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Plate and Frame Heat Exchanger

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By

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MET 495

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Abstract

Heat exchangers are a commonly used device in many different industries, with many different applications. The heat exchanger used in the brewing program here at CWU is a brazed plate and frame heat exchanger, so it cannot be taken apart for cleaning. Due to this, the overall efficiency of the heat exchanger will be reduced, causing fouling, because of the buildup of brewing material. In order to effectively combat this fouling, a heat exchanger must be constructed that can be disassembled for cleaning, and then reassembled with ease, while still being able to perform the same amount of heat transfer as the brazed system. Specifically, a gasketed plate and frame heat exchanger was constructed for this purpose, which utilizes rubber gaskets to seal the system, instead of brazing. This heat exchanger was constructed using twenty stainless steel plates, with four flow holes punched for the fluid paths, and arranged with the attached gaskets in a cross flow pattern. To test the effectiveness of this system, the heat exchanger will operate using cold tap water to cool down water heated to approximately 200 °F. The output temperature of the water will be measured, in order to see how well the heat exchanger is able to transfer heat between the two fluids. The results of this test will indicate the viability of this system, state the specific rate of heat transfer within this system, and compare this value to the previously utilized brazed heat exchanger.

Introduction

Objective:

The main objective of this project is to design and construct a plate and frame heat exchanger that can be utilized in the department's brewing system. Currently, the plate and frame heat exchanger used for brewing is brazed together, and thus cannot be taken apart. Due to this, the brazed heat exchanger cannot be cleaned, and has a buildup of hops, and other various brewing solids, which cannot be cleaned out. This new heat exchanger would utilize gaskets and bolts to lock together, and be able to taken apart for cleaning. Additionally, this would allow the new plate and frame heat exchanger to be modular, and allow for the addition and subtraction of extra heat exchanger plates, to increase or decrease the rate of heat transfer of the system.

Function Statements:

For this heat exchanger system, there are several key objectives that must be met. This heat exchanger will operate for fluid to fluid conditions, between a boiling brewing wort, and cold tap water. The key function statements can be seen below:

- To allow a heat exchange between two fluids of different temperatures.
- Capable of cooling brewing wort to a temperature where yeast can be added.
- Be small enough to allow for easy placement and movement.
- Designed so that the system can be taken apart and cleaned.
- Allow for additional plates to be added, or subtracted, from the system if required.

Requirements:

The key requirements for this heat exchanger are to at the very least match the heat exchanging capacities of the previously used system. Additionally, this system must be modular, and be able to be taken apart for cleaning. The main requirements for the plate and frame heat exchanger are below.

- Take boiling wort from 200°F - 212°F to a maximum temperature of 80°F (preferably 70°F).
- Utilize tap water at ~54°F - 60°F for cooling.
- Be constructed of 20-30 stainless steel plates.
- Plate dimensions must be ~8.75" x 4" at ~1/32" thick (24 gauge SS).
- Properly utilize rubber gaskets to prevent any leaking in the system.
- Use no more than 8 bolts to lock the heat exchanger plates together, in order to have adequate clamping forces on the gaskets.
- Operational at 1 GPM flow rate for the wort channel.
- With stand a maximum of 100 psi pressure load.
- The device must be able to be dissembled and cleaned within 5 minutes.

Success Criteria:

The main success criteria for this project, is to perform the same amount of heat transfer as the previously used brazed heat exchanger. Mainly, the heat exchanger must be able to take ~200 °F wort down to ~ 70 °F .Along with this, the system must be easily taken apart for regular cleaning, and allow for plates to be added and subtracted as needed. Assuming these goals are met, then this project will be successful.

Scope:

This project will focus on the design and manufacturing processes for this heat exchanger. The biggest hurdle will be designing the plates require for the system, and finding a way to press a corrugated pattern into the thin stainless steel. For this, ~1/2" thick steel plates will be CNC machined with the plate patterns, and be used to press the pattern into the thin stainless steel. Additionally, the gaskets must fit into the grooves of the plates. A fairly basic steel-rubber adhesive will be utilized. Overall, the project will focus on the design and construction of a fairly basic modular plate and frame heat exchanger.

Benchmark:

To make sure that this heat exchanger will operate well enough to be used for the brewing system, the benchmark will be to be at least as effective as the currently in use heat exchanger. The current heat exchanger has been in use for quite some time, and thus is fairly corroded with brewing solids. This new heat exchanger must be able to at the very least match the capabilities of the previous one. The easiest way of testing this will be to attach thermocouples to each port on the heat exchangers and compare how well they cool down hot water, as a substitute for boiling wort.

Engineering Merit:

The merit in this project is in optimizing an older heat exchanger design, in order to be able to disassemble the system in order to allow cleaning. Modular optimization comes into play in this project, in being able to add and subtract plates in the heat exchanger, to obtain a better overall heat transfer between liquids.

Additional merit can be found in the application of fluid dynamics and heat transfer for the analysis required in the project. In order to calculate the optimal heat transfer rate for this system, the heat transfer equation: $Q = U*A*\Delta T_{lm}$. Advanced analysis can also incorporate the Reynolds number for both fluids flowing into the exchanger, and calculating their heat transfer coefficients, via Nusselt numbers, in the equation: $Nu = hL/k$.

Manufacturing processes also come into play in this project. In order to produce the plates required for the heat transfer, a press must be designed in order to indent thin stainless steel sheets with a corrugated like pattern, to allow for better fluid flow, and better heat transfer.

