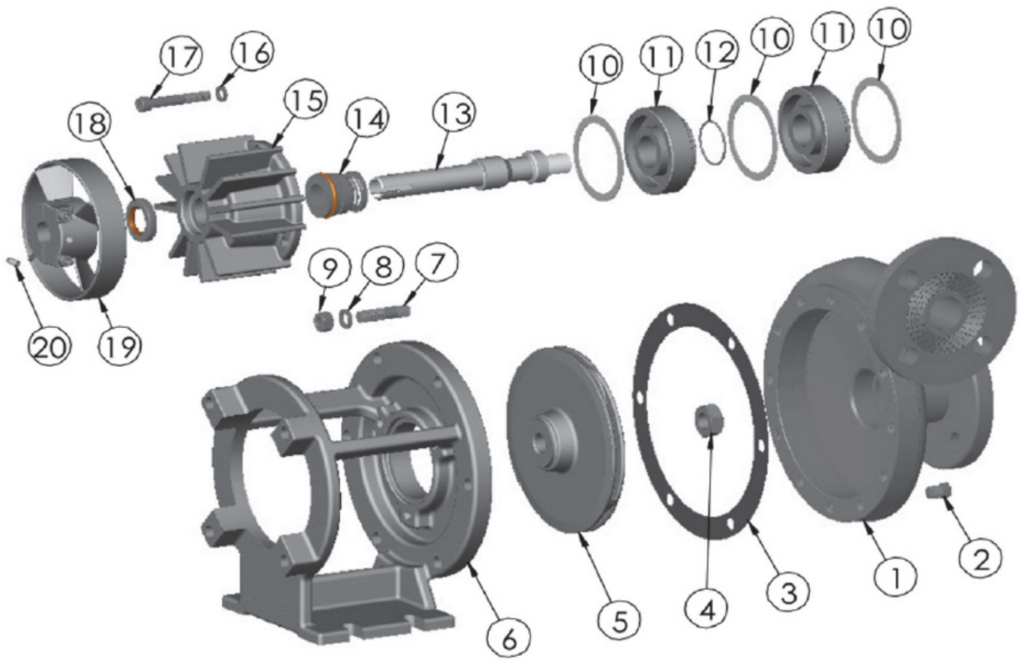
29156



ITEM	PART NO.	DESCRIPTION	QTY.
1	25666	HOUSING- DUCTILE IRON	1
2	21585	PIPE PLUG- 1/8 NPT ZPS	2
* 3	31518	GASKET- HOUSING	1
4	22655	HEX JAM NUT ZPS - 5/8-18	1
5	25910	IMPELLER 5.90 DIA- STL.	1
6	29160	ADAPTOR- DUCTILE IRON	1
7	21261	STUD SS: 3/8-16 X 1.63"	6
8	21266	LOCKWASHER SS- 3/8"	6
9	21268	HEXNUT SS: 3/8-16	6
* 10	29165	GASKET- ISOLATOR	3
* 11	29158	ISOLATOR	2
* 12	29230	O-RING - VITON	1

ITEM	PART NO.	DESCRIPTION	QTY.
13	29166	DRIVE SLEEVE S.S. - 56C	1
* 14	29168	SEAL ASSY - 3/4 T-21 CAR/SIC	1
15	29162	SEAL HOUSING D - HTO80	1
16	29765	WASHER FLAT STL	3
17	29178	CAPSCREW STL: 5/16-18 X 2"	3
* 18	29167	LIP SEAL- VITON	1
19	29164	FAN CLAMP- DUCTILE IRON	1
20	33417	SET SCREW STL: 1/4-28	1
21	33810	CAPSCREW ZPS - 5/16-18 X 1.75	1
22	33273	SHIELD ZPS - HTO80 & 120	1
23	27261	WASHER STL - 7.2MM	1
24	21241	HEXNUT S.S. - 1/4-20	1

HTO™ 80



ITEM	PART NO.	DESCRIPTION	QTY.
1	31871	HOUSING- DUCTILE IRON	1
2	21585	PIPE PLUG- 1/8 NPT ZPS	2
3	31518	GASKET- HOUSING	1
4	22655	HEX JAM NUT: 5/8-18	1
5	25910	IMPELLER 5.90 DIA- DUCTILE IRON	1
6	29160	ADAPTOR- DUCTILE IRON	1
7	21261	STUD SS: 3/8-16 X 1.63"	6
8	21266	LOCKWASHER SS- 3/8"	6
9	21268	HEXNUT SS: 3/8-16	6
10	29165	GASKET- ISOLATOR	3

