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Heat Exchanger Design

Coursework: Numerical Simulation with HTRI Software and Thermal Design with Manual Calculation for Heat Exchanger Design (25%)

Course Code: B51GU | Professor: Dr. Saqaff Alkaff
Course Title: Heat Transfer and Heat Exchangers

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1. NUMERICAL SIMULATION USING HTRI

1.1. Shell and Tube Heat Exchanger

The optimum design of a shell and tube heat exchanger involves the consideration of a number of interacting design parameters as summarized below;

Process:

1. Process fluid assignments to shell side or tube side.
2. Selection of stream temperature specifications.
3. Setting of pressure drop design limits for shell side and tube side.
4. Setting the velocity limits for shell side and tube side.
5. Selecting the fouling coefficients for shell side and tube side (and the heat transfer models).

Mechanical:

1. Selection of heat exchanger TEMA layout and number of passes.
2. Specification of tube parameters; material, layout, size and pitch.
3. Setting the tube length upper and lower design limits.
4. Specification of shell side parameters; materials, baffle spacing, baffle cuts and clearances.
5. Setting the upper and lower design limits (as design constraints) on the shell diameter, baffle cut and baffle spacing.

Optimal thermal design can be achieved using HTRI, however we cannot reply on the software alone. The software convergence and optimization routines which involve multiple iterations (of various combinations, steps and step sizes) will not necessarily achieve a practical and economical design unless we as the designer force the parameters in an intuitive manner.

Further Improvements for the STHE Design:

1. The design (of the selected STHE and the 4 alternatives) should be checked by running the model in the rating mode.
2. The actual pressure drop (DP) can be further optimized to be within 1 kPa of the allowable pressure drop (DP) to ensure that there is no energy wastage if it is in a specified plant. Otherwise, the lower DP can be kept as it will give lower OPEX (operating expenditure).

1.1.1. Simulation Process

Table 1 Shell and Tube Heat Exchanger Independent Variables

Shell and Tube HEX Iteration and Manual Variables	
No.	**Independent Variables**
1	Tube Length
2	Layout Angle
3	TEMA Specification
4	Tube OD (outer diameter)

5	Tube Passes
6	Channel Spacing
7	Tube ID (inner diameter)
8	Tube Thickness
9	Tube Count
10	Baffle Spacing

1. For STHE start with the required inputs and run the simulation until optimal variables are met.
2. Under the Design section, select Tube Pass, Tube Length and Tube Diameter for Iteration Calculations. It will be approximately 500 iterations depending on the steps and step size for each.
3. When this does not yield the optimal results, take the best result and further optimize it manually by adjusting the TEMA Specification.

1.1.2. Reported Summary of Simulation Results

Table 2 HTRI Simulation Results Report Summary of 5 STHEs

Parameter	**Selected STHE Design**	**Alternative STHE 1**	**Alternative STHE 2**	**Alternative STHE 3**	**Alternative STHE 4**
Overdesign %	0.89	6.5	0.84	4.1	1.48
Shell Side DP (kPa)	67.047	74.784	67.046	49.747	70.14
Tube Side DP (kPa)	57.937	58.824	57.93	51.757	30.491
Effective Area (m^2)	155.96	224.68	155.96	166.28	224.73
TEMA Type	BFM	AES	BFM	BFM	AES
Duty (MW)	4.3228	4.3228	4.3228	4.3228	4.3228
Actual U (W/m^2K)	695.83	578.33	695.5	674.22	565.9
Required U (W/m^2K)	689.72	543.06	689.72	647.69	557.64
Shell Orientation	Horizontal	Horizontal	Vertical	Horizontal	Horizontal
Tube Pass	4	5	4	4	4
Baffles	Single-Segmental	Single-Segmental	Single-Segmental	Double-Segmental	Single-Segmental

1.1.3. Selected Shell and Tube Heat Exchanger Design[1]

1.1.3.1. Report Summary and Justification for STHE Design Selection

The **selected STHE (Horizontal 4-Pass BFM Single-Segmental Baffles)** has the optimal values for overdesign %, shell-side and tube-side pressure drops (close to the allowable DP), a low effective area and a horizontal shell orientation.

[1] See Appendix 4.1 for Simulation Data Sheets

The heat exchanger duty was the same for all 5 designs, however the overall performance in terms of overall heat transfer coefficient (U) varied in both the actual value and required value, with the former being higher than the latter in all cases.
For the TEMA Specification;[2]

AES TEMA Rating refers to;
1. A: Front End Stationary Head Type is selected as Channel and Removable Cover
2. E: Shell Type is selected as One Pass Shell
3. S: Rear End Head Type is selected as Floating Head with Basking Device

BFM TEMA Rating refers to;
4. B: Front End Stationary Head Type is selected as Bonnet (Integral Cover)
5. F: Shell Type is selected as Two Pass Shell with Longitudinal Baffle
6. M: Rear End Head Type is selected as Fixed Tube Sheet Like "B" Stationary Head

The final selection was between the Horizontal and Vertical Shells with the lowest overdesign % (to ensure the capital expenditure, i.e. CAPEX is a minimum). Horizontal was selected as it provides easier installation and maintenance when compared to a Vertical STHE. The pressure drop of the selected STHE was close to the allowable DP ensuring that the operating expenditure (OPEX) will not be affected.

The Horizontal Multipass Flow (4-Pass) TEMA BFM Shell with Single-Segmental Baffle STHE is the final selection because it's horizontal orientation renders it easier to install and maintain because tube removal and cleaning is easier for a horizontal installation when compared to a vertical installation. Furthermore, vertical installations are only necessary when compactness and space is a critical issue.

This is a single shell heat exchanger required to meet a duty that involves propylene glycol and water as fluids. The temperature range is from 110 to 30 (falling under low temperature applications) and the pressure range is from 1000 to 420 kPa (falling under low pressure applications). It is assumed that this heat exchanger will fall under the TEMA C category for commercial and general applications.

1.1.4. Alternatives Considered

The following alternative designs were proposed;

1. **<u>Example 1:</u> Increasing the Number of Tube Passes from 4-Pass to 5-Pass**
2. **<u>Example 2:</u> Using a Vertical Shell instead of a Horizontal Shell**
3. **<u>Example 3:</u> Applying Double-Segmental Baffles Instead of Single-Segmental Baffles**
4. **<u>Example 4:</u> Using AES TEMA Specifications Instead of BFM.**

[2] See Appendix 4.6 for TEMA Specification

1.1.5. Example 1: Increasing Number of Tube Passes from 4-Pass to 5-Pass[3]

1.1.6. Example 2: Using a Vertical Shell instead of Horizontal Shell[4]

1.1.7. Example 3: Applying Double-Segmental Baffles instead of Single-Segmental Baffles[5]

1.1.8. Example 4: Selecting a TEMA Specification of AES instead of BFM[6]

1.2. Plate and Frame Heat Exchanger

1.2.1. Simulation Process

Table 3 Plate and Frame Independent Variables

Plate and Frame HEX Iteration and Manual Variables	
No.	**Independent Variables**
1	Manufacturer
2	Model
3	Chevron Angle
4	Channel Spacing
5	Port Diameter
6	Plate Thickness
7	Channels Per Pass

1. Hisaka Model LX-22 is used to meet the allowable pressure drop under the Rating choice.
2. Case mode is switched to Rating instead of Grid Design.
3. Under the Design section, Channel Spacing and Plate Types are selected as iteration variables.
4. Selection of all Alfa-Laval manufacturer models.
5. Channel Spacing Range is set from 1 to 120 (minimum and maximum limits respectively).
6. Iterations are run, when the design is unsatisfactory the Manufacturers are dropped down to 6 selections (Alfa-Laval, APV, Hisaka, and Lanpec with different models having different Chevron angles in order to influence the DP without affecting the over design unduly).
7. When the design is still unsatisfactory in terms of the pressure drop (DP), manual changes by selecting each independent variable in turn and running its variations are done.
8. All manufacturers and all their respective models with variations in Chevron angle, Port Diameter, Channel Spacing etc. (total of approximately 1750 iteration combinations) are run until the best combination is provided.

1.2.2. Plate and Frame Heat Exchanger Design

1.2.2.1. Report Summary and Justification of PFHE Design Simulation Results

[3] See Appendix 4.2 for Simulation Data Sheets
[4] See Appendix 4.3 for Simulation Data Sheets
[5] See Appendix 4.4 for Simulation Data Sheets
[6] See Appendix 4.5 for Simulation Data Sheets

Parameter	PFHE Design
Overdesign %	1.73
Shell Side DP (kPa)	79.499
Tube Side DP (kPa)	20.139
Effective Area (m2)	75.316
Duty (MW)	4.323
Actual U (W/m^2K**)**	1384.191
Required U (W/m^2K**)**	1360.688
Flow	Counter-Current
Pass	Single-Pass (1)

The actual pressure drop (DP) stayed at 20.139 kPa and despite numerous iterations this could not be rectified to the required half of the allowed pressure drop or as close to the allowed DP (60 kPa).

Fouling factor of the PFHE has to be $1/10^{th}$ the value of the STHE as recommended by API 66. This has been rectified by the software and manual changes.

Justification of Chosen Design for PFHE:

Major constraint for PFHE is that the effective area should be lower than the STHE.

With regards to the low actual DP (given that the allowable DP is not required in the downstream design);

1. Diameters of the piping and tubing in the exchanger and leading up to the inlet HEX are adequate, that is why the DP is low.
2. Turbulent flow is avoided at the inlet of HEX to minimize DP.
3. The inlet device is efficient without sharp bends therefore DP is reduced.
4. For high DP or excessive DP in HEX, the fluid will not have enough energy at the outlet of the HEX therefore a pump needs to installed or high pressure inlet pumping will be required.
5. High DP is not economical due to energy loss.

Further Improvements for the STHE Design:

1. The issue of pressure drop can be considered in two scenarios; design of the plant where this PFHE is required is completed or not yet completed. If the upstream and downstream designs are completed, then the following arithmetic calculations can be considered;

Upstream Pressure (kPa)	Allowable DP (kPa)	Actual DP (kPa)	Expected Downstream Pressure (kPa)	Actual Downstream Pressure (kPa)
1000	60	20	940	980

2. If the downstream design has not yet started, then the lower DP is actually preferable because running costs will be lower due to pump inlet pressure (in the downstream section) being lower.
3. We do not need to have high inlet pressure at the tube side. The tub-side inlet pressure of the water will be lower.
4. If we can set the allowable DP lower, then there will be no need to create a higher pressure in the downstream pressure requirements.
5. Port Diameter can be increased to increase the DP (if it needs to be closer to the allowable DP).

1.3. Manipulation of Variables for STHE and PFHE:

There are two ways to manipulate variables on the HTRI software;

- **Manual Manipulation** of any of the Independent Variables that will affect the Corresponding Dependent Variable and bring it into Range.
- **Design Iterations** by Selection of the Variables, Steps and Step Size e.g. 435 iterations for STHE or 1750 iterations for PFHE. The software simulation will automatically set the optimal design within the given constraints.

No.	Dependent Variables	Requirement
1	Overdesign %	• Should be between 0% and 10%. • The industry standard is 5%-10% (realistic). • Although 15% is the maximum upper limit in the industry.
2	Pressure Drop DP, (kPa)	• DP Should be > half (1/2) of allowed DP • And realistically as close as possible • However ideally the lower the DP the better in theory (less than 1/2 of the allowed DP is a "too good to be true" scenario in the industry and usually indicates an error).
3	Area A, (m^2)	Should not be unreasonably large and PFHE A < STHE A

Dependent Variables Background:

Heat exchanger sizing deals with overdesign, pressure drop (DP) and area (A) as the primary design factors to take into consideration, especially for costing.

1. **Overdesign %**

- If we take x% overdesign means the calculation of the heat exchanger considering not the real area A, but with a new area A1 = A*(1+x).
- So if x = 20% then A1=1.2A
- Therefore, capacity won't be Q = U*A*LMTD but instead it will be Q1 = U*A1*LMTD, and therefore Q1 < Q?
- Overdesign or margin should not lead to a smaller HEX. The margin is added to compensate for fouling.
- STHE Sizing: Overdesign % = U-dirty/U-service. For fouling factors or dirt factors.

- Once the HEX is fouled it will take up the overdesign.
- Conventional values are 10% overdesign. We should try to keep it below 10%.
- Capital cost increases in direct proportion with increase in the overdesign %.
- However, designing a very low overdesign HEX may lead to high operation costs if the HEX cannot cope with the fouling lowering the performance, and effective heat exchange rate.

2. Pressure Drop DP

- Ideally, DP should be as low as possible, however in the industry the actual DP is usually more than half of the allowed DP (and more often than not, is almost the allowed DP value), therefore the design should consider this.
- The pressure drop DP should be close to the allowed DP (more than half of the allowed and as close as possible).
- DP is related to the operating costs, in that higher DP leads to higher operating costs as more pumping energy is required.
- However, if an allowable DP is set for the HEX design then it is optimal to
- Higher DP means smaller pipe size which gives a compact HEX design, good for CAPEX.
- However, if an allowable DP and fluid inlet pressure are given or fixed, allowable DP can be utilized as much as possible to enable the heat exchanger to be designed in lowest specification. Higher DP can be resulted from smaller equivalent diameter and port diameter which allows the increase of the fluid velocity and turbulence effect. Heat exchanger with smaller diameters represent smaller size, which is favorable to lower capital cost.
- If allowed DP is given and the plant is already designed, then downstream usually expects this DP, therefore there is energy wastage because there will be a pump to consider this pressure drop as it will already be considered.