Design and Analysis

Analytical Approach:

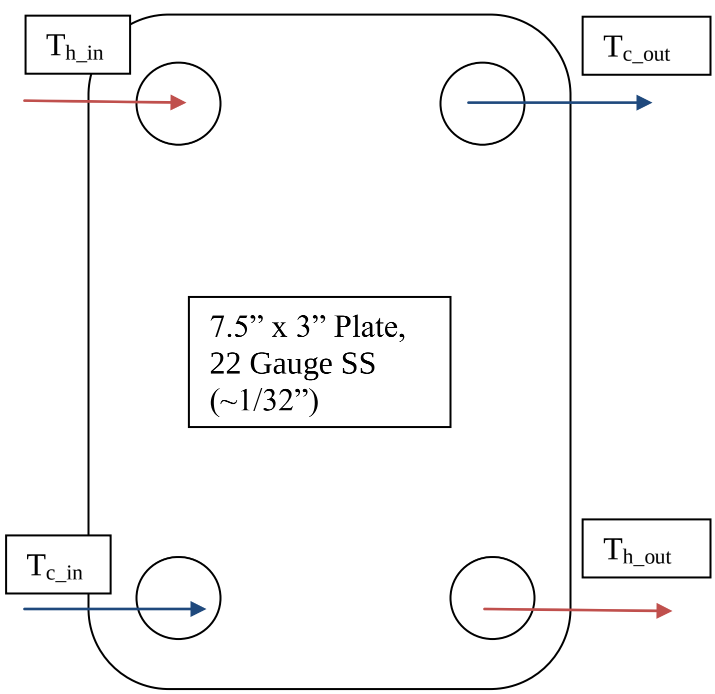
The initial approach to the analysis required for this heat exchanger, was a bit complex. The first attempt for the analysis of this system was done trying to solve for the overall coefficient of heat transfer, U (BTU/h-ft^2-°F), via calculation of each fluid flows heat transfer coefficient, h (BTU/h-ft^2-°F). However, the calculation of h involves calculating each fluid's Reynolds number, and the associate Nusselt number for each flow path. Due to the unpredictable nature of fluids, the calculated values for these coefficients may not be extremely accurate. However, a U value of 360 BTU/h-ft^2-°F was calculated. From here, the rate of heat transfer was calculated using, $Q = UA\Delta T_{lm}$, to obtain a value of Q = 36,740 BTU/h. The calculations for these values can be found in Appendix A. However, as mentioned before this value is not going to be extremely accurate, so a second analysis was performed.

The second approach to the analysis for this heat exchanger was done using a nominal overall heat transfer coefficient. From *Fundamentals of Thermal-Fluid Sciences*[1], a nominal U value was found, specifically from Table 22-1. In the next section are the calculations for the heat transfer rate for this heat exchanger, the hand calculations can also be found in Appendix A. The second method of analysis, which will provide the ideal heat transfer rate, were derived with: Heat Transfer Equation: $Q = U*A*n*\Delta T_{lm}$

Hot Water:
T_{h_in} = 200 °F
T_{h_out} = 70 °F

Cold Water:
T_{c_in} = 60 °F
T_{c_out} = 150 °F

Diagram of heat exchanger plate:



Log Mean Temperature Difference:
$\Delta T_{lm} = \Delta T_1 - \Delta T_2 / \ln(\Delta T_1/\Delta T_2)$
$\Delta T_{lm} = 130°F - 90°F / \ln(130/90)$
$\mathbf{\Delta T_{lm} = 109\ °F}$

Overall Heat Transfer Coefficient:
$\mathbf{U_{nom} = 225\ BTU/h\text{-}ft^2\text{-}°F}$

Plate Area:
$A = (7.5\ in * 3\ in)(1\ ft^2 / 144\ in^2)$
$\mathbf{A = 0.156\ ft^2/Plate}$

Number of Plates:
n = 20 Plates

Heat Transfer:
$Q = U*A*n*\Delta T_{lm}$
$Q = 225\ BTU/h\text{-}ft^2\text{-}°F * 0.156\ ft^2/Plate * 20\ Plates * 109\ °F$
Q = 76640 BTU/h

Comparing the calculated heat transfer rate above, to the rate calculated using the heat transfer coefficients of both fluids, a difference of about a factor of two is seen. That being, the second method, which is more than likely going to give a more accurate results, is about twice as high as the original method. However, the values would be much closer if the same temperature values were used, since in the second analysis, more accurate temperature values were used. Due to this, the log mean temperature difference is almost twice as high in the second analysis, which is what is causing that factor of two difference. However, going back and substituting in the new area and log mean temperature values to the first analysis; you obtain a value of 122,690 BTU/h. This difference is now due to the difference in overall heat transfer coefficients between the two methods. The U value in the first analysis is much higher than the given range of possible values though, so it can be assumed that the second analysis gives a more realistic heat transfer rate, which is the value that will be used for the designs.

For the purpose of this project, the value of ***76,640 BTU/h*** will be used instead of the 122,690 BTU/h value, due to the inaccuracies of the first method of analysis. For comparison, a typical plate and frame heat exchanger can range in heat transfer rate from: Q = ~3,500 – 90,000 BTU/h. Looking at this range, the value of 76,640 BTU/h is near the upper limit for typical heat exchanger, although this analytical value may not necessarily be close to the actual heat transfer rate of the heat exchanger.

Visual Description:

The main components of this heat exchanger are the plates that will be constructed. These plates will be 8-3/4" x 4" in dimensions, and made of 24 gauge (0.024") T-304 Stainless Steel. This steel will be purchased through the machine shop, and will conform to ASME SA240 and ASTM A240 standards. The initial sketches for the plates can be found in Appendix B. Below are SolidWorks renditions of the basic plate design.

