SHELL AND TUBE HEAT EXCHANGER FOR THE COOLING OF ANHIDROSIS PATIENTS

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INTRODUCTION

Anhidrosis is a condition in which a human is unable to sweat, which limits their ability to convectively and conductively regulate heat. Heat exchangers are devices used to transfer heat between a hot fluid and a cold fluid. This report outlines a proposed design of a shell and tube heat exchanger to provide additional cooling to a person suffering from anhidrosis.

The average human body temperature is 98.6 ^{o}F or 37^{o}C [1]. The body is constantly producing heat, and maintains this temperature through the 3 types of heat transfer – convection, conduction and radiation. While the majority of heat loss (around 60%) occurs through radiation, the other 40% is lost through convection and conduction [1] – both of which are dependent, to some degree, on the ability to sweat. As the person is unable to dissipate the appropriate amount of heat, the body temperature could become higher than 37 degrees Celsius. These higher temperatures can have serious impact on organ function and if left unregulated, in severe cases cause mortality [1].

A shell and tube heat exchanger is a type of heat exchanger in which a small tube, or series of tubes is surrounded by a larger shell. A hot fluid flows through the tube, and is cooled by a cold fluid flowing between the tube exterior and shell interior. As a temperature gradient is the driving force for heat transfer, heat flows from the tube-side fluid to the shell-side fluid. In this heat exchanger, blood will be the hot fluid and water will be the cold fluid. Specifications can be made regarding the direction, speed and characterization of each fluid's flow. They have been used in industry for over 150 years, and are often seen in oil refineries and other large chemical process plants.

The proposed heat exchanger will be designed as a shell and tube apparatus for the purpose of removing heat, that would normally be lost via convection and conduction, from a person suffering from anhidrosis.

BACKGROUND

Competition

Anhidrosis is typically treated with medication, avoiding direct sunlight, wearing lightweight clothing and drinking cold fluids. If no medical cause is found for the condition, it cannot be treated with medication, and the individual is forced into a course of treatment solely comprised of avoiding situations where they will sweat [2]. For those that are able to be treated medically, a corticosteroid has been proven to be the most effective form of treatment, but recurrence of symptoms is not uncommon [3]. Other treatments include antihistamines and a medication known as gabapentin. One study showed promising results with administering methylprednisolone via and IV for 3 days, then orally for two weeks [4]. However, this method of treatment has only shown success in one study, and is in preliminary stages of use. As clinicians continue to experiment with medicinal treatment, it can be noted that the treatment options listed here and others would serve as competition for those patients who are able to be medicinally treated.

Many cooling vests exist on the market today, however many of these require that the wearer is able to sweat. Cooling vests transfer moisture from the skin to the front of the garment which helps keep the skin dry as well and promotes heat transfer [5]. This device is not applicable to patients with anhidrosis as there is no moisture on the surface of the skin to be wicked away. An alternative to the wicking cooling vests would be a cold vest, which maintains a temperature of 15 ^{o}C for 2.5 hours. These vest are re-cooled by being submerged in water or put in the freezer for several hours. These vests run from $40-200 and weigh approximately 2 kg [6]. Cold vests effectively cool down the wearer, and are the largest competition to the heat exchanger proposed in this report.

Application

The application of the heat exchanging device extends beyond patients with anhidrosis, for there are a multitude of other diseases and conditions that result in a heat intolerance. Multiple Sclerosis (MS) is a disease of the central nervous system. Loss of vision, fatigue, chronic pain, and a sensitivity to heat are all counted among the MS symptoms. MS affects approximately 2.5 million people worldwide, with 400,000 of those cases occurring in the United States [7]. While MS has a high prevalence, it is not the only disease that can lead to heat intolerance.

Hyperthyroidism has a large number of causes, the most common being Grave's disease, which affects 1 out of every 200 people - amounting to approximately 1.6 million Americans. One common symptom of hyperthyroidism is an intolerance to heat [8]. This presents another large group of people that struggle to regulate body temperature and are at risk of overheating.