ITEM	PART NO.	DESCRIPTION	QTY.
11	29158	ISOLATOR	2
12	29230	O-RING: VITON	1
13	29166	DRIVE SLEEVE: 56C	1
14	29168	SEAL ASSEMBLY	1
15	29162	SEAL HOUSING- DUCTILE IRON	1
16	29765	WASHER STL	3
17	29178	CAPSCREW STL: 5/16-18	3
18	29167	LIP SEAL- VITON	1
19	29164	FAN CLAMP- DUCTILE IRON	1
20	33417	SET SCREW STL: 1/4-28	1

Potential Thermocline Tank Dimensions

Table 3: Potential Thermocline Tank Heights

Thermocline Tank Dimensions					
NPS [in]	*Schedule*				
36	10	STD	20	30	40
D_o [in]	36	36	36	36	36
t [in]	0.312	0.375	0.50	0.625	0.75
D_i [in]	35.38	35.25	35.00	34.75	34.50
Area [in^2]	982.90	975.91	962.11	948.42	934.82
Distribution Plate Distance [in]	16.61	16.73	16.97	17.21	17.46
Total Height [in]	**166.08**	**167.27**	**169.67**	**172.12**	**174.62**

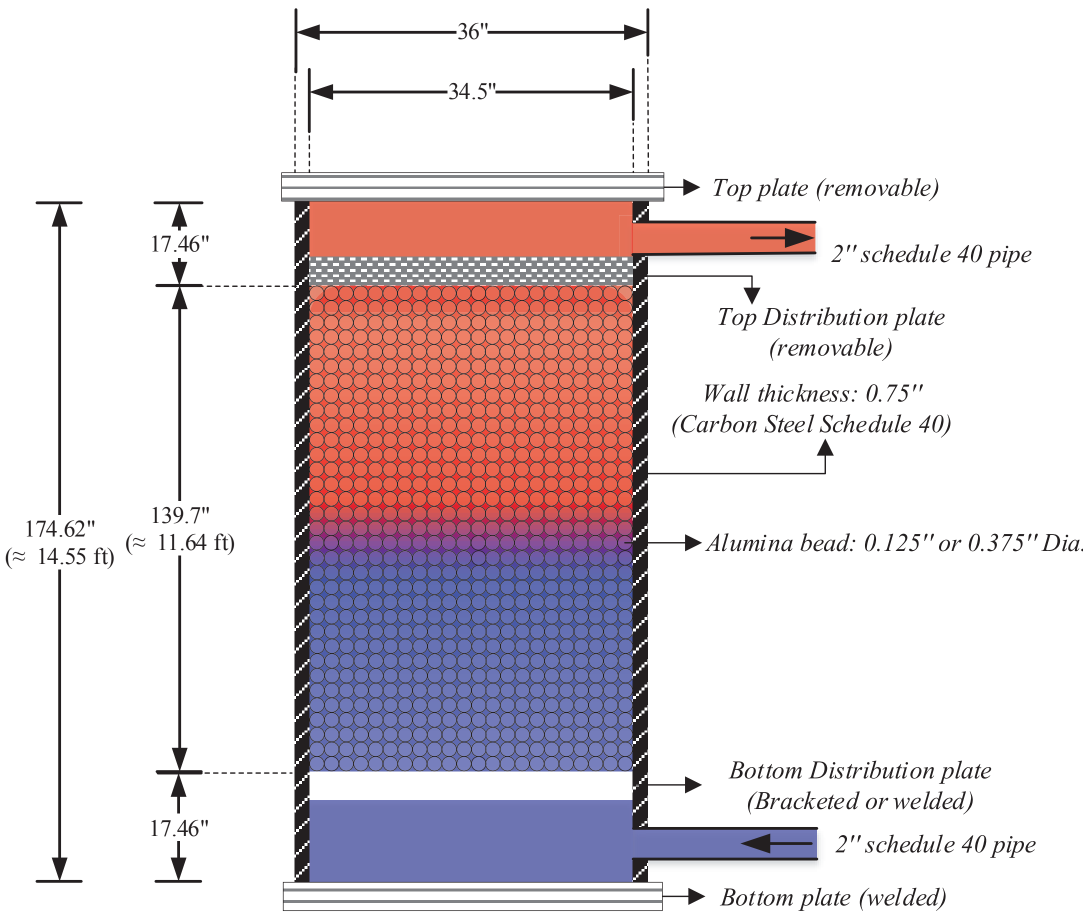


Figure 5: Potential Thermocline Tank Dimensions

Potential Storage Tank Dimensions

Table 4: Potential Storage Tanks Heights

Storage Tank Dimension					
NPS [in]	*Schedule*				
36	10	STD	20	30	40
D_o [in]	36	36	36	36	36
t [in]	0.312	0.375	0.500	0.625	0.750
D_i [in]	35.38	35.25	35.00	34.75	34.50
Area [in^2]	982.90	975.91	962.11	948.42	934.82
Tank Vol [gal]	500				
Volume [m^3]	1.89				
Height [in]	**117.51**	**118.35**	**120.05**	**121.78**	**123.55**