3. Area A

- Too large an area is not feasible, it should be compact and economical. Therefore, care should be taken to optimize the design such that the area is as low as possible without jeopardizing other design factors.

1.4. Application Specific Merits Discussion of Designed Heat Exchangers

The Designed STHE and PFHE are compared with regards to the parameters given below;

Parameter	**Plate and Frame Heat Exchanger**	**Shell and Tube Heat Exchanger**
Compactness	PFHE is smaller and therefore more compact.	STHE has a larger area and is not as compact as the PFHE. It requires more space.

Cost (CAPEX and OPEX)[7]	It is cheaper in terms of the CAPEX.	It is generally less expensive in terms of OPEX.
Ease of Maintenance	It has a relatively simple design. It provides for easier maintenance.	It has a variable design. It allows for design flexibility. Cleaning and maintenance is difficult since enough clearance at one end is required to remove the bundle.
Operating Temperature and Pressure Range	It is better for lower ranges of T and P.	It can be used in systems with higher operating temperatures and pressures.
Allowable Pressure Drop DP Shell-Side: 80 kPa Tube-Side: 60 kPa	Shell-Side DP = 79.499 kPa Tube-Side DP = 20.139 kPa It has a very low DP on the tube-side, which will reduce water inlet pumping pressure (but only if the downstream design is not yet fixed).	It has a lower pressure drop on the shell-side and a higher pressure drop on the tube-side. If the downstream design is fixed, then the STHE is preferable since it is closer to the allowable DP. Shell-Side DP = 67.047 kPa Tube-Side DP = 57.937 kPa
Leakages	PFHE has a more inflexible design and therefore leaks cannot be easily located and rectified.	Due to the inherent nature of STHE (especially the horizontal design selected), tube leaks can be easily located and plugged since pressure testing for the STHE is comparatively easier than for PFHE.
Heat Exchanger Performance	This PFHE has higher actual and required overall heat transfer coefficients (Actual U = 1384.191 W/m^2K and Required U = 1360.688 W/m^2K). This indicates a much better performance compared to the STHE. The convective and conductive heat transfer is superior for PFHE.	For the STHE the overall heat transfer coefficient of the selected design (highest amongst the 5 design cases) is much lower than that of the PFHE, nearly half (Actual U = 695.83 W/m^2K and Required U = 689.72 W/m^2K), indicating a lower performance. **The heat transfer efficiency of the STHE is lesser compared to the PFHE.**
Capacity	PFHE capacity can be increased by the simple addition of more plates.	STHE capacity cannot be increased.

[7] CAPEX = Capital Expenditure while OPEX = Operating Expenditure

2. THERMAL DESIGN USING MANUAL CALCULATIONS

d. Preliminary Analytical Design (Double Pipe Heat Exchanger)

Reference Calculation Examples 1, 2, 11, 12 and 16 are used from the Butterworth text. [See Reference 1]

Thermal Design Algorithm:

1. Creation of Excel Sheet and plugging in of all available data.
2. Obtainment and plugging in of the following properties of cooling water;[8]
   2.1. Specific Heat Capacity
   2.2. Viscosity
   2.3. Density
   2.4. Thermal Conductivity
3. Working out of the cooling water outlet temperature as per heat exchanger duty on hot side equaling the cold side.

Heat Exchanger Duty: $Q = mC_p\Delta T$

Also expressed as;

$Q = mc_p\Delta T = mc_p(T_h - T_c)$ where Q of hot side should theoretically be the same for the cold side.

Heat Exchange Rate on the Hot Side: $Q_H = m_h C_{p_h}(T_{h,in} - T_{h,out})$

Heat Exchange Rate on the Cold Side: $Q_C = m_c C_{p_c}(T_{c,out} - T_{c,in})$

Note: Temperature Difference is given as Positive Heat Flow (Hot to Cold).

4. Find the LMTD (logarithmic mean temperature difference) by assuming the **counter current flow** HEX type.

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Where, $\Delta T_1 = T_{h,in} - T_{c,out}$ and $\Delta T_2 = T_{h,out} - T_{c,in}$

5. Summarize the standard pipe sizes available for double pipe HEX from the question paper.
6. Work for the plain tube calculation first.[9]
   6.1. Find D_w and Y_w.

$$D_w = \frac{1}{2}(D_o + D_i)$$

$$\text{Wall thickness: } y_w = \frac{1}{2}(D_o - D_i)$$

   6.2. Get the reference value for carbon steel thermal conductivity, k .[10]
   6.3. Find the tube side and shell side heat transfer coefficient.[11]

---

[8] The Shock Absorber Handbook Appendix C: Properties of Water. (2007). [ebook] pp.1-2. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9780470516430.app3/pdf [Accessed 29 Nov. 2017].

[9] Follow example 11 in Butterworth. (Only for the first 3 pipes).

[10] Engineeringtoolbox.com. (2017). Thermal Conductivities of Heat Exchanger Materials. [online] Available at: https://www.engineeringtoolbox.com/heat-exchanger-material-thermal-conductivities-d_1488.html [Accessed 30 Nov. 2017].

[11] Refer to Example 1 for tube-side in Butterworth.

6.4. Find S, u, Re, Pr, E, St and alpha α. [12]

6.5. Find l, the hydraulic mean diameter using Table 1. Assume equilateral triangular array of tubes.

6.6. Find S, where $S = \left(\pi {D_i}^2\right) - \left(number\ of\ tubes\ \times \left(\pi {D_{o\ (tube)}}^2\right)\right)$

6.7. Find u, Re, Pr, E, St and α.

6.8. Refer back to example 11;

Adapting the overall heat transfer coefficient equation for conduction and convection;

$$\frac{1}{U} = \frac{1}{\alpha_o} + f_o\left(\frac{1}{\alpha_i} + f_i\right)\left(\frac{D_o}{D_i}\right) + \left(\frac{x}{k}\right)\left(\frac{D_o}{D_w}\right)$$

$$\frac{1}{U} = \frac{1}{\alpha_{shell}} + r_o + \left(\frac{1}{\alpha_{tube}} + r_i\right)\left(\frac{D_{o\ (tube)}}{D_{i\ (tube)}}\right) + \left(\frac{y_w}{k_{carbon\ steel}}\right)\left(\frac{D_{o\ (tube)}}{D_w}\right)$$

7. Fin Tube Calculation (for remaining 10 finned pipes);

7.1. Assume longitudinal extruded fin type.

7.2. Follow example 12

7.3. Find $\frac{A_O}{A_F} = \frac{\frac{\left(\pi\left(D_{i\ (shell)}\right)^2\right)}{4} - no.of\ tubes \times \left[\left(\frac{\pi\left(D_{o\ (tube)}\right)^2}{4}\right) + no.of\ tubes \times Fin\ Height \times Fin\ Thicnkess\right]}{\left(\frac{\pi\left(D_{i\ (shell)}\right)^2}{4}\right)}$

7.4. Assume Fin Thickness as 0.00254 as per example 5.

7.5. Assume Fin Effectiveness as q = 0.95.

7.6. Find α_F, using example 5.

7.6.1. Calculate $\frac{Face\ Flow\ Area}{Min.\ Flow\ Area} = \frac{Y - D_{o\ (tube)}}{Y}$

7.6.2. Plug in the RHS value into; $Flow\ Min. = \frac{Y - D_{o\ (tube)}}{Y} \times Mean\ Fluid\ Velocity\ (shell\ side)$

7.6.3. Find Re and Pr to find $Nu = 0.314 Re^{0.681} Pr^{0.33} \left(\frac{Y_F}{H_F}\right)^{0.2} \left(\frac{Y_F}{\delta_F}\right)^{0.1134}$

7.6.4. Assume Fin Thickness δ_F and Fin Pitch $Y_F = 3.81 \times 10^{-4} m$ as per example 5.

7.6.5. Find $\alpha_F = Nu \frac{k}{D_{o\ (tube)}}$

7.7. Back to example 12, $\frac{1}{\alpha_o} = \frac{1}{2} \times \frac{1}{\alpha_F} \times \frac{A_O}{A_F}$

7.8. Find $\frac{1}{U} = \left(\frac{1}{\alpha_o} + r_o\right) + \left(\frac{1}{\alpha_i} + r_i\right)\frac{D_o}{D_i} + \frac{Y_W}{k_w}\frac{D_o}{D_w}$

7.9. Find α_i : $Nu = 0.023 Re^{0.8} Pr^{0.4}$ (due to single phase convection region) $\alpha_i = Nu \frac{k}{d_{i\ (tube)}}$

7.10. Find $U\ and\ A$;

7.11. Compare A with 10 m length × surface/m given from the question.

7.11.1. If A is less than 10 m the HEX is acceptable.

7.11.2. The first two 8" pipes are suitable.

8. For the tube side pressure drop refer to example 16;

[12] Refer to Example 2 for shell side in Butterworth.

8.1. Find f and ΔP_{tube}, the Fanning friction factor and the pressure drop due to losses in bends equivalent to $0.5\rho V^2$

8.2. $Total\ \Delta P = \Delta P_{tube} + \Delta P_{loss} = \frac{2fL\rho u^2}{D_{i\,(tube)}} + 0.5\rho V^2$ (Minimum Pump Head Required)

9. Tube Side Pressure Drop

9.1. Find f using $\Delta P_{shell} = \frac{2fL\rho u^2}{D_{mean}}$ (Check with the allowable DP given as 120 kPa)

Table 4 Thermal Design Calculations for STHE

Shell and Tube Heat Exchanger Parameters	**Shell Side**	**Tube Side**	**Units**
Fluid	**Hydrocarbon Liquid**	**Water**	-
Flowrate	10.5	6.5	kg/s
Inlet Temperature	90	30	^oC
Outlet Temperature	40	75.73	^oC
Allowable DP	120	-	kPa
Inlet Pressure	500	1000	kPa
Fouling Factor	0.0005	0.00015	m^2K/W

Hydrocarbon Liquid	**Shell Side**	**Units**
Specific Heat Capacity	2.378	kJ/kg.K
Viscosity	0.0005	Ns/m^2
Thermal Conductivity	0.11	W/m.K
Prandtl No.	10.81	-
Density	784	kg/m^3

Water	**Tube Side**	**Units**
Specific Heat Capacity	4.2	kJ/kg.K
Viscosity	0.00089	Ns/m^2
Density	1000	kg/m^3
Thermal Conductivity	0.591	W/m.K
Fouling Resistance	0.0002	m^2K/W

Thermal Conductivity of Carbon Steel	45	W/m.K

$Q_{hydrocarbon} = m_{shell}c_{p,shell}\Delta T_{shell} = mc_p(T_{h,shell} - T_{c,shell})$	1248.45	kJ
$Q_{water} = m_{tube}c_{p,tube}\Delta T_{tube} = mc_p(T_{h,tube} - T_{c,tube})$	1248.45	kJ
$T_{h,tube} = T_{outlet}\ of\ Water$	75.73	^oC

Assume Counter Current Flow HEX

LMTD	**12.01**	**^oC**

Choices of 4, 6 and 8 inches (nominal diameter) shells (Standard Pressure)[13]

FINAL DESIGN:

Design Constraints:

1. Design Requirements (Table 3) including the given flowrates, inlet and outlet temperatures, inlet pressures and fouling factors for the shell side and tube side (outlet temperature and pressure drop were calculated for tube side).
2. Carbon Steel tubes with standard sizes available.
3. Pressure drop on the shell side should not exceed the maximum allowable DP.
4. Pressure drop on the tube side must be calculated such that a suitable pump may be incorporated.
5. Maximum length of the heat exchanger should not exceed 10 m.

Summary of Results and Selection:

1. The first two 8" pipes (indicated in yellow highlight) have the acceptable heat transfer area within the 10 m length limit. (10 m was selected as the pipe length since it is maximum allowed and cannot be exceeded).
2. Pressure Drop for the Water Side.
3. Allowed DP vs Actual DP for the Shell Side
4. Tube Side DP calculation considers the losses in bends.
5. The water outlet temperature (tube-side) is 75.73 ^{o}C.
6. LMTD is 12.01 ^{o}C
7. Both have similar shell-side pressure drops (at the operating cost level these pressure drops will not significantly affect energy consumption or operating costs therefore their minor variation is not considered).
8. The area (which directly influences the capital cost and compactness) is not significantly different and will only affect the one-time capital cost.
9. The deciding factor is tube-side pressure drop 0.57 bar and 0.54 bar, when taking into consideration industrial practice, the lower tube-side DP is preferable as it will directly impact operating costs for the HEX running life-time.
10. Higher DP requires a larger pump, so since the tube-side DP for this selection is slightly lower, we have to consider that and choose the lower tube-side DP option.
11. We are not given a fixed inlet therefore we select the design with the lower pressure drop (on tube-side).