Lastly, approximately 1% of the United States population suffers from a histamine intolerance, which has also been known to lead to heat intolerance [9]. All individuals suffering from these conditions turn to cool vests, medications or even surgery to treat some of their symptoms. The heat exchanging device described in this report could provide a different solution to many of these patients.

Market

The medical device industry is worth 42.8 billion US dollars (USD). This value has seen a 2% increase since 2012 and is projected to see a 13% increase over the next 5 years [10]. This device has the potential to capture a portion of the growing market and gain more widespread notoriety to help patients suffering from various diseases and conditions by alleviating their discomfort and potentially saving their life.

DISCUSSION

Tube-side Considerations

With consideration to the tube side of the heat exchanger, a high thermal conductivity was the leading qualification. The goal of the device is to transfer a set amount of heat from the blood to the water in as small of an area as possible. A high thermal conductivity ensures a low resistance to heat transfer which results in maximum cooling of the blood in a given area. Aluminum 3003 was chosen because it has a thermal conductivity, k, of 190 W/mK and is essentially commercially pure aluminum, grade 1100 [11]. Aluminum 3003 has some manganese in it which increases its strength over pure aluminum by 20% and thus makes it preferred over pure grade [11]. At $2.112 per kilogram, it is also a relatively cheap material [12].

It is important to assess the strength and durability of the material. Aluminum 3003 has a moderate yield strength of 125 MPa. As this is the tube side, a high yield strength is not essential, as it will not be exposed to the outside, so 125 MPa should be sufficient [13]. It is a relatively soft material with a Brinell hardness number of 35, but again, as it is inside the shell it is not necessary that the tube material is particularly strong [14]. Furthermore, Aluminum 3003 is slightly stronger than pure aluminum, which has a Brinell hardness value of 28 [15]. Additionally, aluminum, both grade 1100 and 3003, has a low density. The 3003 grade has a density of 2.73 g/cm^3 which helps in the portability of the device by decreasing weight [16].

With its high thermal conductivity, moderate strength, low density, and spontaneous oxide layer to alleviate toxicity concerns combined with the fact that it is a cheap material make aluminum 3003 the best choice for tube side material.

Shell-side Considerations

The shell-side of the heat exchanger should be made of a material that would will insulate the cold water, is flexible, and does not pose any health risks. Thus, various common insulators were examined, including polystyrene, polyurethane, fiberglass, and cellulose. The most important aspect of the insulator was the degree to which it can insulate. The k values for the materials, from lowest to highest, are polystyrene and polyurethane at 0.03 w/mK, fiberglass at 0.04 w/mK, and cellulose at 0.23 w/mK [17].

The second most important aspect was apparent presence of health risks. Polystyrene is flammable, while fiberglass is dangerous to inhale, as is cellulose to a lesser degree. Polyurethane is actually fire-resistant, making it the safest insulator of the four.

The third most important category was whether the material was flexible. Polystyrene is not, and cellulose is a powder, making it difficult to keep together or apply to the context of a heat exchanger. In contrast, polyurethane and fiberglass are both relatively flexible, allowing for the product to be comfortable to transport, malleable to work with, and less prone to breakage.

The fourth most important factor was cost. From least to most expensive, polystyrene at $0.09 per kilogram, cellulose at $1.28 per kilogram, fiberglass at $1.80 per kilogram, and polyurethane at $4.00 per kilogram [18][19].

Lastly, additional important properties were noted regarding the insulators. Polyurethane is relatively light, has a high load bearing capacity, as well as being impact, water, oil, and grease resistant, and can come in a variety of colors [20][21]. Polystyrene is light, recyclable, resistant to moisture, and prevents bacterial growth. Fiberglass does not absorb water, and cellulose is environmentally friendly, as it is composed of recycled materials [22][23][24].

This report recommends the use polyurethane for the shell-side of the heat exchanger. Although it is a more expensive option compared to the other three, since the goal of the device is to have as small an area as possible, material costs should be minimal. Additionally, polyurethane is fire, water, oil, and grease resistant, light, has an exceptionally low k value, flexible, is fairly sturdy, and can be made in different colors.