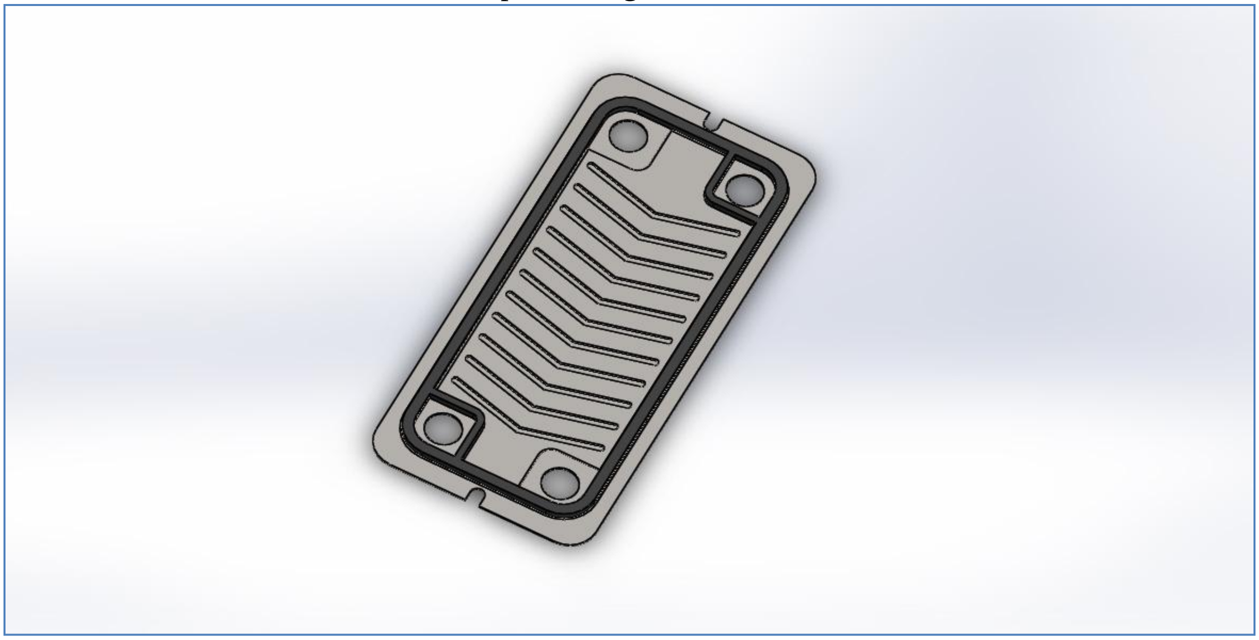


Figure 1. Single heat exchanger plate, Design 3: HE-001 with HE-002 gasket.

As seen in the SolidWorks rendition, the plate will have several small grooves, allowing for better flow and heat transfer. Additionally, the rubber gaskets that will be required are also shown in the model. When assembled, these plates will be stacked in an alternating pattern, to allow an alternating cross flow. The next two Figures are of the top and bottom plates. Notice that the top plate will have input and output tubing attached, and the bottom plate does not have any holes.

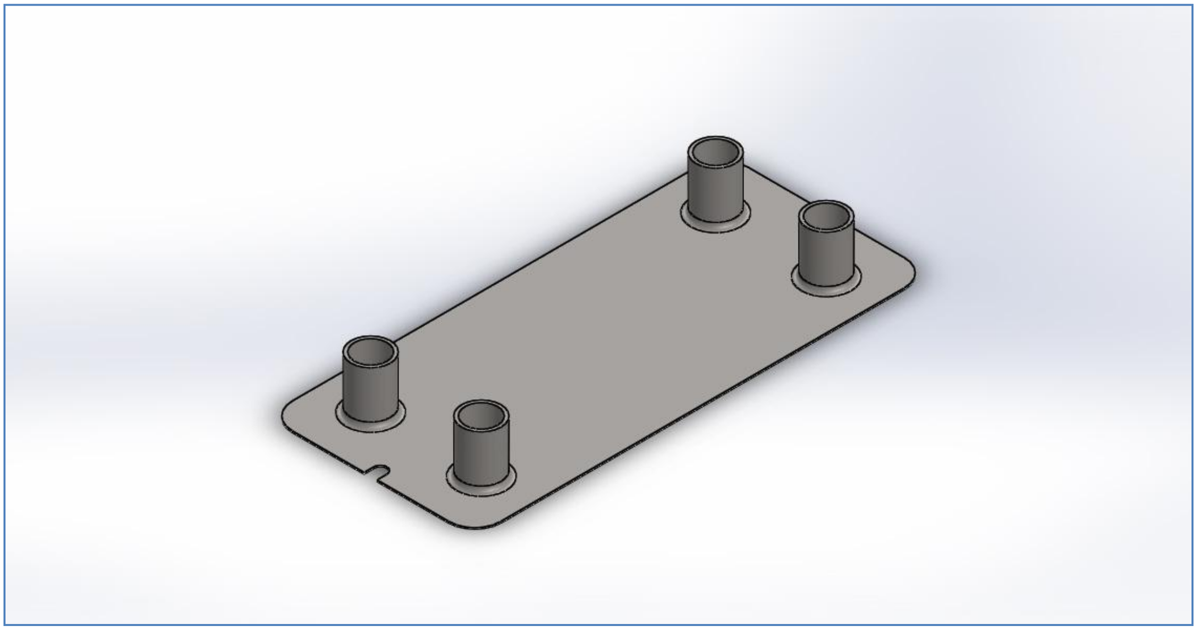


Figure 2. Top plate, HE-011.

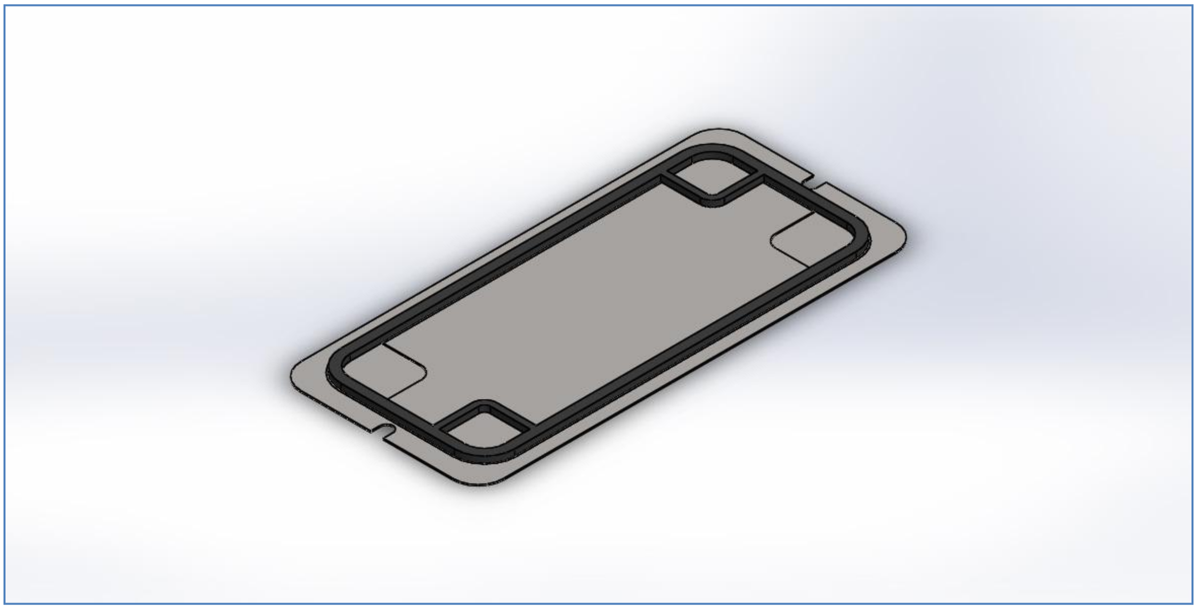


Figure 3. Bottom plate with gasket, HE-010 and HE-002.