[13] See Appendix 4.8

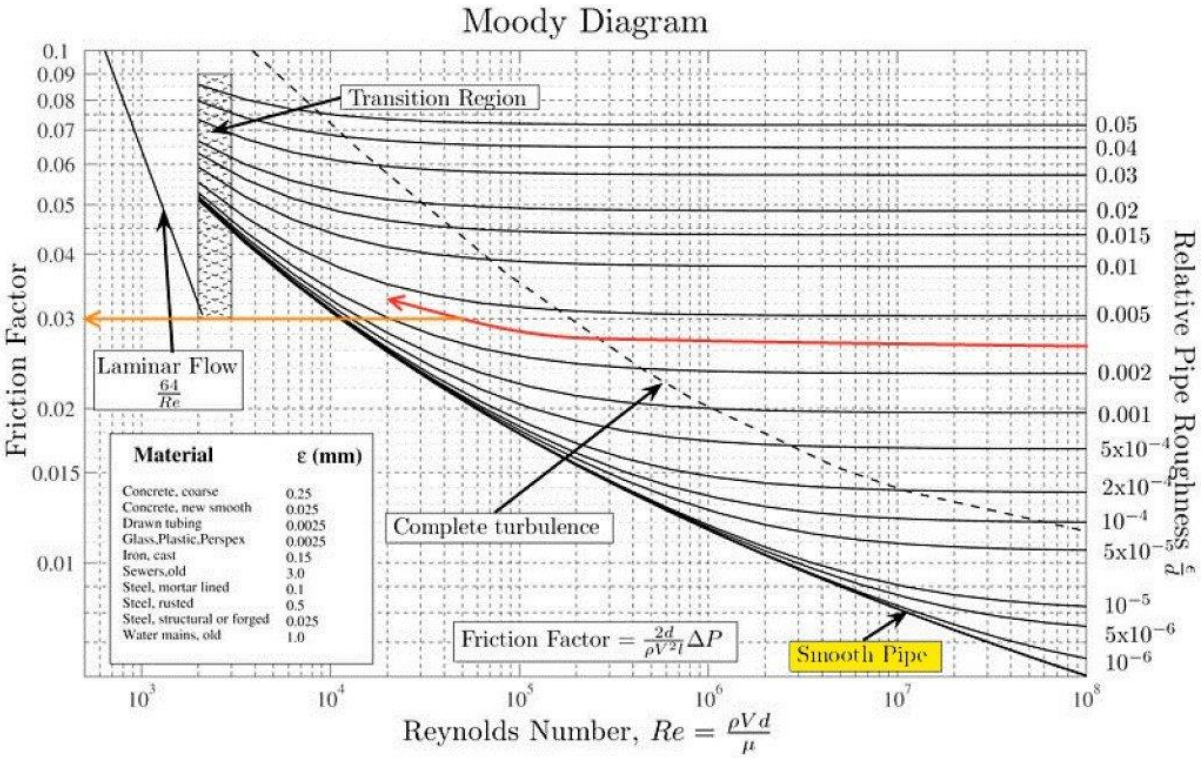
THERMAL DESIGN OF THE STHE:

Table 5 Thermal Design of the Shell and Tube Heat Exchanger

Nominal Pipe Diameter (inches)	**8”**
Required Heat Transfer Area with Fins	**115.97 m²**
Heat Transfer Area Available at 10m with Fins	**134.6 m²**
Tube-Side Pressure Drop	**54232 kPa**
Shell Side Pressure Drop	**1945 kPa**

Alternative Manual Calculation Method for Pressure Drop:

- Utilize the Moody Correlation equation and the Moody Diagram
- $f = 0.005496\left[1 + \left(2000\frac{\varepsilon}{d} + \frac{10^6}{Re}\right)^{0.33}\right]$
- This correlation is suitable for carbon steel applications in heat exchanger piping.



3. REFERENCES:

[1] Butterworth, D. (1978). Introduction to Heat Transfer. Engineering Design Guide No. 18. International Journal of Energy Research, [online] 2(4), pp.35-42. Available at: http://www.hts.org.uk/downloads/introductiontoheattransfer.pdf [Accessed 20 Nov. 2017].

[2] Thermopedia (1988). Figure 3. TEMA nomenclature. © 1988 by Tubulare Exchanger Manufacturers Association..[image]Available at: http://www.thermopedia.com/content/5542/1002SATHEFig3.gif [Accessed 28 Nov. 2017].

[3] Moody Diagram. (2017). [image] Available at: https://usercontent1.hubstatic.com/6837190_f1024.jpg [Accessed 28 Nov. 2017].

[4] The Shock Absorber Handbook Appendix C: Properties of Water. (2007). [ebook] pp.1-2. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9780470516430.app3/pdf [Accessed 29 Nov. 2017].

[5] Engineeringtoolbox.com. (2017). Thermal Conductivities of Heat Exchanger Materials. [online] Available at: https://www.engineeringtoolbox.com/heat-exchanger-material-thermal-conductivities-d_1488.html [Accessed 30 Nov. 2017].

4. APPENDICES:

4.1. SHELL AND TUBE SELECTED DESIGN:

4.1.1. STHE Output Summary:

Output Summary Page 1

Released to the following HTRI Member Company:
HWUM
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Xist E 7.2.1 28/11/2017 19:37 SN: 12902-2109343071 **SI Units**

Design - Horizontal Multipass Flow TEMA BFM Shell With Single-Segmental Baffles

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)	52.500		32.500	
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	110.00	65.00	30.00	61.48
Inlet P/Avg	(kPa)	500.00	466.48	1000.0	971.04
dP/Allow.	(kPa)	67.047	80.000	57.932	60.000
Fouling	(m2-K/W)		0.000400		0.000180

Exchanger Performance					
Shell h	(W/m2-K)	1708.8	Actual U	(W/m2-K)	695.83
Tube h	(W/m2-K)	7644.5	Required U	(W/m2-K)	689.72
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	4.3228
Cold regime	(--)	Sens. Liquid	Eff. area	(m2)	155.96
EMTD	(Deg C)	40.2	Overdesign	(%)	0.89

Shell Geometry			Baffle Geometry		
TEMA type	(--)	BFM	Baffle type		Single-Seg.
Shell ID	(mm)	660.40	Baffle cut	(Pct Dia.)	33.55
Series	(--)	1	Baffle orientation	(--)	Parallel
Parallel	(--)	1	Central spacing	(mm)	884.74
Orientation	(deg)	0.00	Crosspasses	(--)	8

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	205.00
Tube OD	(mm)	25.40	Shell outlet	(mm)	258.88
Length	(m)	7.31	Inlet height	(mm)	31.22
Pitch ratio	(--)	1.3333	Outlet height	(mm)	25.93
Layout	(deg)	30	Tube inlet	(mm)	154.05
Tubecount	(--)	270	Tube outlet	(mm)	154.05
Tube Pass	(--)	4			

Thermal Resistance, %		Velocities, m/s	Min	Max	Flow Fractions	
Shell	40.72				A	0.006
Tube	11.64	Tubeside	1.46	1.70	B	0.736
Fouling	43.85	Crossflow	0.53	0.66	C	0.166
Metal	3.79	Window	1.07	1.19	E	0.092
					F	0.000

4.1.2. STHE Final Results:

Final Results Page 5

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 19:37 SN: 12902-2109343071 **SI Units**

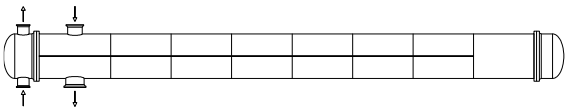
Design - Horizontal Multipass Flow TEMA BFM Shell With Single-Segmental Baffles

Process Data		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	65.00	30.00	61.48
Skin temperature, Min/Max	(Deg C)	46.16	92.51	33.93	66.72
Wall temperature, Min/Max	(Deg C)	39.02	77.45	38.04	75.39
Pressure, In/Average	(kPa)	500.00	466.48	1000.0	971.04
Pressure drop, Total/Allowed	(kPa)	67.047	80.000	57.932	60.000
Velocity, Mid/Max allow	(m/s)	0.65		1.47	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)		1708.8		7644.5
Heat transfer safety factor	(--)		1.0000		1.0000
Fouling resistance	(m2-K/W)		0.000400		0.000180

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	689.72	/	1239.2	/	695.83
Heat duty, Calculated/Specified	(MegaWatts)	4.3228	/			
Effective overall temperature difference	(Deg C)	40.2				
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	40.84	*	0.9954	*	0.9885

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	1444.7
Approximate tubeside	(L)	1003.3

Shell Construction Information

TEMA shell type	BFM		Shell ID	(mm)	660.40
Shells Series	1 Parallel	1	Total area	(m2)	157.60
Passes Shell	2 Tube	4	Eff. area	(m2/shell)	155.96
Shell orientation angle (deg)	0.00				
Impingement present	Rods		Impingement rod rows		2
Pairs seal strips	0		Passlane seal rods (mm)	0.000	No. 0
Shell expansion joint	No		Rear head support plate	No	
Weight estimation Wet/Dry/Bundle	7758.4	/ 5311.5 / 3702.4	(kg/shell)		

Baffle Information

Type	Parallel	Single-Seg.	Baffle cut (% dia)	33.55		
Crosspasses/shellpass		8	No.	(Pct Area)	(mm) to C.L	
Central spacing	(mm)	884.74	1	29.58	108.63	
Inlet/Outlet Spacing	(mm)	1045.6	2	0.00	0.00	
Turn Spacing	(mm)	884.74				
Baffle thickness	(mm)	12.70	Long. baffle length	(m)	6.35	
Insulated long baffle		No				
Use deresonating baffles		No				

Tube Information

Tube type		Plain	Tubecount per shell		270
Overall length	(m)	7.31	Pct tubes removed (both)		2.96
Effective length	(m)	7.239	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	76.20	Wall thickness	(mm)	2.769
Area ratio	(out/in)	1.2788	Pitch (mm) 33.867	Ratio	1.3333
Tube metal		Carbon steel	Tube pattern (deg)		30

4.1.3. STHE Program "Rating Data Sheet":

HTRI

HEAT EXCHANGER RATING DATA SHEET

Page 18
SI Units

Service of Unit				Item No.			
Type BFM		Orientation Horizontal		Connected In 1 Parallel	1 Series		
Surf/Unit (Gross/Eff) 157.60 / 155.96 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 157.60 / 155.96 m2			
PERFORMANCE OF ONE UNIT							
Fluid Allocation		Shell Side		Tube Side			
Fluid Name		Propylene Glycol		Water			
Fluid Quantity, Total	kg/s	52.500		32.500			
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00		
Liquid	wt%	100.00	100.00	100.00	100.00		
Temperature (In/Out)	C	110.00	65.00	30.00	61.48		
Density	kg/m3	987.64	1015.6	994.79	981.78		
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564		
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320		
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527		
Critical Pressure	kPa						
Inlet Pressure	kPa	500.00		1000.0			
Velocity	m/s		0.65		1.47		
Pressure Drop, Allow/Calc	kPa	80.000	67.047	60.000	57.932		
Average Film Coefficient	W/m2-K	1708.8		7644.5			
Fouling Resistance (min)	m2-K/W	0.000400		0.000180			
Heat Exchanged	4.3228 MegaWatts	MTD (Corrected)	40.2 C	Overdesign	0.89 %		
Transfer Rate, Service	689.72 W/m2-K	Calculated	695.83 W/m2-K	Clean	1239.2 W/m2-K		
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)			
		Shell Side	Tube Side				
Design Pressure	kPaG	517.11	1034.2				
Design Temperature	C	137.78	60.00				
No Passes per Shell		2	4				
Flow Direction		Downward	Upward				
Connections	In mm	1 @ 205.00	1 @ 154.05				
Size &	Out mm	1 @ 258.88	1 @ 154.05				
Rating	Liq. Out mm	@	1 @				
Tube No. 270.00	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm	Tube pattern 30		
Tube Type Plain		Material Carbon steel		Pairs seal strips	0		
Shell ID 660.40 mm		Kettle ID mm		Passlane Seal Rod No.	0		
Cross Baffle Type	Parallel Single-Seg.	%Cut (Diam) 33.55		Impingement Plate	Rods		
Spacing(c/c) 884.74 mm		Inlet 1045.6 mm		No. of Crosspasses	8		
Rho-V2-Inlet Nozzle 2561.5 kg/m-s2		Shell Entrance 0.00 kg/m-s2		Shell Exit 3330.5 kg/m-s2			
		Bundle Entrance 125.68 kg/m-s2		Bundle Exit 324.15 kg/m-s2			
Weight/Shell 5311.5 kg		Filled with Water 7758.4 kg		Bundle 3702.4 kg			
Notes:		Thermal Resistance, %		Velocities, m/s		Flow Fractions	
		Shell 40.72		Shellside 0.65		A 0.006	
		Tube 11.64		Tubeside 1.47		B 0.736	
		Fouling 43.85		Crossflow 0.71		C 0.166	
		Metal 3.79		Window 1.72		E 0.092	
						F 0.000	

4.1.4. STHE TEMA Data Sheet:

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HEAT EXCHANGER SPECIFICATION SHEET Page 19 **SI Units**

Job No. 1

Customer	Dr. Saqaff Alkaff	Reference No.	
Address	Heriot Watt University Malaysia	Proposal No.	
Plant Location	Putrajaya	Date 28/11/2017	Rev 3
Service of Unit		Item No.	
Size	660.4 x 7315 mm Type BFM Horizontal	Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff)	157.6 / 155.96 m2 Shell/Unit 1	Surf/Shell (Gross/Eff)	157.6 / 155.96 m2

PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Propylene Glycol		Water	
Fluid Quantity, Total	kg/hr	189000		117000	
Vapor (In/Out)					
Liquid		189000	189000	117000	117000
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	110.00	65.00	30.00	61.48
Specific Gravity		0.9881	1.0161	0.9952	0.9822
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527
Latent Heat	kJ/kg				
Inlet Pressure	kPa	500.00		1000.0	
Velocity	m/s	0.65		1.47	
Pressure Drop, Allow /Calc	kPa	80.000	67.047	60.000	57.932
Fouling Resistance (min)	m2-K/W	0.000400		0.000180	

Heat Exchanged	4322784 W		MTD (Corrected)	40.2 C
Transfer Rate, Service	689.72 W/m2-K	Clean 1239.2 W/m2-K	Actual	695.83 W/m2-K

CONSTRUCTION OF ONE SHELL

Sketch (Bundle/Nozzle Orientation)



			Shell Side	Tube Side
Design/Test Pressure		kPaG	517.11 /	1034.2 /
Design Temperature		C	137.78	60.00
No Passes per Shell			2	4
Corrosion Allowance		mm	3.175	3.175
Connections Size & Rating	In	mm	1 @ 205.00	1 @ 154.05
	Out	mm	1 @ 258.88	1 @ 154.05
	Intermediate		@	@

Tube No.	270	OD	25.400 mm	Thk(Avg)	2.769 mm	Length	7.315 m	Pitch	33.867 mm
Tube Type	Plain			Material	Carbon steel			Tube pattern	30
Shell	Carbon steel	ID	660.40	OD	679.45 mm	Shell Cover			
Channel or Bonnet						Channel Cover			
Tubesheet-Stationary						Tubesheet-Floating			
Floating Head Cover						Impingement Plate	Rods		
Baffles-Cross		Type	Single-Seg.	%Cut (Diam)	33.55	Spacing(c/c)	884.74	Inlet	1045.6 mm
Baffles-Long				Seal Type	None				
Supports-Tube				U-Bend				Type	None
Bypass Seal Arrangement	0 pairs seal strips			Tube-Tubesheet Joint	Expanded (No groove)				
Expansion Joint				Type					
Rho-V2-Inlet Nozzle	2561.5 kg/m-s2			Bundle Entrance	125.68	Bundle Exit	324.15 kg/m-s2		

Gaskets-Shell Side		Tube Side	
-Floating Head			
Code Requirements		TEMA Class	R
Weight/Shell	5311.5 kg	Filled with Water 7758.4 kg	Bundle 3702.4 kg

Remarks:

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4.2. SHELL AND TUBE EXAMPLE 1 ALTERNATIVE (5-PASS):

4.2.1. Alternative 1 STHE Output Summary:

Output Summary Page 1

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Xist E 7.2.1 28/11/2017 20:18 SN: 12902-2109343071 **SI Units**

Design - Horizontal Multipass Flow TEMA AES Shell With Single-Segmental Baffles

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)	52.500		32.500	
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	110.00	65.00	30.00	61.48
Inlet P/Avg	(kPa)	500.00	462.61	1000.0	970.59
dP/Allow.	(kPa)	74.784	80.000	58.824	60.000
Fouling	(m2-K/W)		0.000400		0.000180

Exchanger Performance					
Shell h	(W/m2-K)	1167.9	Actual U	(W/m2-K)	578.33
Tube h	(W/m2-K)	6794.9	Required U	(W/m2-K)	543.06
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	4.3228
Cold regime	(--)	Sens. Liquid	Eff. area	(m2)	224.68
EMTD	(Deg C)	35.4	Overdesign	(%)	6.50

Shell Geometry			Baffle Geometry		
TEMA type	(--)	AES	Baffle type		Single-Seg.
Shell ID	(mm)	787.40	Baffle cut	(Pct Dia.)	17.17
Series	(--)	1	Baffle orientation	(--)	Perpend.
Parallel	(--)	1	Central spacing	(mm)	247.95
Orientation	(deg)	0.00	Crosspasses	(--)	27

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	205.00
Tube OD	(mm)	25.40	Shell outlet	(mm)	205.00
Length	(m)	7.31	Inlet height	(mm)	35.24
Pitch ratio	(--)	1.3333	Outlet height	(mm)	34.49
Layout	(deg)	30	Tube inlet	(mm)	154.05
Tubecount	(--)	390	Tube outlet	(mm)	154.05
Tube Pass	(--)	5			

Thermal Resistance, %		Velocities, m/s	Min	Max	Flow Fractions	
Shell	49.52				A	0.227
Tube	10.88	Tubeside	1.20	1.68	B	0.514
Fouling	36.45	Crossflow	0.45	0.66	C	0.029
Metal	3.15	Window	0.65	0.68	E	0.230
					F	0.000

4.2.2. Alternative 1 STHE Final Results:

Final Results Page 5

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Xist E 7.2.1 28/11/2017 20:18 SN: 12902-2109343071 **SI Units**

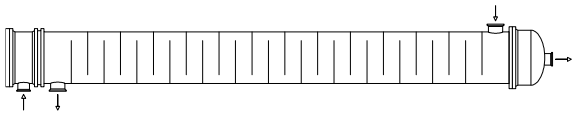
Design - Horizontal Multipass Flow TEMA AES Shell With Single-Segmental Baffles

Process Data		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	65.00	30.00	61.48
Skin temperature, Min/Max	(Deg C)	44.53	88.34	33.81	66.86
Wall temperature, Min/Max	(Deg C)	38.26	75.79	37.41	74.08
Pressure, In/Average	(kPa)	500.00	462.61	1000.0	970.59
Pressure drop, Total/Allowed	(kPa)	74.784	80.000	58.824	60.000
Velocity, Mid/Max allow	(m/s)	0.65		1.21	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)		1167.9		6794.9
Heat transfer safety factor	(--)		1.0000		1.0000
Fouling resistance	(m2-K/W)		0.000400		0.000180

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	543.06	/	909.98	/	578.33
Heat duty, Calculated/Specified	(MegaWatts)	4.3228	/			
Effective overall temperature difference	(Deg C)	35.4				
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	36.58	*	0.9686	*	1.0000

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	2063.6
Approximate tubeside	(L)	1352.1

Shell Construction Information

TEMA shell type	AES		Shell ID	(mm)	787.40
Shells Series	1 Parallel	1	Total area	(m2)	227.65
Passes Shell	1 Tube	5	Eff. area	(m2/shell)	224.68
Shell orientation angle (deg)	0.00				
Impingement present	Rods		Impingement rod rows		2
Pairs seal strips	0		Passlane seal rods (mm)	0.000	No. 0
Shell expansion joint	No		Rear head support plate	No	
Weight estimation Wet/Dry/Bundle	12187	/ 8772.7 / 5866.8	(kg/shell)		

Baffle Information

Type	Perpend.	Single-Seg.	Baffle cut (% dia)	17.17	
Crosspasses/shellpass		27	No.	(Pct Area)	(mm) to C.L
Central spacing	(mm)	247.95	1	14.18	258.53
Inlet spacing	(mm)	560.93	2	0.00	0.00
Outlet spacing	(mm)	460.11			
Baffle thickness	(mm)	6.35			
Use deresonating baffles		No			

Tube Information

Tube type		Plain	Tubecount per shell		390
Overall length	(m)	7.31	Pct tubes removed (both)		3.08
Effective length	(m)	7.220	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	95.25	Wall thickness	(mm)	2.769
Area ratio	(out/in)	1.2788	Pitch (mm)	33.867 Ratio	1.3333
Tube metal		Carbon steel	Tube pattern (deg)		30

4.2.3. Alternative 1 STHE Rating Data Sheet:

HTRI

HEAT EXCHANGER RATING DATA SHEET

Page 37
SI Units

Service of Unit				Item No.			
Type AES		Orientation Horizontal		Connected In 1 Parallel	1 Series		
Surf/Unit (Gross/Eff) 227.65 / 224.68 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 227.65 / 224.68 m2			
PERFORMANCE OF ONE UNIT							
Fluid Allocation		Shell Side		Tube Side			
Fluid Name		Propylene Glycol		Water			
Fluid Quantity, Total	kg/s	52.500		32.500			
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00		
Liquid	wt%	100.00	100.00	100.00	100.00		
Temperature (In/Out)	C	110.00	65.00	30.00	61.48		
Density	kg/m3	987.64	1015.6	994.79	981.78		
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564		
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320		
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527		
Critical Pressure	kPa						
Inlet Pressure	kPa	500.00		1000.0			
Velocity	m/s		0.65		1.21		
Pressure Drop, Allow/Calc	kPa	80.000	74.784	60.000	58.824		
Average Film Coefficient	W/m2-K	1167.9		6794.9			
Fouling Resistance (min)	m2-K/W	0.000400		0.000180			
Heat Exchanged	4.3228 MegaWatts	MTD (Corrected)	35.4 C	Overdesign	6.50 %		
Transfer Rate, Service	543.06 W/m2-K	Calculated	578.33 W/m2-K	Clean	909.98 W/m2-K		
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)			
		Shell Side	Tube Side				
Design Pressure	kPaG	517.11	1034.2				
Design Temperature	C	137.78	60.00				
No Passes per Shell		1	5				
Flow Direction		Downward	Upward				
Connections Size & Rating	In mm	1 @ 205.00	1 @ 154.05				
	Out mm	1 @ 205.00	1 @ 154.05				
	Liq. Out mm	@	1 @				
Tube No. 390.00	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm	Tube pattern 30		
Tube Type Plain		Material Carbon steel		Pairs seal strips	0		
Shell ID 787.40 mm		Kettle ID mm		Passlane Seal Rod No.	0		
Cross Baffle Type Perpend.	Single-Seg.	%Cut (Diam) 17.17		Impingement Plate	Rods		
Spacing(c/c) 247.95 mm		Inlet 560.93 mm		No. of Crosspasses	27		
Rho-V2-Inlet Nozzle 2561.5 kg/m-s2		Shell Entrance 0.00 kg/m-s2		Shell Exit 3989.7 kg/m-s2			
		Bundle Entrance 480.20 kg/m-s2		Bundle Exit 1762.9 kg/m-s2			
Weight/Shell 8772.7 kg		Filled with Water 12187 kg		Bundle 5866.8 kg			
Notes:		Thermal Resistance, %		Velocities, m/s		Flow Fractions	
		Shell 49.52		Shellside 0.65		A 0.227	
		Tube 10.88		Tubeside 1.21		B 0.514	
		Fouling 36.45		Crossflow 1.08		C 0.029	
		Metal 3.15		Window 1.27		E 0.230	
						F 0.000	

4.2.4. Alternative 1 STHE TEMA Data Sheet:

HEAT EXCHANGER SPECIFICATION SHEET — Page 38 — **SI Units**

Job No. 1

Customer	Dr. Saqaff Alkaff	Reference No.	
Address	Heriot Watt University Malaysia	Proposal No.	
Plant Location	Putrajaya	Date 28/11/2017	Rev 3
Service of Unit		Item No.	
Size	787.4 x 7315 mm Type AES Horizontal	Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff)	227.65 / 224.68 m2 Shell/Unit 1	Surf/Shell (Gross/Eff)	227.65 / 224.68 m2

PERFORMANCE OF ONE UNIT

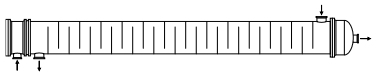
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Propylene Glycol		Water	
Fluid Quantity, Total	kg/hr	189000		117000	
Vapor (In/Out)					
Liquid		189000	189000	117000	117000
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	110.00	65.00	30.00	61.48
Specific Gravity		0.9881	1.0161	0.9952	0.9822
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527
Latent Heat	kJ/kg				
Inlet Pressure	kPa	500.00		1000.0	
Velocity	m/s	0.65		1.21	
Pressure Drop, Allow/Calc	kPa	80.000	74.784	60.000	58.824
Fouling Resistance (min)	m2-K/W	0.000400		0.000180	

Heat Exchanged 4322784 W MTD (Corrected) 35.4 C

Transfer Rate, Service 543.06 W/m2-K Clean 909.98 W/m2-K Actual 578.33 W/m2-K

CONSTRUCTION OF ONE SHELL

Sketch (Bundle/Nozzle Orientation)



			Shell Side	Tube Side
Design/Test Pressure		kPaG	517.11 /	1034.2 /
Design Temperature		C	137.78	60.00
No Passes per Shell			1	5
Corrosion Allowance		mm	3.175	3.175
Connections Size & Rating	In	mm	1 @ 205.00	1 @ 154.05
	Out	mm	1 @ 205.00	1 @ 154.05
	Intermediate		@	@

Tube No. 390 OD 25.400 mm Thk(Avg) 2.769 mm Length 7.315 m Pitch 33.867 mm

Tube Type Plain Material Carbon steel Tube pattern 30

Shell Carbon steel ID 787.40 OD 809.63 mm | Shell Cover (Remove.)