Apparatus Design

The apparatus is intended to be worn as a backpack with adjustable straps that will allow the system to be level with the artery from which the blood is removed. The shell side will have water flowing through it, and the tube side will have the blood. The water will be brought back to working temperature by pumping it through an ice container using a pump with a max flow rate of 27 L/min [25]. With 2.5 kg of ice in the container, the device will be able to provide continuous cooling for 51 minutes, it is assumed that the ice/water mixture will remain at $0^{o}C$ for the entirety of this time. The pump will be powered with a portable battery pack [26].

With these shell and tube materials in mind, the design model for this single, counter-current flow shell and tube exchanger will weigh 81.7 kg when filled with water and the total cost of all the materials and fluids that comprise the system, including labor costs, will be $3,596. The whole unit will have a total volume of $0.0034m^3$, with a shell radius of 0.03m, and a total unit length of 1.2m. For these design calculations, it was assumed that there would be no pressure drop throughout the system as it is intended to be worn as a backpack type apparatus, with adjustable straps that will allow the system to be level with the heart; however, ASPEN determined there was a pressure drop of 0.00023 bar on the tube side, which is relatively small. Similarly, ASPEN calculated an actual pressure drop of 0.00037 bar on the shell side, which will be overcome by the pump. The horizontal orientation of the heat exchanger means the pressure drop will be due solely to viscous forces between the shell and tube materials and respective fluids flowing past them.

Feasability

The biggest competition this heat exchanger faces are companies like FlexiFreeze and Polar Products. This heat exchanger is portable like its competitors, but the device itself weights

81.7kg, the ice adds an additional 2.5kg, the pump adds 0.86kg and the battery pack adds approximately 4kg [25][26]. Totaling 88.66kg, it is far heavier than both its alternatives - the vests weigh about 2kg [6].

In addition, the device itself costs $3,596 including labor costs, the ice costs approximately $3 if it is not made at the users' residence, the pump costs $150 and the battery pack costs $230 [25][26]. At a total of $3,979, it is much more expensive than the vests, which cost between $40-200 [6]. The medication is a bit more difficult to evaluate as cost will depend on an individual's health care plan. When accounting for office visit costs as well, corticosteroid injections can cost anywhere from $75-300 for patients without health insurance. Insured patients will often pay a copay of $10-50 for their treatment [27]. Because symptoms are known to recur with corticosteroid treatment, it is not unlikely that patients will pay several times for medical treatment of their anhidrosis. If a patient receives more than 12 treatments, the heat exchanger device becomes comparable in price. Other drugs like gabapentin, which is taken orally, costs anywhere from $15-46 for 30 capsules, depending on the dosage [28]. Antihistamines vary from $7-40 dollars for an average of 24 capsules, depending on what it is targeting [29]. The exact antihistamine the patient uses will depend on the doctor's recommendation, but both of these drugs are continuous treatment methods. In terms of long term treatment, the heat exchanger device becomes competitive; it will pay for itself in approximately 7 years, but this does not include the cost of maintenance and repair.

The heat exchanger also proposes the biggest additional health risk due to the potential of aluminum poisoning in the blood, and the general concern with removing blood from the body. The ice vests do not propose any significant health issues. Corticosteroid usage can potentially lead to thinning of skin, tissue and bones. Antihistamines and gabapentin have various side effects like dizziness, nausea and vomiting, confusion, and blurred vision.

The cold vests need to be prepped in advance to use and only provide relief for a few hours before needing to be recharged. With medications, patients must remember to take a pill every day and potentially travel to doctors' offices to get corticosteroid injections. Furthermore, there can be significant long term costs associated with long term medicinal treatment. The heat exchanger device is ready to use at all times, and can provide continuous cooling for 51 minutes, so long as there is ice readily accessible. After this time, all the ice will have melted and will need to be replaced.

Furthermore, the heat exchanger device must be carried around, imposing new difficulties on the user in everyday tasks like driving a car, shopping at a store, cleaning the house, exercising, and watching over children. The lightweight vest can be hidden under clothing, and the medicinal imposes no physical burden on the user beyond either taking a pill daily or traveling to a physician for treatment.