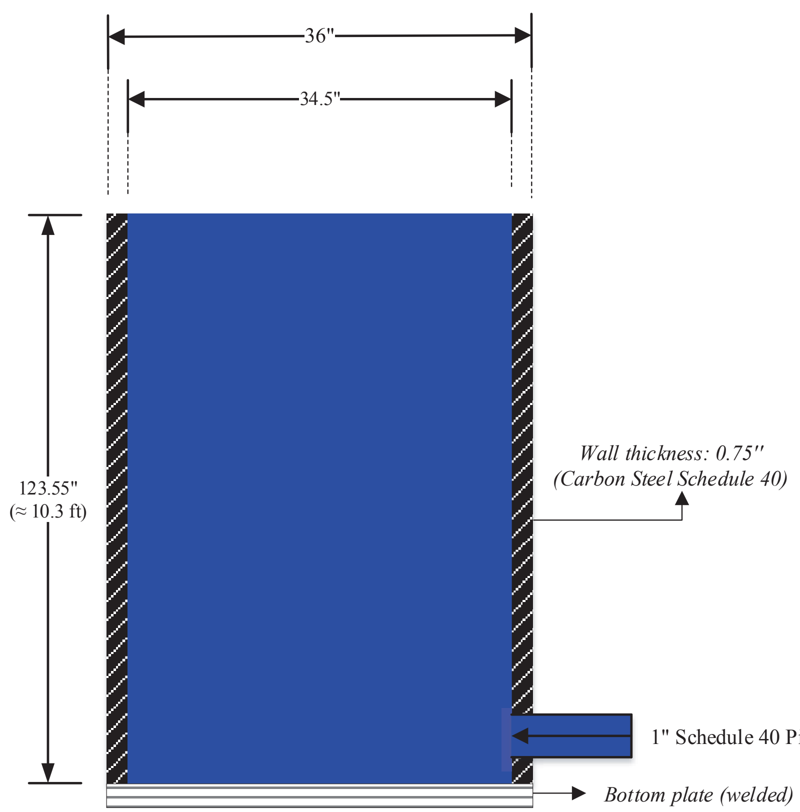
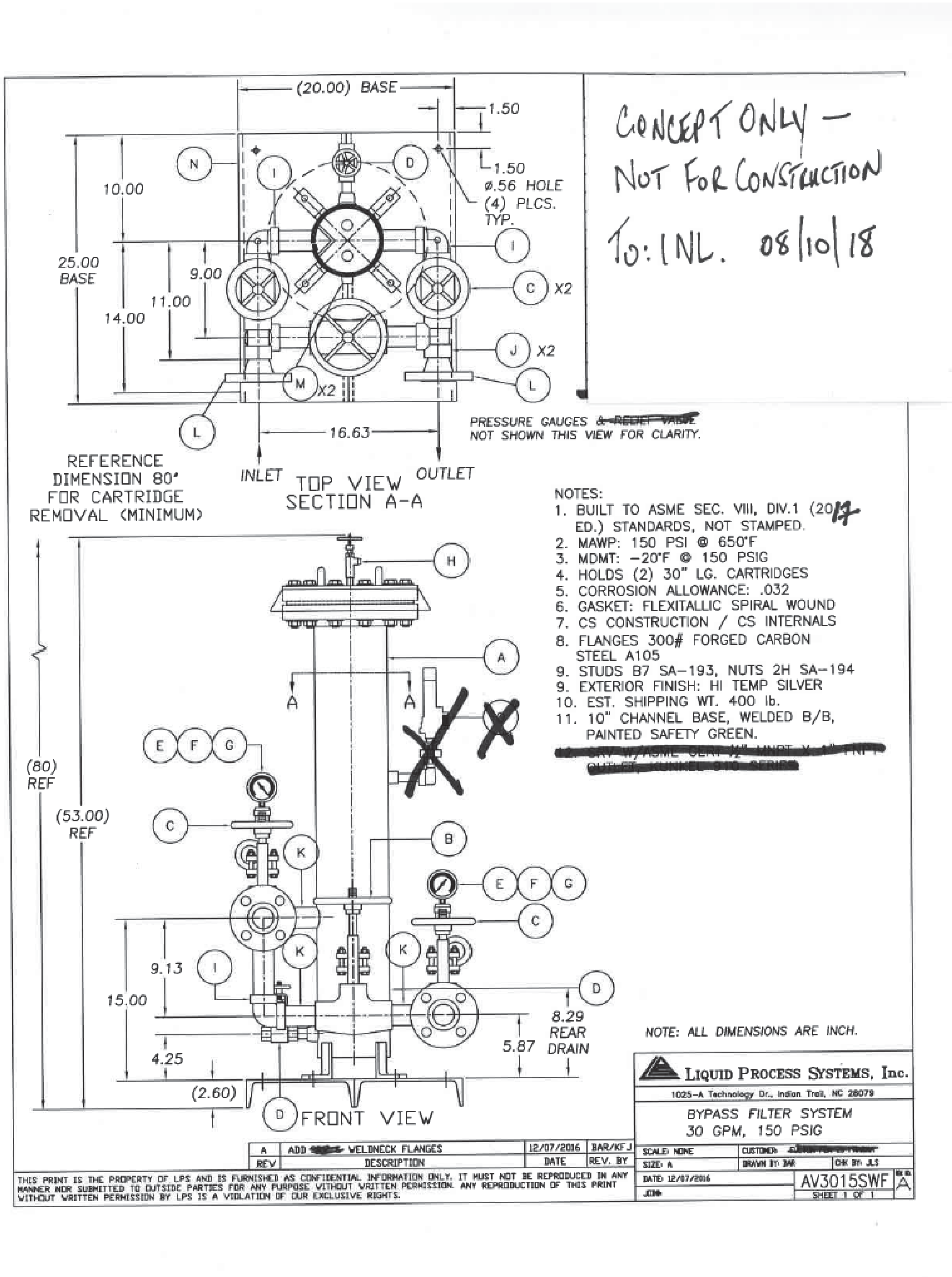