Channel or Bonnet | Channel Cover

Tubesheet-Stationary | Tubesheet-Floating

Floating Head Cover | Impingement Plate Rods

Baffles-Cross Type Single-Seg. %Cut (Diam) 17.17 Spacing(c/c) 247.95 Inlet 560.93 mm

Baffles-Long Seal Type None

Supports-Tube U-Bend Type None

Bypass Seal Arrangement 0 pairs seal strips Tube-Tubesheet Joint Expanded (No groove)

Expansion Joint Type

Rho-V2-Inlet Nozzle 2561.5 kg/m-s2 Bundle Entrance 480.20 Bundle Exit 1762.9 kg/m-s2

Gaskets-Shell Side Tube Side

-Floating Head

Code Requirements TEMA Class R

Weight/Shell 8772.7 kg Filled with Water 12187 kg Bundle 5866.8 kg

Remarks:

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4.3. SHELL AND TUBE EXAMPLE 2 ALTERNATIVE (VERTICAL SHELL):

4.3.1. Alternative 2 STHE Output Summary:

Output Summary Page 1

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 20:21 SN: 12902-2109343071 **SI Units**

Design - Vertical Multipass Flow TEMA BFM Shell With Single-Segmental Baffles

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)	52.500		32.500	
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	110.00	65.00	30.00	61.48
Inlet P/Avg	(kPa)	500.00	466.48	1000.0	971.04
dP/Allow.	(kPa)	67.046	80.000	57.930	60.000
Fouling	(m2-K/W)		0.000400		0.000180

Exchanger Performance					
Shell h	(W/m2-K)	1708.8	Actual U	(W/m2-K)	695.50
Tube h	(W/m2-K)	7613.5	Required U	(W/m2-K)	689.72
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	4.3228
Cold regime	(--)	Sens. Liquid	Eff. area	(m2)	155.96
EMTD	(Deg C)	40.2	Overdesign	(%)	0.84

Shell Geometry			Baffle Geometry		
TEMA type	(--)	BFM	Baffle type		Single-Seg.
Shell ID	(mm)	660.40	Baffle cut	(Pct Dia.)	33.55
Series	(--)	1	Baffle orientation	(--)	Parallel
Parallel	(--)	1	Central spacing	(mm)	884.74
Orientation	(deg)	90.00	Crosspasses	(--)	8

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	205.00
Tube OD	(mm)	25.40	Shell outlet	(mm)	258.88
Length	(m)	7.31	Inlet height	(mm)	31.22
Pitch ratio	(--)	1.3333	Outlet height	(mm)	25.93
Layout	(deg)	30	Tube inlet	(mm)	154.05
Tubecount	(--)	270	Tube outlet	(mm)	154.05
Tube Pass	(--)	4			

Thermal Resistance, %		Velocities, m/s			Flow Fractions	
Shell	40.70		Min	Max	A	0.006
Tube	11.68	Tubeside	1.46	1.70	B	0.736
Fouling	43.83	Crossflow	0.53	0.66	C	0.166
Metal	3.79	Window	1.07	1.19	E	0.092
					F	0.000

4.3.2. Alternative 2 STHE Final Results:

Final Results Page 5

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 20:21 SN: 12902-2109343071 **SI Units**

Design - Vertical Multipass Flow TEMA BFM Shell With Single-Segmental Baffles

Process Data		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	65.00	30.00	61.48
Skin temperature, Min/Max	(Deg C)	46.17	92.51	33.95	66.72
Wall temperature, Min/Max	(Deg C)	39.03	77.45	38.06	75.39
Pressure, In/Average	(kPa)	500.00	466.48	1000.0	971.04
Pressure drop, Total/Allowed	(kPa)	67.046	80.000	57.930	60.000
Velocity, Mid/Max allow	(m/s)	0.65		1.47	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)		1708.8		7613.5
Heat transfer safety factor	(--)		1.0000		1.0000
Fouling resistance	(m2-K/W)		0.000400		0.000180

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	689.72	/	1238.2	/	695.50
Heat duty, Calculated/Specified	(MegaWatts)	4.3228	/			
Effective overall temperature difference	(Deg C)	40.2				
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	40.84	*	0.9954	*	0.9885

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	1444.7
Approximate tubeside	(L)	1003.3

Shell Construction Information

TEMA shell type		BFM		Shell ID	(mm)		660.40
Shells Series	1	Parallel	1	Total area	(m2)		157.60
Passes Shell	2	Tube	4	Eff. area	(m2/shell)		155.96
Shell orientation angle (deg)		90.00					
Impingement present		Rods		Impingement rod rows			2
Pairs seal strips		0		Passlane seal rods (mm)	0.000	No.	0
Shell expansion joint		No		Rear head support plate		No	
Weight estimation Wet/Dry/Bundle		7758.4	/	5311.5	/	3702.4	(kg/shell)

Baffle Information

Type		Parallel	Single-Seg.	Baffle cut (% dia)	33.55	
Crosspasses/shellpass			8	No. (Pct Area)	(mm) to C.L	
Central spacing	(mm)		884.74	1 29.58	108.63	
Inlet/Outlet Spacing	(mm)		1045.6	2 0.00	0.00	
Turn Spacing	(mm)		884.74			
Baffle thickness	(mm)		12.70	Long. baffle length	(m)	6.35
Insulated long baffle			No			
Use deresonating baffles			No			

Tube Information

Tube type		Plain	Tubecount per shell		270
Overall length	(m)	7.31	Pct tubes removed (both)		2.96
Effective length	(m)	7.239	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	76.20	Wall thickness	(mm)	2.769
Area ratio	(out/in)	1.2788	Pitch (mm) 33.867	Ratio	1.3333
Tube metal		Carbon steel	Tube pattern (deg)		30

4.3.3. Alternative 2 STHE Rating Data Sheet:

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HEAT EXCHANGER RATING DATA SHEET

Page 18
SI Units

Service of Unit				Item No.			
Type BFM		Orientation Vertical		Connected In 1 Parallel 1 Series			
Surf/Unit (Gross/Eff) 157.60 / 155.96 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 157.60 / 155.96 m2			
PERFORMANCE OF ONE UNIT							
Fluid Allocation		Shell Side			Tube Side		
Fluid Name		Propylene Glycol			Water		
Fluid Quantity, Total	kg/s	52.500			32.500		
Vapor (In/Out)	wt%	0.00	0.00		0.00	0.00	
Liquid	wt%	100.00	100.00		100.00	100.00	
Temperature (In/Out)	C	110.00	65.00		30.00	61.48	
Density	kg/m3	987.64	1015.6		994.79	981.78	
Viscosity	mN-s/m2	1.8623	7.0593		0.7973	0.4564	
Specific Heat	kJ/kg-C	2.0570	1.5979		4.2181	4.2320	
Thermal Conductivity	W/m-C	0.1966	0.1994		0.6155	0.6527	
Critical Pressure	kPa						
Inlet Pressure	kPa	500.00			1000.0		
Velocity	m/s		0.65			1.47	
Pressure Drop, Allow/Calc	kPa	80.000	67.046		60.000	57.930	
Average Film Coefficient	W/m2-K	1708.8			7613.5		
Fouling Resistance (min)	m2-K/W	0.000400			0.000180		
Heat Exchanged 4.3228 MegaWatts		MTD (Corrected) 40.2 C			Overdesign 0.84 %		
Transfer Rate, Service 689.72 W/m2-K		Calculated 695.50 W/m2-K			Clean 1238.2 W/m2-K		
CONSTRUCTION OF ONE SHELL					Sketch (Bundle/Nozzle Orientation)		
		Shell Side	Tube Side				
Design Pressure	kPaG	517.11	1034.2				
Design Temperature	C	137.78	60.00				
No Passes per Shell		2	4				
Flow Direction							
Connections	In mm	1 @ 205.00	1 @ 154.05				
Size &	Out mm	1 @ 258.88	1 @ 154.05				
Rating	Liq. Out mm	@	1 @				
Tube No. 270.00	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm	Tube pattern 30		
Tube Type Plain		Material Carbon steel			Pairs seal strips 0		
Shell ID 660.40 mm		Kettle ID mm			Passlane Seal Rod No. 0		
Cross Baffle Type Parallel	Single-Seg.	%Cut (Diam) 33.55			Impingement Plate Rods		
Spacing(c/c) 884.74 mm		Inlet 1045.6 mm			No. of Crosspasses 8		
Rho-V2-Inlet Nozzle 2561.5 kg/m-s2		Shell Entrance 0.00 kg/m-s2			Shell Exit 3330.5 kg/m-s2		
		Bundle Entrance 125.68 kg/m-s2			Bundle Exit 324.15 kg/m-s2		
Weight/Shell 5311.5 kg		Filled with Water 7758.4 kg			Bundle 3702.4 kg		
Notes:		Thermal Resistance, %		Velocities, m/s		Flow Fractions	
		Shell 40.70		Shellside 0.65		A 0.006	
		Tube 11.68		Tubeside 1.47		B 0.736	
		Fouling 43.83		Crossflow 0.71		C 0.166	
		Metal 3.79		Window 1.72		E 0.092	
						F 0.000	

4.3.4. Alternative 2 STHE TEMA Data Sheet:

HTRI

HEAT EXCHANGER SPECIFICATION SHEET Page 19 **SI Units**

Job No. 1

Customer	Dr. Saqaff Alkaff	Reference No.	
Address	Heriot Watt University Malaysia	Proposal No.	
Plant Location	Putrajaya	Date 28/11/2017	Rev 3
Service of Unit		Item No.	
Size	660.4 x 7315 mm Type BFM Vertical	Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff)	157.6 / 155.96 m2 Shell/Unit 1	Surf/Shell (Gross/Eff)	157.6 / 155.96 m2

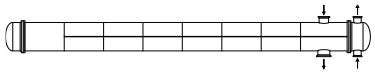
PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Propylene Glycol		Water	
Fluid Quantity, Total	kg/hr	189000		117000	
Vapor (In/Out)					
Liquid		189000	189000	117000	117000
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	110.00	65.00	30.00	61.48
Specific Gravity		0.9881	1.0161	0.9952	0.9822
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527
Latent Heat	kJ/kg				
Inlet Pressure	kPa	500.00		1000.0	
Velocity	m/s	0.65		1.47	
Pressure Drop, Allow /Calc	kPa	80.000	67.046	60.000	57.930
Fouling Resistance (min)	m2-K/W	0.000400		0.000180	

Heat Exchanged	4322784 W		MTD (Corrected)	40.2 C
Transfer Rate, Service	689.72 W/m2-K	Clean 1238.2 W/m2-K	Actual	695.50 W/m2-K

CONSTRUCTION OF ONE SHELL — Sketch (Bundle/Nozzle Orientation)

			Shell Side	Tube Side
Design/Test Pressure		kPaG	517.11 /	1034.2 /
Design Temperature		C	137.78	60.00
No Passes per Shell			2	4
Corrosion Allow ance		mm	3.175	3.175
Connections Size & Rating	In	mm	1 @ 205.00	1 @ 154.05
	Out	mm	1 @ 258.88	1 @ 154.05
	Intermediate		@	@



Tube No. 270	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm				
Tube Type Plain	Material Carbon steel	Tube pattern 30						
Shell Carbon steel	ID 660.40	OD 679.45 mm	Shell Cover					
Channel or Bonnet			Channel Cover					
Tubesheet-Stationary			Tubesheet-Floating					
Floating Head Cover			Impingement Plate Rods					
Baffles-Cross	Type Single-Seg.	%Cut (Diam) 33.55	Spacing(c/c) 884.74	Inlet 1045.6 mm				
Baffles-Long	Seal Type None							
Supports-Tube	U-Bend	Type None						
Bypass Seal Arrangement 0 pairs seal strips	Tube-Tubesheet Joint Expanded (No groove)							
Expansion Joint	Type							
Rho-V2-Inlet Nozzle 2561.5 kg/m-s2	Bundle Entrance 125.68	Bundle Exit 324.15 kg/m-s2						
Gaskets-Shell Side	Tube Side							
-Floating Head								
Code Requirements			TEMA Class R					
Weight/Shell 5311.5 kg	Filled w ith Water 7758.4 kg		Bundle 3702.4 kg					

Remarks:

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4.4. SHELL AND TUBE EXAMPLE 3 ALTERNATIVE (DOUBLE-SEGMENTAL BAFFLES):

4.4.1. Alternative 3 STHE Output Summary:

Output Summary Page 1

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 20:22 SN: 12902-2109343071 **SI Units**

Design - Horizontal Multipass Flow TEMA BFM Shell With Double-Segmental Baffles

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)	52.500		32.500	
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	110.00	65.00	30.00	61.48
Inlet P/Avg	(kPa)	500.00	475.13	1000.0	974.12
dP/Allow.	(kPa)	49.747	80.000	51.757	60.000
Fouling	(m2-K/W)		0.000400		0.000180

Exchanger Performance					
Shell h	(W/m2-K)	1608.2	Actual U	(W/m2-K)	674.22
Tube h	(W/m2-K)	7235.2	Required U	(W/m2-K)	647.69
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	4.3228
Cold regime	(--)	Sens. Liquid	Eff. area	(m2)	166.28
EMTD	(Deg C)	40.1	Overdesign	(%)	4.10

Shell Geometry			Baffle Geometry		
TEMA type	(--)	BFM	Baffle type		Double-Seg.
Shell ID	(mm)	685.80	Baffle cut	(Pct Dia.)	25.61
Series	(--)	1	Baffle orientation	(--)	Parallel
Parallel	(--)	1	Central spacing	(mm)	434.14
Orientation	(deg)	0.00	Crosspasses	(--)	16