Generally speaking, removing large quantities of blood from the body is ill advised. The one medical practice for which this is common used is dialysis (treatment for kidney failure), where they use a catheter to remove and the blood. Many complications arise with this process. A study done by a research group in China with 865 patients found, “catheter-related complications included catheter-related infection (catheter exit-site infection, catheter tunnel infection and catheter-related bloodstream infection), catheter dysfunction (thrombosis, catheter malposition or kinking, and fibrin shell formation) and central vein stenosis” [30]. These complications would all still remain with the heat exchanger device, as they are relating strictly to the process of removing blood from and returning it to the body. Additional risk factors would be associated with this device, as it is designed so that the patient is up and moving while the device is in use - not while the person is stationary and in a disinfected room. Movement would also pose the added risks of leaks, which could lead to large amounts of blood loss.

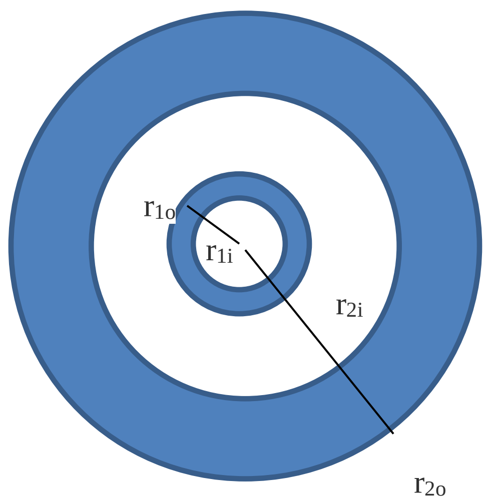
Beyond the complications and risks that are associated with removing blood from the body, are those that come with the tube-side material. The heat exchanger uses aluminum as the tube side material, due its low resistivity to heat transfer. Aluminum can however, be toxic to humans. High levels present in the bloodstream can lead to neurocognitive deficits, interruptions in the nervous system, kidney failure and even mortality in cases of prolonged exposure [31]. While an aluminum oxide layer may be formed on the inside of the tube, this is still toxic when in high levels in the bloodstream [31]. This oxide layer is stable for pH values between 4 and 9 [32]; the pH of blood is typically between 7.35 and 7.45, making it well within range [33]. Thus, there is potential that the threat of aluminum poisoning would be mitigated through the formation of this layer. These serious and negative effects of the aluminum would likely outweigh its benefit as far as practical application of the device is concerned.

In addition to material implications, it is important to look at the physiology of the experiment. While a 1 degree temperature change may seem small, there is a large potential for adverse and negative physiological effects upon return of the cooled blood to the body. Induced hypothermia ($T=35$ ºC) is popularly used in cardiac surgery due to the protective effects on the heart [34]. This technique infuses cold fluid into the bloodstream. The core body temperature needs to carefully monitored throughout this process, as it was found that a drop in temperature just 0.6 degrees C more than the target value resulted in increased mortality [34]. While this device is designed to take the body temperature to just below what it would normally be, the core body temperature of the user would have to be carefully monitored to ensure that the machine was not over-cooling.

It should also be noted that this design expects the heart to pump the blood through the heat exchanger. The average healthy adult male heart has a power of 2 W [35], it was calculated that the additional power required to move the blood through the heat exchanger would be .0017 W. As this is a very small addition, it can be assumed that the heart would be able to handle this additional workload. It should however, be noted that users may be at an increased risk for heart failure, which is often seen in overweight patients due to the increased workload on the heart [34]. Not only would the heart be doing extra work, but the body may also present signs of shock. The volume of blood required to fill the tube will be 0.608 L. The body begins to show signs of hypovolemic shock after losing 0.5 L of blood. As this volume of blood will be consistently out of the body, the user may exhibit some signs of hypovolemic shock.