Below are two SolidWorks renditions of the fully assembled heat exchanger. The first is of the entire system assembled, and the second shows a sectional view of the system.

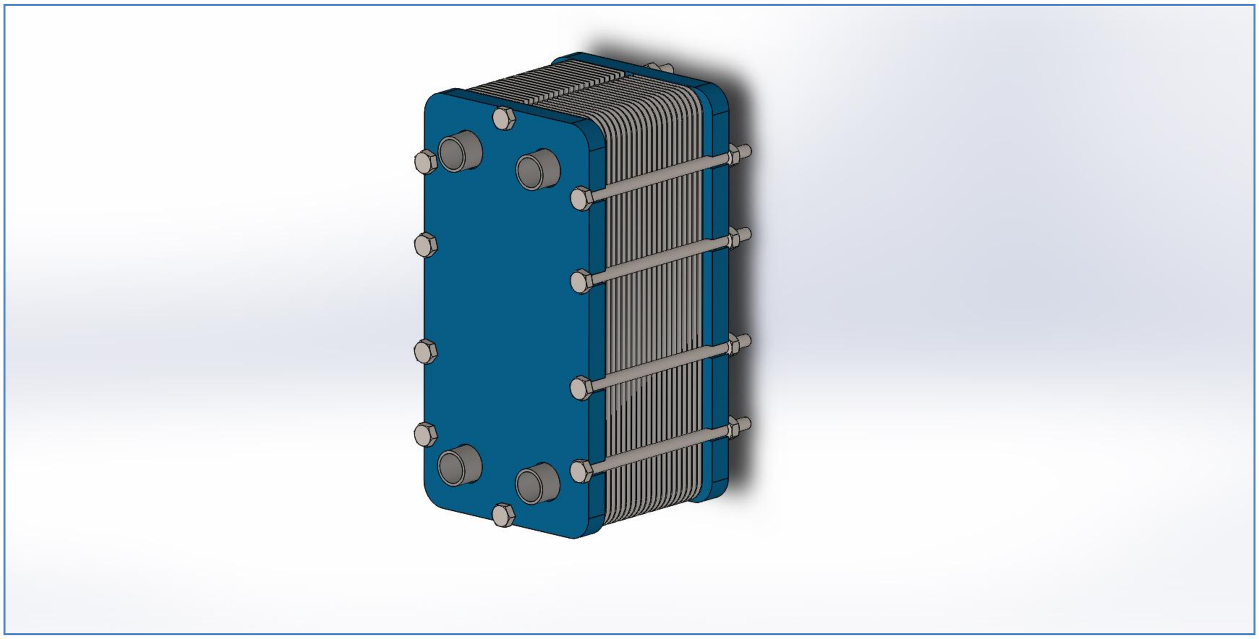


Figure 4. Fully assembled heat exchanger.

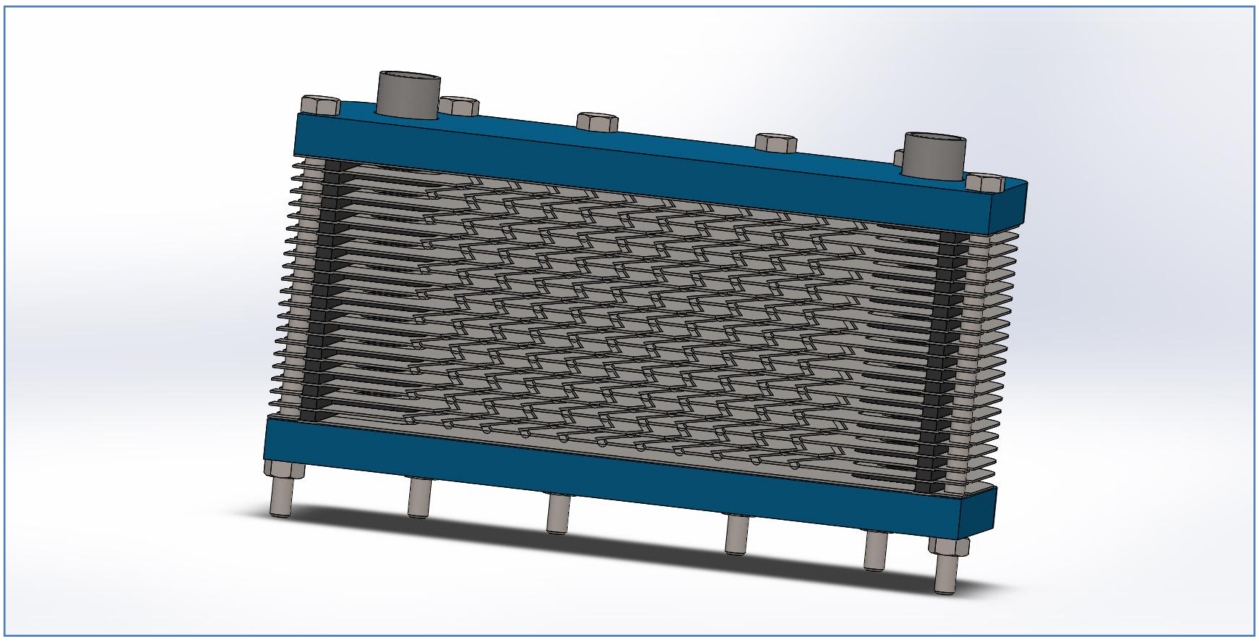


Figure 5. Sectional view of the heat exchanger.

Benchmark:

The main benchmark for this heat exchanger will be to match the heat transfer rate of the currently used brazed heat exchanger in the department's brewing system. The ideal benchmark for this heat exchanger will be to reduce the temperature of the input wort from ~200 °F down to 70 °F. The exact rate of heat transfer that will be used for a benchmark will be determined when testing begins. The previously used brazed heat exchanger will be tested first, which will also allow for a proper procedural method for testing to be developed. With the data taken from the brazed heat exchanger, the rate of heat transfer will be calculated, and this value can then be used for comparison and as a solid benchmark for the modular heat exchanger.