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	205.00
Tube OD	(mm)	25.40	Shell outlet	(mm)	258.88
Length	(m)	7.31	Inlet height	(mm)	43.92
Pitch ratio	(--)	1.3333	Outlet height	(mm)	21.70
Layout	(deg)	30	Tube inlet	(mm)	154.05
Tubecount	(--)	288	Tube outlet	(mm)	154.05
Tube Pass	(--)	4			

Thermal Resistance, %		Velocities, m/s			Flow Fractions	
Shell	41.92		Min	Max	A	0.017
Tube	11.92	Tubeside	1.37	1.59	B	0.809
Fouling	42.49	Crossflow	0.44	0.72	C	0.051
Metal	3.67	Window	0.73	0.98	E	0.123
					F	0.000

4.4.2. Alternative 3 STHE Final Results:

Final Results Page 5

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 20:22 SN: 12902-2109343071 **SI Units**

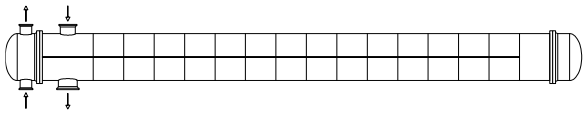
Design - Horizontal Multipass Flow TEMA BFM Shell With Double-Segmental Baffles

Process Data		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	65.00	30.00	61.48
Skin temperature, Min/Max	(Deg C)	44.91	92.08	33.70	66.71
Wall temperature, Min/Max	(Deg C)	38.36	77.26	37.47	75.24
Pressure, In/Average	(kPa)	500.00	475.13	1000.0	974.12
Pressure drop, Total/Allowed	(kPa)	49.747	80.000	51.757	60.000
Velocity, Mid/Max allow	(m/s)	0.71		1.38	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)		1608.2		7235.2
Heat transfer safety factor	(--)		1.0000		1.0000
Fouling resistance	(m2-K/W)		0.000400		0.000180

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	647.69	/	1172.3	/	674.22
Heat duty, Calculated/Specified	(MegaWatts)	4.3228	/			
Effective overall temperature difference	(Deg C)	40.1				
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	40.92	*	0.9924	*	0.9882

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	1571.9
Approximate tubeside	(L)	1086.7

Shell Construction Information

TEMA shell type	BFM		Shell ID	(mm)	685.80
Shells Series	1 Parallel	1	Total area	(m2)	168.11
Passes Shell	2 Tube	4	Eff. area	(m2/shell)	166.28
Shell orientation angle (deg)	0.00				
Impingement present	Rods		Impingement rod rows		2
Pairs seal strips	2		Passlane seal rods (mm)	0.000	No. 0
Shell expansion joint	No		Rear head support plate	No	
Weight estimation Wet/Dry/Bundle	8263.2	/ 5605.8 / 3927.0	(kg/shell)		

Baffle Information

Type	Parallel	Double-Seg.	Baffle cut (% dia)	25.61		
Crosspasses/shellpass		16	No.	(Pct Area)	(mm) to C.L	
Central spacing	(mm)	434.14	1	41.09	167.28	
Inlet/Outlet Spacing	(mm)	723.56	2	39.45	108.62	
Turn Spacing	(mm)	434.14	Baffle overlap	(mm)	58.66	
Baffle thickness	(mm)	6.35	Long. baffle length	(m)	6.80	
Insulated long baffle		No				
Use deresonating baffles		No				

Tube Information

Tube type		Plain	Tubecount per shell		288
Overall length	(m)	7.31	Pct tubes removed (both)		3.47
Effective length	(m)	7.236	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	79.38	Wall thickness	(mm)	2.769
Area ratio	(out/in)	1.2788	Pitch (mm)	33.867 Ratio	1.3333
Tube metal		Carbon steel	Tube pattern (deg)		30

4.4.3. Alternative 3 STHE Rating Data Sheet:

HTRI

HEAT EXCHANGER RATING DATA SHEET

Page 26
SI Units

Service of Unit				Item No.			
Type BFM		Orientation Horizontal		Connected In 1 Parallel 1 Series			
Surf/Unit (Gross/Eff) 168.11 / 166.28 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 168.11 / 166.28 m2			
PERFORMANCE OF ONE UNIT							
Fluid Allocation		Shell Side		Tube Side			
Fluid Name		Propylene Glycol		Water			
Fluid Quantity, Total	kg/s	52.500		32.500			
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00		
Liquid	wt%	100.00	100.00	100.00	100.00		
Temperature (In/Out)	C	110.00	65.00	30.00	61.48		
Density	kg/m3	987.64	1015.6	994.79	981.78		
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564		
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320		
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527		
Critical Pressure	kPa						
Inlet Pressure	kPa	500.00		1000.0			
Velocity	m/s		0.71		1.38		
Pressure Drop, Allow/Calc	kPa	80.000	49.747	60.000	51.757		
Average Film Coefficient	W/m2-K	1608.2		7235.2			
Fouling Resistance (min)	m2-K/W	0.000400		0.000180			
Heat Exchanged 4.3228 MegaWatts		MTD (Corrected) 40.1 C		Overdesign 4.10 %			
Transfer Rate, Service 647.69 W/m2-K		Calculated 674.22 W/m2-K		Clean 1172.3 W/m2-K			
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)			
		Shell Side	Tube Side				
Design Pressure	kPaG	517.11	1034.2				
Design Temperature	C	137.78	60.00				
No Passes per Shell		2	4				
Flow Direction		Downward	Upward				
Connections	In mm	1 @ 205.00	1 @ 154.05				
Size &	Out mm	1 @ 258.88	1 @ 154.05				
Rating	Liq. Out mm	@	1 @				
Tube No. 288.00	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm	Tube pattern 30		
Tube Type Plain		Material Carbon steel		Pairs seal strips 2			
Shell ID 685.80 mm		Kettle ID mm		Passlane Seal Rod No. 0			
Cross Baffle Type Parallel	Double-Seg.	%Cut (Diam) 25.61		Impingement Plate Rods			
Spacing(c/c) 434.14 mm		Inlet 723.56 mm		No. of Crosspasses 16			
Rho-V2-Inlet Nozzle 2561.5 kg/m-s2		Shell Entrance 0.00 kg/m-s2		Shell Exit 3621.9 kg/m-s2			
		Bundle Entrance 216.18 kg/m-s2		Bundle Exit 639.76 kg/m-s2			
Weight/Shell 5605.8 kg		Filled with Water 8263.2 kg		Bundle 3927.0 kg			
Notes:		Thermal Resistance, %		Velocities, m/s		Flow Fractions	
		Shell 41.92		Shellside 0.71		A 0.017	
		Tube 11.92		Tubeside 1.38		B 0.809	
		Fouling 42.49		Crossflow 0.69		C 0.051	
		Metal 3.67		Window 1.16		E 0.123	
						F 0.000	

4.4.4. Alternative 3 STHE TEMA Data Sheet:

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HEAT EXCHANGER SPECIFICATION SHEET Page 27 **SI Units**

Job No. 1

Customer	Dr. Saqaff Alkaff	Reference No.	
Address	Heriot Watt University Malaysia	Proposal No.	
Plant Location	Putrajaya	Date 28/11/2017	Rev 3
Service of Unit		Item No.	
Size 685.8 x 7315 mm	Type BFM Horizontal	Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff) 168.11 / 166.28 m2	Shell/Unit 1	Surf/Shell (Gross/Eff) 168.11 / 166.28 m2	

PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Propylene Glycol		Water	
Fluid Quantity, Total	kg/hr	189000		117000	
Vapor (In/Out)					
Liquid		189000	189000	117000	117000
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	110.00	65.00	30.00	61.48
Specific Gravity		0.9881	1.0161	0.9952	0.9822
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527
Latent Heat	kJ/kg				
Inlet Pressure	kPa	500.00		1000.0	
Velocity	m/s	0.71		1.38	
Pressure Drop, Allow/Calc	kPa	80.000	49.747	60.000	51.757
Fouling Resistance (min)	m2-K/W	0.000400		0.000180	

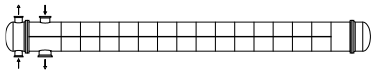
Heat Exchanged 4322784 W MTD (Corrected) 40.1 C

Transfer Rate, Service 647.69 W/m2-K Clean 1172.3 W/m2-K Actual 674.22 W/m2-K

CONSTRUCTION OF ONE SHELL

Sketch (Bundle/Nozzle Orientation)

			Shell Side	Tube Side
Design/Test Pressure		kPaG	517.11 /	1034.2 /
Design Temperature		C	137.78	60.00
No Passes per Shell			2	4
Corrosion Allowance		mm	3.175	3.175
Connections Size & Rating	In	mm	1 @ 205.00	1 @ 154.05
	Out	mm	1 @ 258.88	1 @ 154.05
	Intermediate		@	@



Tube No. 288 OD 25.400 mm Thk(Avg) 2.769 mm Length 7.315 m Pitch 33.867 mm

Tube Type Plain Material Carbon steel Tube pattern 30

Shell Carbon steel	ID 685.80 OD 704.85 mm	Shell Cover	
Channel or Bonnet		Channel Cover	
Tubesheet-Stationary		Tubesheet-Floating	
Floating Head Cover		Impingement Plate Rods	

Baffles-Cross Type Double-Seg. %Cut (Diam) 25.61 Spacing(c/c) 434.14 Inlet 723.56 mm

Baffles-Long Seal Type None

Supports-Tube U-Bend Type None

Bypass Seal Arrangement 2 pairs seal strips Tube-Tubesheet Joint Expanded (No groove)

Expansion Joint Type

Rho-V2-Inlet Nozzle 2561.5 kg/m-s2 Bundle Entrance 216.18 Bundle Exit 639.76 kg/m-s2

Gaskets-Shell Side Tube Side

-Floating Head

Code Requirements TEMA Class R

Weight/Shell 5605.8 kg Filled with Water 8263.2 kg Bundle 3927.0 kg

Remarks:

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4.5. SHELL AND TUBE EXAMPLE 4 ALTERNATIVE (AES TEMA SPECIFICATION):

4.5.1. Alternative 4 STHE Output Summary:

Output Summary Page 1

Released to the following HTRI Member Company:
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Xist E 7.2.1 28/11/2017 20:25 SN: 12902-2109343071 **SI Units**

Design - Horizontal Multipass Flow TEMA AES Shell With Single-Segmental Baffles

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)	52.500		32.500	
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	110.00	65.00	30.00	61.48
Inlet P/Avg	(kPa)	500.00	464.93	1000.0	984.76
dP/Allow.	(kPa)	70.140	80.000	30.491	60.000
Fouling	(m2-K/W)		0.000400		0.000180

Exchanger Performance					
Shell h	(W/m2-K)	1159.9	Actual U	(W/m2-K)	565.90
Tube h	(W/m2-K)	5805.6	Required U	(W/m2-K)	557.64
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	4.3228
Cold regime	(--)	Sens. Liquid	Eff. area	(m2)	224.73
EMTD	(Deg C)	34.5	Overdesign	(%)	1.48

Shell Geometry			Baffle Geometry		
TEMA type	(--)	AES	Baffle type		Single-Seg.
Shell ID	(mm)	787.40	Baffle cut	(Pct Dia.)	19.21
Series	(--)	1	Baffle orientation	(--)	Perpend.
Parallel	(--)	1	Central spacing	(mm)	245.32
Orientation	(deg)	0.00	Crosspasses	(--)	27

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	205.00
Tube OD	(mm)	25.40	Shell outlet	(mm)	258.88
Length	(m)	7.31	Inlet height	(mm)	54.97
Pitch ratio	(--)	1.3333	Outlet height	(mm)	21.26
Layout	(deg)	30	Tube inlet	(mm)	154.05
Tubecount	(--)	390	Tube outlet	(mm)	154.05
Tube Pass	(--)	4			

Thermal Resistance, %		Velocities, m/s			Flow Fractions	
Shell	48.79		Min	Max	A	0.214
Tube	12.47	Tubeside	1.07	1.11	B	0.466
Fouling	35.66	Crossflow	0.42	0.63	C	0.029
Metal	3.08	Window	0.57	0.59	E	0.223
					F	0.067

4.5.2. Alternative 4 STHE Final Results:

Final Results Page 5

Released to the following HTRI Member Company:
HWUM
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Xist E 7.2.1 28/11/2017 20:25 SN: 12902-2109343071 **SI Units**

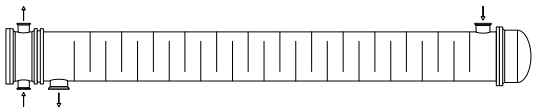
Design - Horizontal Multipass Flow TEMA AES Shell With Single-Segmental Baffles

Process Data		Hot Shellside		Cold Tubeside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	65.00	30.00	61.48
Skin temperature, Min/Max	(Deg C)	44.90	85.31	34.22	63.36
Wall temperature, Min/Max	(Deg C)	38.66	72.38	37.81	70.62
Pressure, In/Average	(kPa)	500.00	464.93	1000.0	984.76
Pressure drop, Total/Allowed	(kPa)	70.140	80.000	30.491	60.000
Velocity, Mid/Max allow	(m/s)	0.62		1.07	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)	1159.9		5805.6	
Heat transfer safety factor	(--)	1.0000		1.0000	
Fouling resistance	(m2-K/W)	0.000400		0.000180	

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	557.64	/	879.58	/	565.90
Heat duty, Calculated/Specified	(MegaWatts)	4.3228	/			
Effective overall temperature difference	(Deg C)	34.5				
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	35.80	*	0.9635	*	1.0000