Overall, the heat exchanger device is heavier and bulkier than its competition. Use of the device does not necessitate advance preparation like the vests do, and the device provides continuous cooling (with ice replacement), whereas the vests lose their cooling ability after only a few short hours and dosage must be re-administered routinely in order to provide continuously cooling. It is the most expensive out of all the options, but becomes financially competitive when assessing long term costs and treatment. The medical complications associated with the device would likely make it completely impractical for use.

RESULTS



ASPEN Results
r_{1i} = 0.0127m
r_{1o} = 0.02m
r_{2i} = 0.026m
r_{2o} = 0.03m
Single Pass Countercurrent Double Pipe
Tube Composition is Aluminum 3003
Length of tube (L) = 1.2192m
Average Velocity of water (v) = 0.09 m/s
Average Velocity of blood (vb) = 0.15 m/s
Overall Heat Transfer Coefficient (U) = 0.23 kW/m^2K
Inside of tube is same temperature as blood
Area (A) = 0.1 m^2

Given Parameters HOT STREAM: Blood, Tube
Mass flow rate of hot stream (mh) = 0.08 kg/s
Specific Heat of Blood (Cph) = 3.49 kJ/kg k
Temperature In for Hot Stream (Thi) = 38°C = 311 K
Temperature Out for Hot Stream (Tho) = 37°C = 310 K

Given Parameters COLD STREAM: Water, Shell
Mass flow rate of cold stream (mc) = 0.08 kg/s
Specific Heat of Water (Cpc) = 4.189 kJ/kg k
Temperature In for Cold Stream (Tci) = 1°C = 274 K

Researched Values
Kinematic Viscosity of Water at 274K (V) = 1.7E-6 m^2/s [38]
Coefficient of Convective Heat Transfer of Transitioning Water in Pipe (h) = 10,000 W/m^2K [39]

K value of Aluminum 3003 (k) = 190 W/mK [40]
Kinematic Viscosity of Blood at 311K (Vb) = 2.57e-6 m^2/s [41]
Density of Blood (ρ) = 1060 kg/m^3 [42]

Rate of heat transfer calculation:

$$q = m * Cp * dT = \ 0.08 \frac{kg}{s} * 3.49 \frac{kJ}{kg * K} (38\ C - 37\ C) = 0.279\ kW$$

Aspen value = 0.3 kW

The difference between the rate of heat transfer calculated and the ASPEN value is small only 0.021 kW. Any variation is most likely due to the change in specific heat of the fluids through the pipe, or ASPEN isn't precise enough.

Change in water temperature calculation:

$$q = 0.279\ kW = \ 0.08 \frac{kg}{s} * 4.189 \frac{kJ}{kg * K} (To\ C - 274\ C) \rightarrow Tco = 1.83\ C$$

Aspen value = 1.83°C

There is no difference between change in water temperature calculated and the ASPEN value.

Area check

$$A = 0.1\ m^2 = \ 2\pi(0.0127m)(L) \rightarrow L = 1.253\ m$$

Aspen value = 1.2192m

The difference between the area calculated and the ASPEN value is only 0.0338m. The variation in the area calculation most likely arises from the method ASPEN used to calculate the area and our method. ASPEN utilizes its value for the overall heat transfer coefficient and its values for the resistances between the inside and outside of the pipe, while our team used the given outer radius to calculate the area.

Overall Heat Transfer Calculation using Temperatures:

$$dTlm = \frac{37K - 35.17K}{\ln(\frac{37K}{35.17K})} = 36.077K$$

$$U = \frac{q}{A * dTlm} = \frac{0.279kW}{0.1m^2 * 36.077K} = 0.077 \frac{kW}{m^2K}$$

Aspen Value = 0.23 kW/m^2K

The difference between the overall heat transfer coefficient calculated and the ASPEN value is only 0.153 kW/m^2K. For calculating the overall heat transfer, two different methods were utilized. The first method used the temperatures of the fluids at the inlet and outlet. The number calculated varied slightly from ASPEN's value. This discrepancy most likely arises from variation in the rate of heat transfer and variation in the overall heat transfer coefficient as detailed above.