Performance Predictions

Analysis of this system generates a heat transfer rate of 76,640 BTU/h. This value is fairly high, when compared to the range of standard plate and frame heat exchanger. Due to this, it is expected that the system will actually generate a lower heat transfer rate. An approximate guess for this, assuming that we are only able to obtain ~60% of the maximum calculated value, gives a value of ***46,000 BTU/h***. This heat transfer rate is closer to a nominal value for many standard heat exchangers, and may very likely be a better value to expect.

Based on the calculations performed for this heat exchanger system, the predicted output temperature of the wort will be 75 °F. The wort temperature must be under 80 °F, and ideally will be 70 °F. Since it is generally difficult to be able to reach the ideal values initially, the first set-up of the heat exchanger is expected to generate a somewhat high, non ideal, wort output temperature. However, due to the modular nature of this heat exchanger, the addition of more plates should allow for a more ideal output temperature to be reached, although 75 °F will still be the predicted output temperature.

Scope of Testing and Evaluation:

The main testing for this project will come in measuring the actual output temperatures from the heat exchanger. The main objective of this system is to produce cooled wort at approximately 70 °F. Without performing testing on the currently utilized brazed heat exchanger, a more accurate temperature benchmark is currently unknown, although it will be assumed that this heat exchanger does reach ~70 °F. As mentioned previously, thermocouples will be utilized to measure these temperature values. Ideally, four K-Type thermocouples will be utilized, one connected to each flow channel, two for input and two for output. These thermocouples will then be connected to Fluke voltmeters, to measure temperature values. Every 15 seconds the temperature value of the system will be recorded, and an average value will be calculated from the data. This will allow for a more averaged value, and allow any irregularities to be seen. This set-up will be used exactly the same with the old brazed heat exchanger and the modular heat exchanger. Accurately measuring these temperature values will be the most important aspect of testing in this experiment.

The data collected from the testing will then be used to measure an approximate rate of heat transfer for both systems. These values can then be compared, where the log mean temperature difference of each system will be calculated. Although the rate of heat transfer for both systems will be looked at, as mentioned before, the main success requirement, and focus, of the testing will be to see the output temperature of the wort, and make sure that this temperature is adequately low enough.

Optimization:

There will be a few different ways that this system will be optimized. Once the system is fully assembled, additionally plates will allow for the optimization of output temperatures and heat transfer rates, assuming that the values vary from the calculated predictions. The number of plates in the heat exchanger will be able to vary from 20-30 plates, and the addition of plates will help to optimize the output temperature of the cooled fluid. However, the designs were done so that 20 plates should be sufficient, but the additional plates will allow for any adjustment if necessary, due to the assumptions that needed to be made in the calculations.

Optimization will also be performed in terms of the gaskets used in the heat exchanger. Since the plates in the heat exchanger will be pressed together, a suitable durometer of rubber must be selected in order to allow the gaskets to compress under a clamping load, but not compress enough to where the fluid flow becomes restricted. For this, three different durometer rubbers will be looked at for viability: 50, 60, and 70 duro rubber. Based on the figure below, and the calculations found in the appendix[2], it appears that 70 duro rubber will be the best choice, due to it compressing enough to allow the plates to fully contact and prevent any leaks, while not compressing too much to where flow will be restricted, which if the major problem with 50 duro rubber. Although 70 duro rubber is chosen, 60 duro rubber could be suitable, but 70 duro is a more commonly used rubber, and is cheaper to purchase.

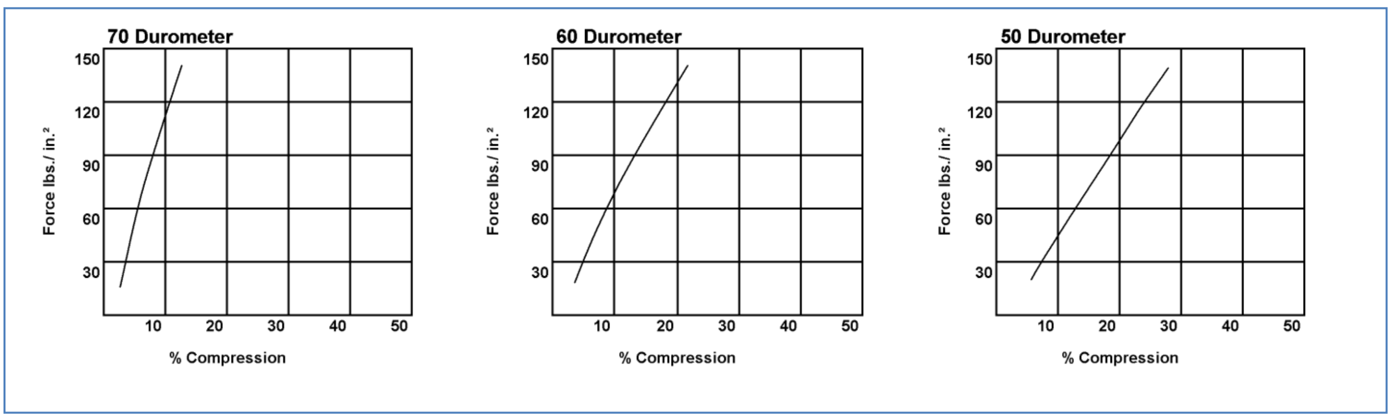


Figure 6. Durometer compression rates of rubber, Reference: Diversified Silicon Products Inc.

Operational Limits:

The main limit factors for this heat exchanger are the input water temperatures, and the flow rate at which these inputs enter the system. The hot water input must not exceed boiling temperatures; otherwise the rubber will begin to fail. Additionally, the system must not exceed over 100 psi of pressure, due to safety concerns of an untested heat exchanger system.

Methods and Construction

Plate Construction:

For this project, a method for constructing the heat exchanger plates must be determined. The method that will be used for the construction of these plates is to machine two press plates with the desired patterns for the heat exchanger plates. These plates will be CNC machined to have a top and bottom pattern, which will allow for the flat heat exchanger plates to be inserted in between and via the use of a hydraulic press, indent the desired pattern into the stainless steel heat exchanger plates. However, alignment must be taken into consideration for these press plates, and two alignment holes will be drilled through both plates, in order to prevent any misalignment during the pressing of the stainless steel. Additionally, extra grooves may be machined for alignment purposes of the stainless steel plates, in order to keep them properly centered.