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	2072.1
Approximate tubeside	(L)	1352.3

Shell Construction Information

TEMA shell type	AES		Shell ID	(mm)	787.40
Shells Series	1 Parallel	1	Total area	(m2)	227.65
Passes Shell	1 Tube	4	Eff. area	(m2/shell)	224.73
Shell orientation angle (deg)	0.00				
Impingement present	Rods		Impingement rod rows		2
Pairs seal strips	0		Passlane seal rods (mm)	25.400	No. 4
Shell expansion joint	No		Rear head support plate	No	
Weight estimation Wet/Dry/Bundle	12213	/ 8789.9 / 5859.1	(kg/shell)		

Baffle Information

Type	Perpend.	Single-Seg.	Baffle cut (% dia)	19.21	
Crosspasses/shellpass		27	No. (Pct Area)	(mm) to C.L	
Central spacing	(mm)	245.32	1 16.58	242.42	
Inlet spacing	(mm)	561.20	2 0.00	0.00	
Outlet spacing	(mm)	527.18			
Baffle thickness	(mm)	6.35			
Use deresonating baffles		No			

Tube Information

Tube type		Plain	Tubecount per shell		390
Overall length	(m)	7.31	Pct tubes removed (both)		3.85
Effective length	(m)	7.221	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	93.66	Wall thickness	(mm)	2.769
Area ratio	(out/in)	1.2788	Pitch (mm)	33.867 Ratio	1.3333
Tube metal		Carbon steel	Tube pattern (deg)		30

4.5.3. Alternative 4 STHE Rating Data Sheet:

HTRI

HEAT EXCHANGER RATING DATA SHEET

Page 33
SI Units

Service of Unit				Item No.			
Type AES		Orientation Horizontal		Connected In 1 Parallel 1 Series			
Surf/Unit (Gross/Eff) 227.65 / 224.73 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 227.65 / 224.73 m2			
PERFORMANCE OF ONE UNIT							
Fluid Allocation		Shell Side		Tube Side			
Fluid Name		Propylene Glycol		Water			
Fluid Quantity, Total	kg/s	52.500		32.500			
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00		
Liquid	wt%	100.00	100.00	100.00	100.00		
Temperature (In/Out)	C	110.00	65.00	30.00	61.48		
Density	kg/m3	987.64	1015.6	994.79	981.78		
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564		
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320		
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527		
Critical Pressure	kPa						
Inlet Pressure	kPa	500.00		1000.0			
Velocity	m/s		0.62		1.07		
Pressure Drop, Allow/Calc	kPa	80.000	70.140	60.000	30.491		
Average Film Coefficient	W/m2-K	1159.9		5805.6			
Fouling Resistance (min)	m2-K/W	0.000400		0.000180			
Heat Exchanged	4.3228 MegaWatts	MTD (Corrected)	34.5 C	Overdesign	1.48 %		
Transfer Rate, Service	557.64 W/m2-K	Calculated	565.90 W/m2-K	Clean	879.58 W/m2-K		
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)			
		Shell Side	Tube Side				
Design Pressure	kPaG	517.11	1034.2				
Design Temperature	C	137.78	60.00				
No Passes per Shell		1	4				
Flow Direction		Downward	Upward				
Connections In	mm	1 @ 205.00	1 @ 154.05				
Size & Out	mm	1 @ 258.88	1 @ 154.05				
Rating Liq. Out	mm	@	1 @				
Tube No. 390.00	OD 25.400 mm	Thk(Avg) 2.769 mm	Length 7.315 m	Pitch 33.867 mm	Tube pattern 30		
Tube Type Plain		Material Carbon steel		Pairs seal strips	0		
Shell ID 787.40 mm		Kettle ID mm		Passlane Seal Rod No.	4		
Cross Baffle Type Perpend.	Single-Seg.	%Cut (Diam) 19.21		Impingement Plate	Rods		
Spacing(c/c) 245.32 mm		Inlet 561.20 mm		No. of Crosspasses	27		
Rho-V2-Inlet Nozzle 2561.5	kg/m-s2	Shell Entrance 0.00	kg/m-s2	Shell Exit 4486.2	kg/m-s2		
		Bundle Entrance 410.15	kg/m-s2	Bundle Exit 1617.6	kg/m-s2		
Weight/Shell 8789.9 kg		Filled with Water 12213 kg		Bundle 5859.1 kg			
Notes:		Thermal Resistance, %		Velocities, m/s		Flow Fractions	
		Shell 48.79		Shellside 0.62		A 0.214	
		Tube 12.47		Tubeside 1.07		B 0.466	
		Fouling 35.66		Crossflow 1.11		C 0.029	
		Metal 3.08		Window 1.09		E 0.223	
						F 0.067	

4.5.4. Alternative 4 STHE TEMA Data Sheet:

HEAT EXCHANGER SPECIFICATION SHEET — Page 34 — **SI Units**

Job No. 1

Customer	Dr. Saqaff Alkaff	Reference No.	
Address	Heriot Watt University Malaysia	Proposal No.	
Plant Location	Putrajaya	Date 28/11/2017	Rev 3
Service of Unit		Item No.	
Size	787.4 x 7315 mm Type AES Horizontal	Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff)	227.65 / 224.73 m2 Shell/Unit 1	Surf/Shell (Gross/Eff)	227.65 / 224.73 m2

PERFORMANCE OF ONE UNIT

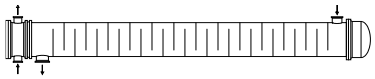
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Propylene Glycol		Water	
Fluid Quantity, Total	kg/hr	189000		117000	
Vapor (In/Out)					
Liquid		189000	189000	117000	117000
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	110.00	65.00	30.00	61.48
Specific Gravity		0.9881	1.0161	0.9952	0.9822
Viscosity	mN-s/m2	1.8623	7.0593	0.7973	0.4564
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.0570	1.5979	4.2181	4.2320
Thermal Conductivity	W/m-C	0.1966	0.1994	0.6155	0.6527
Latent Heat	kJ/kg				
Inlet Pressure	kPa	500.00		1000.0	
Velocity	m/s	0.62		1.07	
Pressure Drop, Allow/Calc	kPa	80.000	70.140	60.000	30.491
Fouling Resistance (min)	m2-K/W	0.000400		0.000180	

Heat Exchanged 4322784 W MTD (Corrected) 34.5 C

Transfer Rate, Service 557.64 W/m2-K Clean 879.58 W/m2-K Actual 565.90 W/m2-K

CONSTRUCTION OF ONE SHELL

Sketch (Bundle/Nozzle Orientation)



			Shell Side	Tube Side
Design/Test Pressure		kPaG	517.11 /	1034.2 /
Design Temperature		C	137.78	60.00
No Passes per Shell			1	4
Corrosion Allowance		mm	3.175	3.175
Connections Size & Rating	In	mm	1 @ 205.00	1 @ 154.05
	Out	mm	1 @ 258.88	1 @ 154.05
	Intermediate		@	@

Tube No. 390 OD 25.400 mm Thk(Avg) 2.769 mm Length 7.315 m Pitch 33.867 mm

Tube Type Plain Material Carbon steel Tube pattern 30

Shell Carbon steel ID 787.40 OD 809.63 mm Shell Cover (Remove.)

Channel or Bonnet Channel Cover

Tubesheet-Stationary Tubesheet-Floating

Floating Head Cover Impingement Plate Rods

Baffles-Cross Type Single-Seg. %Cut (Diam) 19.21 Spacing(c/c) 245.32 Inlet 561.20 mm

Baffles-Long Seal Type None

Supports-Tube U-Bend Type None

Bypass Seal Arrangement 0 pairs seal strips Tube-Tubesheet Joint Expanded (No groove)

Expansion Joint Type

Rho-V2-Inlet Nozzle 2561.5 kg/m-s2 Bundle Entrance 410.15 Bundle Exit 1617.6 kg/m-s2

Gaskets-Shell Side Tube Side

-Floating Head

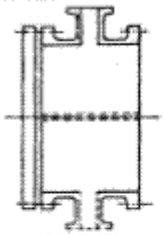
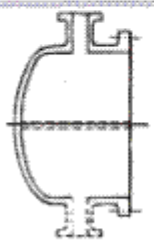
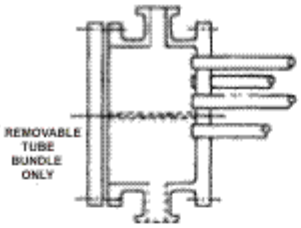
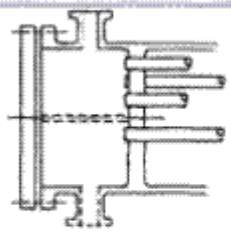
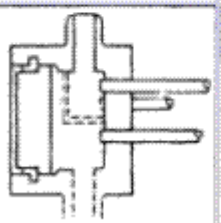
Code Requirements TEMA Class R

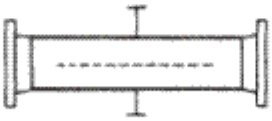
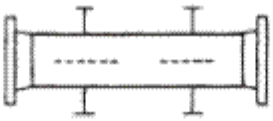
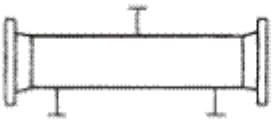
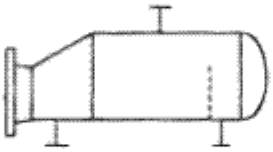
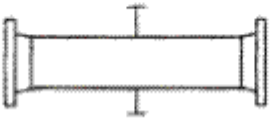
Weight/Shell 8789.9 kg Filled with Water 12213 kg Bundle 5859.1 kg

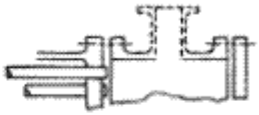
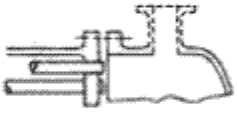
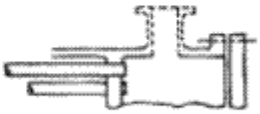
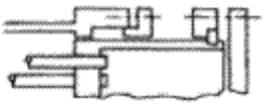
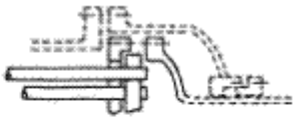
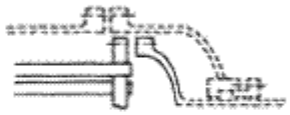
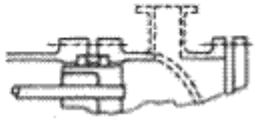
Remarks:

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4.6. TEMA SPECIFICATION

	FROND END STATIONARY HEAD TYPES
A	 CHANNEL AND REMOVABLE COVER
B	 BONNET (INTEGRAL COVER)
C	 CHANNEL INTEGRAL WITH TUBE-SHEET AND REMOVABLE COVER
N	 CHANNEL INTEGRAL WITH TUBE-SHEET AND REMOVABLE COVER
D	 SPECIAL HIGH PRESSURE CLOSURE

	SHILL TYPES
E	 ONE PASS SHELL
F	 TWO PASS SHELL WITH LONGITUDINAL BAFFLE
G	 SPLIT FLOW
H	 DOUBLE SPLIT FLOW
J	 DIVIDED FLOW
K	 KETTLE TYPE REBOILER
X	 CROSS FLOW

	READ END HEAD TYPES
L	 FIXED TUBESHEET LIKE "A" STATIONARY HEAD
M	 FIXED TUBESHEET LIKE "B" STATIONARY HEAD
N	 FIXED TUBESHEET LIKE "N" STATIONARY HEAD
P	 OUTSIDE PACKED FLOATING HEAD
S	 FLOATING HEAD WITH BASKING DEVICE
T	 PULL THROUGH FLOATING HEAD
U	 U-TUBE BUNDLE
W	 EXTERNALLY SEALED FLOATING TUBESHEET

4.7. PLATE AND FRAME DESIGN:

4.7.1. PFHE Output Summary:

Output Summary Page 1

Released to the following HTRI Member Company:
HWUM
USER

Xphe E 7.2 28/11/2017 18:33 SN: 12902-2109343071 **SI Units**

Rating - Single Pass Countercurrent Flow

See Data Check Messages Report for Warning Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hotside		Coldside	
Fluid name		Propylene Glycol		Water	
Flow rate	(kg/s)		52.500		32.500
Temperature, Inlet/Outlet	(Deg C)	110.00	64.98	30.00	61.47
Weight fraction vapor, Inlet/Outlet	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, Average/Skin	(Deg C)	87.49	53.04	45.74	50.44
Pressure, Inlet/Average	(kPa)	500.00	460.25	1000.0	989.93
Pressure drop, Total/Allow	(kPa)	79.499	80.000	20.139	60.000
Nominal channel velocity	(m/s)		0.74		0.46
Fouling resistance	(m2-K/W)		0.0000		0.0000
Equivalent shear stress	(Pa)		48.20		14.55
Maldistribution parameter	(--)		0.11		0.14

Exchanger Performance					
Hot film coefficient	(W/m2-K)	1759.3	Actual U	(W/m2-K)	1384.191
Cold film coefficient	(W/m2-K)	8513.6	Required U	(W/m2-K)	1360.688
Hot regime		Sens. Liquid	Duty	(MegaWatts)	4.323
Cold regime		Sens. Liquid	Area	(m2)	75.316
EMTD	(Deg C)	42.2	Overdesign	(%)	1.73