Figure 6: Potential Storage Tanks Dimensions

Potential Filtration System



Appendix B
Instrumentation Specifications

Table 5: Preliminary Instrumentation Specifications

Manufacturer	Part Name	Part Description	Model Number	Operating Range	Electrical Requirement
Thermocouples					
Omega	Type K Thermocouples	1/8" Sheath Diameter, Grounded, 12" Length	KQSS-18G-12	-270 to 1372C	Powered by NI Module
				Tolerance value 2.2C or 0.75% (0 to 1250C)	
				Connector Body Rated to 180°C (356°F)	
Omega	Standard Mating Connector	-	OSTW-K-F	Connector	
Omega	Cable Clamp Standard Connector	-	PCLM	Cable clamp	
Pressure Meters					
Differential Pressure Transmitter					
Omega	Wet/Wet Differential Pressure Transducers	High Accuracy Wet/Wet Differential Pressure Transmitter	PX81D0-100DI	0 to 100 psi difference	10 to 40 VDC
				-46 to 121C	
				±0.25% of span	
				4 to 20 mA Output	
				1/4-18 FNPT Connection	
Gauge Pressure Transmitter					
Omega	High-Performance Thin-Film Transmitter	Pressure Transducer	PX5500C1-050GI	0 to 50 psig	10 to 40 VDC
				-40 to 85C	
				±0.1% of full span	
				4 to 20 mA Output	
				1/4-18 FNPT Connection	

Manufacturer	Part Name	Part Description	Model Number	Operating Range	Electrical Requirement
Level Differential Pressure Transmitter					
Omega	Wet/Wet Differential Pressure Transducers	High Accuracy Wet/Wet Differential Pressure Transmitter	PX81D0-100DI	0 to 100 psi difference	10 to 40 VDC
				-46 to 121C	
				±0.25% of span	
				4 to 20 mA Output	
				1/4-18 FNPT Connection	
Flow Meter					
GE	Panaflow MV80 Meter	Volume Flow Vortex Meter	MV80-V-08-C-300-L-DD-DC2-1AHL-HT-PE-CC-NC	2.2 to 67 gpm	12-36 VDC
				Up to 750F (400C)	
				±0.7% of rate	
				Max 300 psia	
				Turn-down up to 100:1	
				4-20 mA output HART Protocol	
				1" 150lb or 300lb Flange Connection	