Before the plates can be pressed however, they must be cut to size. This will be done utilizing the step-shear, in order to cut the plates to the required dimensions. Overall, at least thirty plates must be sheared to the correct dimensions, so this may be a very time consuming process. As shown in the earlier designs, the heat exchanger plates will require several holes, for flow and for alignment. These holes will be punched, due to how thin the plates are. There must be four 5/8” holes for the flow channels, and two 1/4” slotted holes for alignment.

Following the construction of the main plates, the front and back plates must also be machined. ½” steel will be utilized as, in order to make sure that the end plates are rigid, and do not allow any flex on the main heat exchanger plates, when they are under high pressure loads, at an upwards of 100 psi. The following images showcase the model for the press plates.

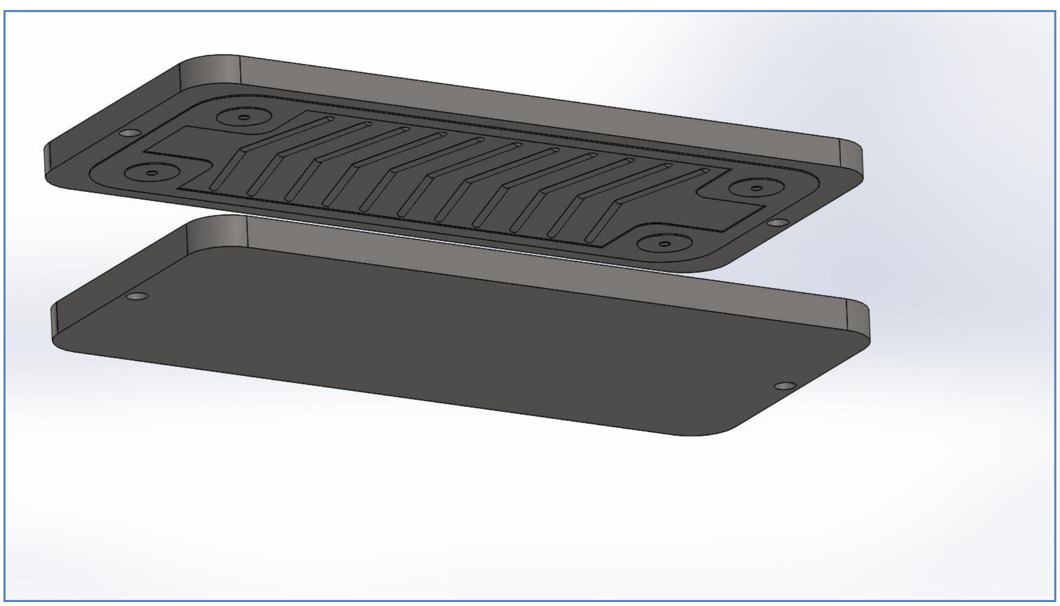


Figure 7. Top press plate shown.

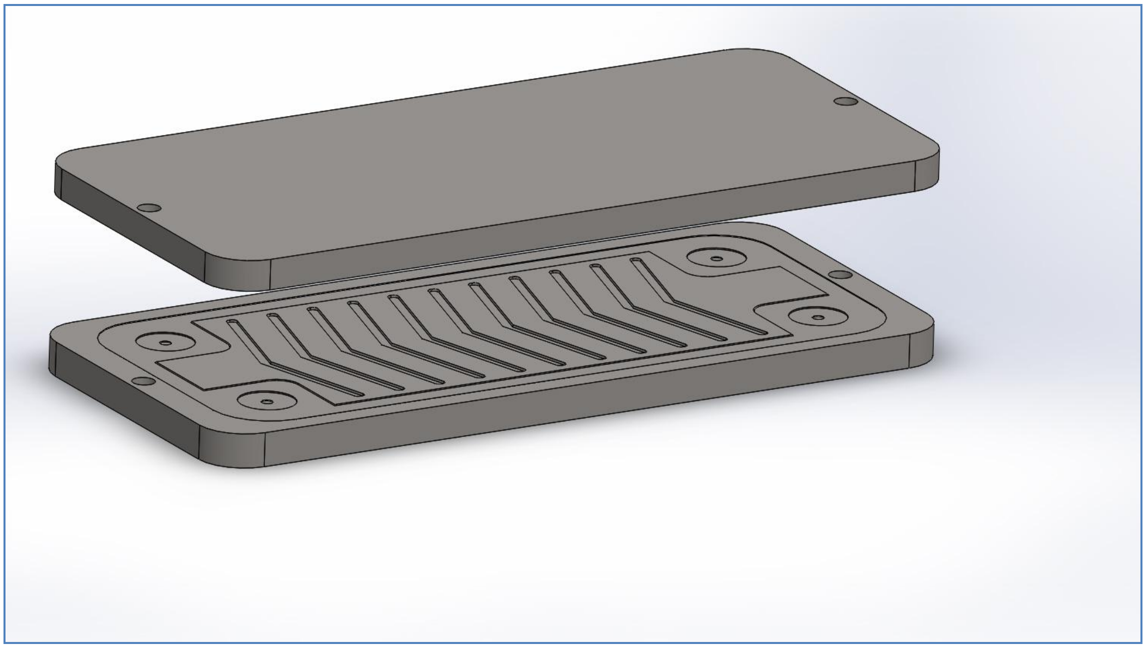


Figure 8. Bottom press plate shown.

Gasket Construction:

The gaskets for this heat exchanger will be constructed of 70 Duro Neoprene rubber. Due to the high cost of having these gaskets custom cut, the quotes ranged from $150-$300, just for 20 gaskets, they will be hand cut. This will be utilized by 3D-Printing out a stencil of the Gasket, from the SolidWorks model. The gaskets will then be cut out of the rubber sheets, via the use of the stencil.

Parts List:

This project will utilize several different parts, which are listed below:

- Stainless Steel plates.
  - The main component of the system.
- Rubber gaskets.
  - The gaskets will be attached to the SS plates, using DAP adhesive.
- ¼" Bolts.
  - Eight bolts will be utilized, to allow for sufficient clamping forces on the plates and gaskets.
- End Plates.
  - Front and back plates will be machined for the heat exchanger. The front plate will allow for fluid channels to enter.
- Press Plates
  - Plates must be machined to allow the 24 gauge Stainless Steel to be pressed to the desired shape.

The full parts list can be found in Appendix D.