Unit Geometry			Pack Configuration	
Units in series/parallel	(--)	1 / 1	Group #	1
No. of passes, hot/cold	(--)	1 / 1	Plate Type 1	1
Total plates/channels	(--)	123 / 122	Plate Type 2	1
Flow configuration	(--)	Countercurrent	Channels	61
Inlet port locations	(--)	Same Side	Hot pass #	1
Flow path	(--)	Diagonal	Cold pass #	1
Hot inlet flow direction	(--)	Upflow	Channel (Per pass)	61

Plate Geometry			Plate Type 1		
Channel width	(mm)	467.50	Manufacturer	(--)	Alfa Laval
Channel spacing	(mm)	2.489	Plate ID	(--)	M15-B
Equivalent diameter	(mm)	4.149	Chevron angle	(deg)	30.00
Average plate pitch	(mm)	3.089			
Port diameter	(mm)	150.00	**Plate Type 2**		
Tightened pack length	(mm)	377.48	Manufacturer	(--)	Alfa Laval
Horizontal port c-c	(mm)	304.80	Plate ID	(--)	M15-B
Vertical port c-c	(mm)	1295.40	Chevron angle	(deg)	30.00

Port Velocities, m/s	Hot	Cold
Inlet	3.01	1.85
Outlet	2.93	1.87

Pressure Drop, % of Total	Hot	Cold
Channel	77.9	84.0
Other	22.1	16.0

Thermal Resistance, %	
Hot side	78.68
Cold side	16.26
Fouling	0.00
Metal	5.07

4.7.2. PFHE Final Results:

Final Results

Released to the following HTRI Member Company:
HWUM
USER

Xphe E 7.2 28/11/2017 18:33 SN: 12902-2109343071 **SI Units**

Rating - Single Pass Countercurrent Flow

Process Data		Hotside		Coldside	
Fluid name		Propylene Glycol		Water	
Fluid condition		Sens. Liquid		Sens. Liquid	
Total flow rate	(kg/s)	52.500		32.500	
Weight fraction vapor, In/Out	(--)	0.0000	0.0000	0.0000	0.0000
Temperature, In/Out	(Deg C)	110.00	64.98	30.00	61.47
Temperature, Average/Skin	(Deg C)	87.49	53.04	45.74	50.44
Skin temperature, Max/Min	(Deg C)	108.62	36.94	71.86	30.51
Pressure, Inlet/Outlet	(kPa)	500.00	420.50	1000.0	979.86
Pressure drop, Total/Allowed	(kPa)	79.499	80.000	20.139	60.000
Port pressure drop, In/Out	(kPa)	-2.978	20.575	-1.158	4.382
Port velocity, In/Out	(m/s)	3.01	2.93	1.85	1.87
Nominal channel velocity	(m/s)		0.74		0.46
Average film coef.	(W/m2-K)		1759.3		8513.6
Heat transfer safety factor	(--)		1.0000		1.0000
Fouling resistance	(m2-K/W)		0.0000		0.0000
Fouling thickness	(mm)		0.000		0.000
Equivalent shear stress	(Pa)		48.20		14.55
Maldistribution parameter	(--)		0.11		0.14

Overall Performance Data						
Overall coef, Design/Clean/Actual	(W/m2-K)	1360.688	/ 1384.191	/ 1384.191		
Heat duty, Calculated/Specified	(MegaWatts)	4.3226	/ 0.0000			
Effective mean temperature difference	(Deg C)	41.39	* 1.019	= 42.18		

See Runtime Message Report for Warning Messages.

Unit Geometry			Common Plate Geometry		
Total effective area	(m2)	75.316			
Number of units, series/parallel	(--)	1 / 1	Channel width	(mm)	467.50
Number of passes, hot/cold	(--)	1 / 1	Channel spacing	(mm)	2.489
Number of channels, total/per pass	(--)	122 / 122	Equivalent diameter	(mm)	4.149
Number of plates, total/effective	(--)	123 / 121	Average plate pitch	(mm)	3.089
Number of plate types	(--)	1	Port diameter	(mm)	150.00
Number of channel types	(--)	1	Tightened pack length	(mm)	377.48
Flow configuration, first hot channel	(--)	Countercurrent	Horizontal distance of port centers	(mm)	304.80
Flow path across plate	(--)	Diagonal	Vertical distance of port centers	(mm)	1295.40

Port Geometry		Hot Inlet	Hot Outlet	Cold Inlet	Cold Outlet
Location (front/back)	(--)	Front	Front	Front	Front
Location (top/bottom)	(--)	Bottom	Top	Top	Bottom
Location (left/right)	(--)	Left	Right	Left	Right
Diameter	(mm)	150.00	150.00	150.00	150.00
Connection diameter	(mm)	150.00	150.00	150.00	150.00
Connection material	(--)	316 Stainless steel (17 Cr, 12 Ni)			

4.8. THERMAL DESIGN CALCULATION TABLES:

	Standard Choices of 4, 6 and 8 inches (nominal diameter) multi-tube pipe units (Standard Pressure)													
	4"	4"	4"	4"	4"	6"	6"	6"	8"	8"	8"	8"	8"	
Shell Outer Diameter (Given)	114.3	114.3	114.3	114.3	114.3	168.3	168.3	168.3	219.1	219.1	219.1	219.1	219.1	mm
Shell Inner Diameter	102.26	102.26	102.26	102.26	102.26	154.08	154.08	154.08	202.74	202.74	202.74	202.74	202.74	mm
Tube Outer Diameter (Given)	19.02	22.2	25.4	19.02	22.2	19.02	19.02	25.4	19.02	22.2	25.4	19.02	22.2	mm
Tube Inner Diameter	14.8	17.98	18.6	14.8	17.98	14.8	14.8	19.86	14.8	17.98	19.86	14.8	17.98	mm
Number of Tubes (Given)	7	7	7	7	7	19	14	7	19	19	19	19	19	-
Total Area of Tubes	0.001204235	0.0017773	0.001902	0.001204235	0.0017773	0.0032686	0.0024085	0.0021684	0.0032686	0.0048242	0.0058858	0.0032686	0.0048242	m2
Fins Number (Given)	0	0	0	16	16	16	16	16	16	16	16	16	16	-
Fins Height (Given)	0	0	0	5.33	5.33	5.33	5.33	12.7	8.64	7.11	5.33	7.11	5.33	mm
Assume Fin Thickness	0.00254	m												
Assume Fin Pitch	0.000381	m												
Dw	16.91	20.09	22	16.91	20.09	16.91	16.91	22.63	16.91	20.09	22.63	16.91	20.09	mm
Tube Wall Thickness (Given)	2.11	2.11	3.4	2.11	2.11	2.11	2.11	2.77	2.11	2.11	2.77	2.11	2.11	mm
Fluid mean velocity	8.719226247	5.9077486	5.5204628	8.719226247	5.9077486	3.2123465	4.3596131	4.8422019	3.2123465	2.1765389	1.7839691	3.2123465	2.1765389	m/s
Reynold Number	144993.8747	119349.8	115371.47	144993.8747	119349.8	53418.796	72496.937	108051.83	53418.796	43970.978	39808.569	53418.796	43970.978	-
Prandtl Number	6.324873096													
E	0.020841935													
Stanton Number	0.00071834	0.0007476	0.0007528	0.00071834	0.0007476	0.0008815	0.000828	0.000763	0.0008815	0.0009174	0.0009363	0.0008815	0.0009174	-
Tube HT Coefficient	26306.15883	18549.394	17454.262	26306.15883	18549.394	11893.27	15161.375	15516.883	11893.27	8386.3611	7015.3332	11893.27	8386.3611	W/m2K

Triangular Pitch	23.775	27.75	31.75	23.775	27.75	23.775	23.775	31.75	23.775	27.75	31.75	23.775	27.75	mm
Hydralic Mean Diameter	18.81908772	21.965497	25.131694	18.81908772	21.965497	18.819088	18.819088	25.131694	18.819088	21.965497	25.131694	18.819088	21.965497	mm
Channel Flow Area	0.006224111	0.0055035	0.004666	0.006224111	0.0055035	0.0132475	0.0146681	0.0150989	0.0268842	0.0249282	0.0226552	0.0268842	0.0249282	m2
Fluid Mean Velocity	2.151770144	2.4335324	2.8702829	2.151770144	2.4335324	1.0109749	0.9130603	0.8870083	0.4981678	0.5372577	0.591161	0.4981678	0.5372577	m/s
Reynold Number	63495.14252	83815.476	113107.8	63495.14252	83815.476	29832.182	26942.885	34953.892	14700.101	18504.174	23295.584	14700.101	18504.174	-
Prandtl Number	10.81													
E	0.019806611													
Stanton Number	0.000616831	0.0005827	0.000548	0.000616831	0.0005827	0.0007201	0.0007353	0.0006971	0.0008326	0.0007942	0.0007576	0.0008326	0.0007942	-
Shell HT Coefficient	2474.515585	2643.6977	2932.3436	2474.515585	2643.6977	1357.332	1251.7412	1152.8352	773.26998	795.51514	834.96987	773.26998	795.51514	W/m2K

Fin Calculations														
Surface Value (Given)	0.84	0.98	1.12	3.23	3.97	8.76	6.46	8.23	12.78	13.46	11.14	10.92	10.76	m2/m
Tube Surface Area	0.84	0.98	1.12	0.84	0.98	2.27	1.67	1.12	2.27	2.65	3.03	2.27	2.65	m2/m
Fin Surface Area	0.00	0.00	0.00	2.39	2.99	6.49	4.79	7.11	10.51	10.81	8.11	8.65	8.11	m2/m
Free Area Flow Outside Tube (Extruded Fins), Ao	0.006	0.006	0.005	0.006	0.006	0.013	0.015	0.015	0.027	0.025	0.023	0.027	0.025	m2
Gross Area, AF	0.008	0.008	0.008	0.008	0.008	0.019	0.019	0.019	0.032	0.032	0.032	0.032	0.032	m2
Ao/AF				0.7578	0.6700	0.7102	0.7865	0.8097	0.8325	0.7720	0.7016	0.8326	0.7720	-
Fin effectiveness				0.95										
Min Flow Velocity	10.75885072	12.167662	14.351415	10.75885072	12.167662	5.0548747	4.5653016	4.4350417	2.4908392	2.6862883	2.955805	2.4908392	2.6862883	m/s
Reynold Number	320865.0782	423551.45	571576.66	320865.0782	423551.45	150753.35	136152.63	176635.29	74285.195	93508.623	117721.44	74285.195	93508.623	-
Prandtl Number	10.81													

Nu Shell	#DIV/0!	#DIV/0!	#DIV/0!	1766.54791	2134.2384	1056.1355	985.35238	988.92714	592.17077	720.18046	892.4265	615.70942	762.90386	-
Alpha shell				10216.62829	10575.055	6108.0391	5698.673	4282.7553	3424.7521	3568.4617	3864.8392	3560.8852	3780.1542	W/m2K
1/alpha0				7.80726E-05	6.669E-05	0.0001224	0.0001453	0.000199	0.0002559	0.0002277	0.0001911	0.0002461	0.000215	-
Nu Tube				647.4828758	554.12266	291.27542	371.88126	511.74577	291.27542	249.27657	230.21298	291.27542	249.27657	-
Alpha i				25855.56619	18213.932	11631.336	14850.123	15228.688	11631.336	8193.6848	6850.7489	11631.336	8193.6848	-

	Without Fins			With Fins										
Overall HT	834.388567	846.13789	825.53651	1145.099155	1147.446	1022.0829	1023.1922	957.92385	899.37294	896.5149	878.1818	907.34546	906.87165	W/m2K
Heat Transfer Area (Required)	124.599914	122.86974	125.93597	90.79104047	90.605347	101.7185	101.60822	108.53132	115.59692	115.96544	118.38636	114.58121	114.64108	m2
Heat Transfer Area Available at 10m	8.4	9.8	11.2	32.3	39.7	87.6	64.6	82.3	127.8	134.6	111.4	109.2	107.6	m2
	Available >> Required (Acceptable)													

Length of HEX	10	10	10	10	10	10	10	10	10	10	10	10	10	m
Tube Side Pressure Drop														
Friction Factor, f	0.00529406	0.0054469	0.0054748	0.00529406	0.0054469	0.0062288	0.0059003	0.0055299	0.0062288	0.0064612	0.0065875	0.0062288	0.0064612	-
Pressure Drop within Tube	828112	897020	1212480	828112	897020	215077	166182	109538	52223	51863	57960	52223	51863	Pa
Loss in Bends (Given 0.5 velocity head)	38012	17451	15238	38012	17451	5160	9503	11723	5160	2369	1591	5160	2369	Pa
Total Pressure Drop	866124	914471	1227718	866124	914471	220236	175685	121261	57383	54232	59551	57383	54232	Pa
	<1000kPa (Acceptable)													

Shell Side Pressure Drop														
Friction Factor, f	0.006037774	0.0077551	0.0078652	0.007174344	0.0077551	0.0086283	0.0081312	0.0080863	0.0086283	0.0094389	0.0099012	0.0086283	0.0094389	-
Pressure Drop within Shell	23292	32784	40428	27677	32784	7348	5648	3969	1784	1945	2159	1784	1945	Pa
	<120kPa (Acceptable)													

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