Overall Heat Transfer Calculation using Resistances:

$$Re = \frac{vD}{V} = \frac{0.09\frac{m}{s} * 0.0525m}{1.7 * 10^{-6}\ m^2/s} = 2779\ (Transitioning)$$

$$R\ conduction = \frac{\ln(\frac{ro}{ri})}{2\pi * k} = \frac{\ln(\frac{0.02m}{0.0127m})}{2\pi * 190\frac{W}{mK}} = 0.38\frac{K}{kW}$$

$$R\ convection = \frac{1}{hA} = \frac{1}{10{,}000\frac{W}{m^2K} * 0.1m^2} = 1\frac{K}{kW}$$

$$U = \frac{1}{A\Sigma R} = \frac{1}{0.1m^2 * \left(0.38\frac{K}{kW} + 1\frac{K}{kW}\right)} = 0.96\frac{kW}{m^2 * K}$$

Aspen Value = 0.23 kW/m^2K

The difference between the overall heat transfer coefficient calculated and the ASPEN value is only 0.73 kW/m^2K. The second method utilized used resistance calculations. From this, some variation between our value and the ASPEN value was present. Most likely this arises from differences in the h value used to calculate the resistance due to convective heat transfer. Our method for finding the h value was found by calculating a Reynolds number to determine the regime of flow, then looking up an h value that would most likely fall within that regime of flow. ASPEN most likely has more accurate data or a calculation to determine the h value.

Efficiency Calculation:

$$\varepsilon = \frac{\mathrm{dTh}}{Thi - Tci} = \frac{1\ K}{311K - 274K} = 0.027$$

Pressure Drop Calculation:

$$Re = \frac{0.15\frac{m}{s} * 0.0254m}{2.57 * 10^{-6}\ m^2/s} = 1482.5(Laminar)$$

$$f = \frac{64}{Re} = 0.0432$$

$$h\ major = \frac{2fLvb^2}{D * g} = \frac{2 * 0.0432 * 1.2192m * \left(\frac{0.15m}{s}\right)^2}{0.0254m * \frac{9.81m}{s^2}} = 0.009\ m$$

$$dP = \rho gh = 1060\frac{kg}{m^3} * 9.81\frac{m}{s^2} * 0.009\ m = 99\ Pa$$

Aspen Value: 23 Pa

The difference between pressure drop calculated and the ASPEN value is only 76 Pa. Since pascals are a very small unit of pressure, this is not a significant difference. This is most likely due to the kinematic viscosity of blood value being for an environment static at 311 K, but the temperature of the environment changes as it passes through the heat exchanger.

Cooling Vest Parameters
K value of skin (k)= 0.209 W/mK [43]
Width of Epidermis at chest (L) = 0.0005m [44]
Area of Chest and Back (A) = 0.855 m^2 [45]
Coefficient of Natural Convective Heat Transfer for Water = 3000 W/m^2K [38]

$$R\ conduction = \frac{\mathrm{L}}{k * A} = \frac{0.0005\mathrm{m}}{0.209\frac{W}{m^2 * k} * 0.855m^2} = 2.798\frac{K}{kW}$$

$$R\ convection = \frac{1}{h * A} = \frac{1}{3000\frac{W}{m^2K} * 0.855m^2} = 0.39\frac{K}{kW}$$

$$q = \frac{\mathrm{dT}}{\Sigma R} = \frac{(38\ C - 37\ C)}{\left(2.798\frac{K}{kW} + 0.39\frac{K}{kW}\right)} = 0.314\ kW$$

Hand calculations were also performed on a cooling vest apparatus. It was determined that a cooling vest would have a slower rate of heat transfer, but would eliminate a lot of the significant health hazards presented by our current design.