Testing Methods

Testing Overview:

The main form of testing that will be performed in this project will be measuring the temperature output values of the heat exchanger. The most critical aspect of this device is that it must produce wort with an exit temperature of ~70 °F. All of the input and output temperatures will be measured utilizing thermocouples, similar to many thermodynamics and heat transfer labs. If possible, this project may be worked to coincide with the heat transfer class, and allow for some extra testing, and allow the students to see another application of the material that they are covering. With this data, a rate of heat transfer for the system can also be calculated, although as mentioned, the most critical thing for this heat exchanger is the wort exit temperature. So long as the heat exchanger has a sufficient rate of heat transfer to achieve this goal, then the project will be successful.

A secondary, although still important piece of testing that will be required for this system, is leakage testing. This testing will just be visual. For this heat exchanger to operate properly there must be no leakage in the system. In order to test for this, once the heat exchanger is fully assembled, a mock trial will be done using tap water, in order to make sure that the system does not have any leaks, and that the gaskets do a sufficient job of containing the working fluids of the heat exchanger. During this testing, the system will also be ramped up to higher operating pressures, to approximately 100 psi, make sure that the system will not fail under this load. The flow rate of the cooling water may be ramped up to allow for a greater amount of heat transfer, so the system must be able to allow for this increased load.

Testing Procedures:

1. Connect thermocouples to the input and output ports of the heat exchanger.
    a. This will require four thermocouples.
2. Attach each thermocouple to a multimeter, to record temperature values.
3. Connect the hot water hosing to the hot water input on the heat exchanger.
    a. Make sure no water is flowing yet.
4. Connect the cold water hosing to the cold water input on the heat exchanger.
    a. Make sure no water is flowing yet.
5. Connect both output hoses to both output ports on the heat exchanger.

6. Slowly begin to allow the cool water to flow through the heat exchanger.
7. After ~1 minute, allow the hot water to flow through the system.
8. Record the four multimeter temperature readings every 15 seconds.
9. Record data until running out of hot water.
10. Carefully detach hosing, and clean up the system/surrounding area.

Experimental Results:

The first tests performed were leakage tests, to make sure that the system would work properly. There were no leaks, and during this testing the back pressure and flow rate through each flow path was recorded. The two flow paths were the two copper colored hose attachments, and the two brass colored ones. For the temperature tests, the copper-copper flow path will be hot water, and the brass-brass flow path will be the cooling water.

Copper-Copper (Hot)		Brass-Brass (Cold)	
Pressure (psi)	Flow rate (GPH)	Pressure (psi)	Flow rate (GPH)
0.44	30	0.47	30
1.04	50	0.95	50
1.95	70	2.4	70
4	90	3.81	80
5.07	100	4.49	90
		5.5	95

The next set of testing data includes temperature and flow rate values for both flow paths. From this data, you can see that the heat exchanger is working, although not effectively as intended. During testing, it was noted that there appeared to be a small internal leak, so after testing the system was taken apart and the gaskets were sealed, so that the next test would hopefully yield better results. The second set of testing was not as successful as the first, and the full data sheets can be found in Appendix I.

Time (s)	$T_{H,In}$ (°C)	$T_{H,Out}$ (°C)	$T_{L,In}$ (°C)	$T_{L,Out}$ (°C)	$V_{H,Out}$ (GPM)	$V_{L,Out}$ (GPM)
30	39	32.7	22.3	26	1	1.6
60	40.6	33.9	22.7	26.8	1	1.7
90	41.5	34.6	23.1	27.6	1	1.8
120	42	35	23.5	28.6	1	1.7
150	42.3	35.3	23.9	29.8	1	1.7
180	42.5	35.5	24.3	30	1.1	1.8
210	42.5	35.7	24.9	31	1.1	1.7
240	42.5	35.8	25.1	32	1.1	1.7

Budget and Scheduling

Budget:

The budget for this project can be found in Appendix D. The major costs of this project will come from the steel. The estimated cost for the stainless steel required for the main plates is $29.07. Additionally, steel for the end plates must be purchased, and will cost an estimated $28.70, along with press plate material, which will be $22.52. So in total, the highest cost for this project is going to be in steel, totaling ~$110. However, the school will be covering the cost of the steel, so the project will actually be well under the original estimated budget of $156.38. To save money, the rubber gaskets will be custom cut, from a 3D printed stencil. The stencil cost $8.80 to print, while the rubber cost $27.72.

Scheduling:

The main schedule for this project can be found in Appendix E. This project is estimated to take 102.5 hours. The majority of the estimated time is expected to be during the construction phase. There will most likely be trial and error when it comes to perfecting the construction methods to make the plates. Additionally, more time will most likely be used to make several practice plates, that will not be used in the final assembly.

Detailing on the construction phase of this project, a majority of the time will be spent constructing the plates. It is estimated that the construction phase directly related to the plate manufacturing will take 22 hours. If there are any errors that occur during the initial place manufacturing phase, additional hours will tack on. Hopefully, this phase goes smoothly, since it is the most critical for the success of this project. Below is a smaller version of the full Gantt chart that can be found in Appendix E.

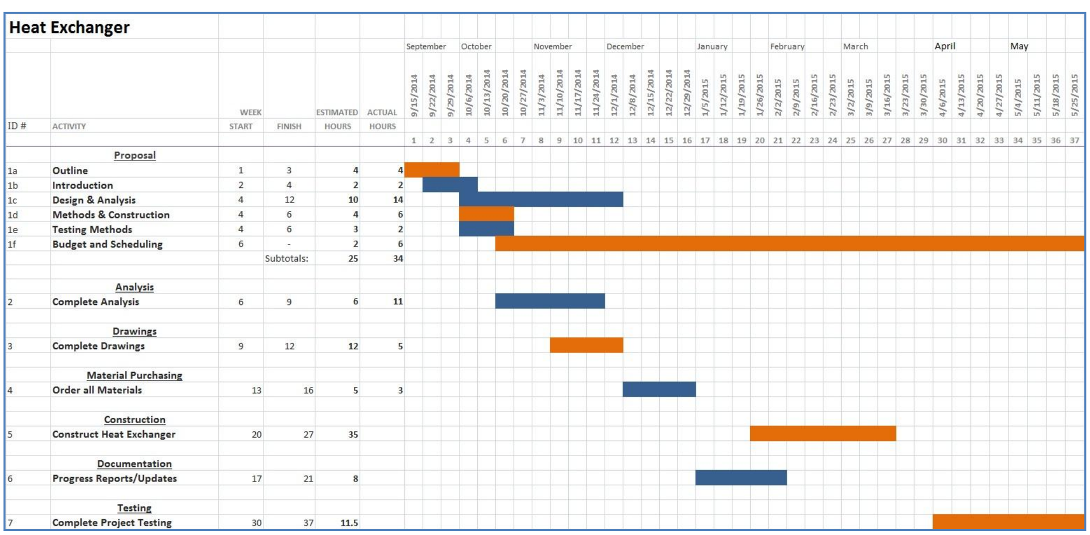


Figure 9. Condensed Gantt chart.