TEMA sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.:	Your Reference:				
5	Date: Rev No.:	Job No.:				
6	Size : 51 - 1219.2 mm	Type: BDM Horizontal		Connected in: 1 parallel 1 series		
7	Surf/unit(eff.) 0.1 m^2	Shells/unit 1		Surf/shell(eff.) 0.1 m^2		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Water		Blood	
11	Fluid quantity, Total	kg/s	0.08		0.08	
12	Vapor (In/Out)	kg/s	0	0	0	0
13	Liquid	kg/s	0.08	0.08	0.08	0.08
14	Noncondensable	kg/s	0	0	0	0
15						
16	Temperature (In/Out)	°C	1	1.83	38	37
17	Bubble / Dew point	°C	/	/	/	/
18	Density Vapor/Liquid	kg/m^3	/ 1005.68	/ 1005.45	/ 1060	/ 1060
19	Viscosity	mPa-s	/ 1.4295	/ 1.4056	/ 0.727	/ 0.727
20	Molecular wt, Vap					
21	Molecular wt, NC					
22	Specific heat	kJ/(kg-K)	/ 4.197	/ 4.197	/ 3.49	/ 3.49
23	Thermal conductivity	W/(m-K)	/ 0.57	/ 0.571	/ 0.5192	/ 0.5192
24	Latent heat	kJ/kg				
25	Pressure (abs)	bar	1.01325	1.01288	1.01325	1.01302
26	Velocity (Mean/Max)	m/s	0.09 / 0.09		0.15 / 0.15	
27	Pressure drop, allow./calc.	bar	0.20684	0.00037	0.11013	0.00023
28	Fouling resistance (min)	m^2-K/W	0		0 0	Ao based
29	Heat exchanged 0.3	kW		MTD (corrected) 36.08		°C
30	Transfer rate, Service 54.8		Dirty 230		Clean 230	W/(m^2-K)
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**	
32			Shell Side	Tube Side		
33	Design/Vacuum/test pressure	bar	3.44738 / /	3.44738 / /		
34	Design temperature	°C	76.67	76.67		
35	Number passes per shell		1	1		
36	Corrosion allowance	mm	3.18	3.18		
37	Connections In	mm	1 38.1 / -	1 / -		
38	Size/Rating Out		1 38.1 / -	1 / -		
39	Nominal Intermediate		/ -	/ -		
40	Tube #: 1 OD: 40 Tks. Average 7.3 mm Length: 1219.2 mm Pitch: m Tube pattern: 0					
41	Tube type: Plain Insert: None Fin#: #/m Material: Aluminum 3003					
42	Shell Carbon Steel ID 52.5 OD 60.32 mm			Shell cover -		
43	Channel or bonnet Carbon Steel			Channel cover -		
44	Tubesheet-stationary Carbon Steel -			Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel Type Unbaffled Cut(%d) Spacing: c/c mm					
47	Baffle-long - Seal Type				Inlet mm	
48	Supports-tube U-bend 0 Type					
49	Bypass seal Tube-tubesheet joint Expanded only (2 grooves)(App.A 'i')					
50	Expansion joint - Type None					
51	RhoV2-Inlet nozzle 5 Bundle entrance 1 Bundle exit 1 kg/(m-s^2)					
52	Gaskets - Shell side - Tube side Flat Metal Jacket Fibe					
53	Floating head -					
54	Code requirements ASME Code Sec VIII Div 1 TEMA class Not TEMA, Code only					
55	Weight/Shell 79.9 Filled with water 81.7 Bundle 6.6 kg					
56	Remarks					
57						
58						

CONCLUSION

Based on the discussion of the feasibility, cost, weight and competition it is our recommendation that this heat exchanger not be used. The risks and complications associated with use far outweigh the benefits. A steady state heat exchanger is not the best option to use, due to the implications it places the user, including needing an input, as well as weight and size. Currently, it seems that the best option is to continue using the cooling jacket, which needs to be replaced every 2.5 hours and is an example of unsteady state heat transport.

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STATEMENT OF WORK

Tylar Farmer did the hand calculations, the Aspen work as well as justification for shell-side material. Hannah Meyer did the intro, conclusion, feasibility discussion and editing. Anna Tomani did the background and discussion of cost, weight, pressure drop, tube-side material and competition. All 3 group members attended meetings and helped as needed with other sections.