Milestones:

The major milestones of this project are listed below, along with the week that they will coincide with:

- Complete press plate machining. Week 21: 2/2/15
- Press all of the stainless steel plates, and attach gaskets. Week 24: 2/23/15
- Construct end plates for the heat exchanger. Week 25: 3/2/15
- Have the system fully assembled. Week 27: 3/16/15
- Perform leakage testing. Week 31: 4/13/15
- Fully complete testing of the system. Week 34: 5/4/15

Project Management:

The main aspect of project management in this project has been related to machines and personnel. In order to complete the construction aspect of this project, available school resources were utilized heavily. In order to machine the press plates, the CNC machines had to be utilized, along with the receiving help in order to generate the CNC code. Additionally, the 3D printer was utilized, so proper procedures had to be followed, along with additional help, in order to complete the related objective. Financially, the school also helped to support this project, by covering the cost of the steel, since the project in the end will be going back to the school.

Discussion

Design Evolution:

The design of this project has changed a great deal since the initial sketches. Initially, the main plates were designed to have more ridges, although these ridges would be shallower. The second design of the plates featured less ridges, but with a greater depth. The main purpose of the change is to help increase turbulence in the system, which will allow for a better heat transfer between the opposing fluids. Additionally, the initial plate designs did not include any sort of alignment system. The redesigned plates included two holes, at the bottom and top of the plate that will allow for two alignment rods. In the design and analysis section of this report, the current plate designs can be seen. In total, the plates have gone through three redesigns, and the images comparing each design can be seen below.

Another large change that has occurred since the inception of this project is the ideal thickness for the heat exchanger plates. Originally, the plates were going to be ~1/16" thick stainless steel. After analysis and comparison to other heat exchanger designs, this thickness has been reduced to less than 1/32". The thinner material will allow for a better heat exchanger between the fluids, and will also allow the steel to be formed much easier.

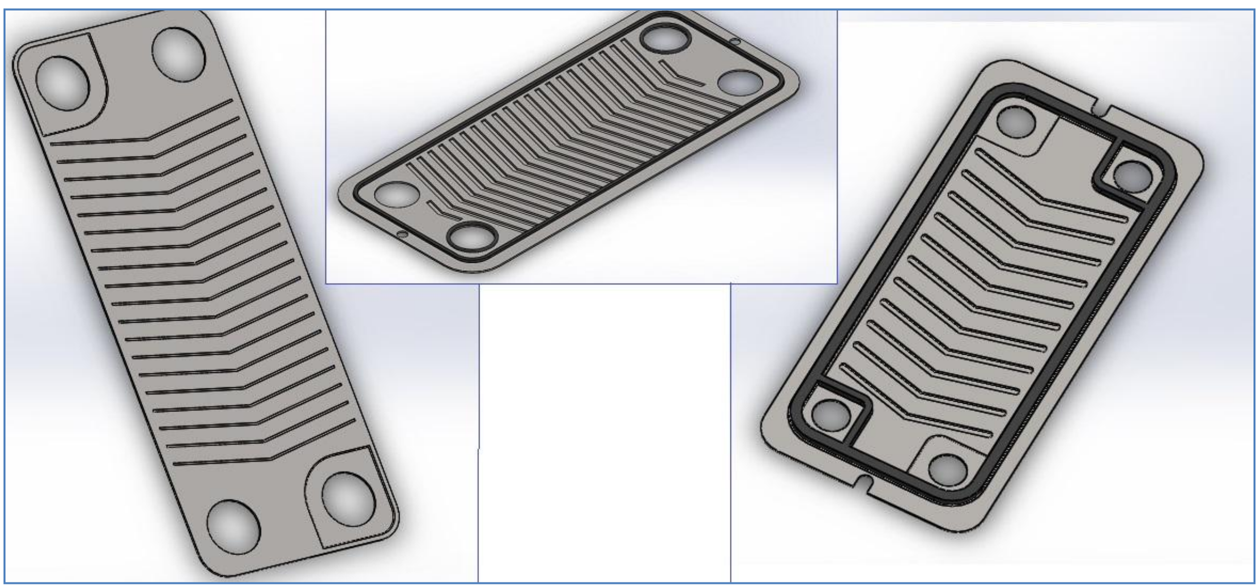


Figure 10. Comparison of the plate designs. Newest design is on the right, oldest on the left.

Risk Analysis:

Overall, this project does not have a high amount of associated risk. The two main events during the course of this project that may have some slight risk involved are the plate pressing and testing phases. During the plate pressing, a hydraulic cylinder will be utilized to supply enough force to yield the stainless steel, and form it to the desired shape. When dealing with equipment like this, there is always an inherent safety risk, although due to the small size of the plates, and relatively low required force, this should not be a huge safety risk. Additionally, when testing the system, if there is any leakage or failure of the gaskets, scalding hot water could be sent flying. However, the gaskets are fairly thick, and should prevent this from occurring.

Project Evolution:

Assuming that this project is successful, a commercial deal could be pursued. Due to the relatively low availability of modular heat exchangers, this project could become a product for smaller home-brewers looking to obtain a compact and functional heat exchanger. If this project were to continue further into commercialism, a good deal of money would have to be spent initially, to make higher quality press plates, and possible gasket dies. From here, these heat exchangers could be made quicker, while lowering the overall cost.

Conclusion

This project has great engineering potential. Heat exchangers are a large part of many different vital systems, ranging from HVAC applications to nuclear reactors. Having the opportunity to design and construct a heat exchanger allows for a better understanding and appreciation of how these devices affect many different aspects of the real world. The completion of this project will cement key concepts from the more non-intuitive theoretical classes, such as: thermodynamics, fluid mechanics, and heat transfer, while also tying in materials, manufacturing, and project management. Overall, this project can provide a great learning experience touching on many different aspects of engineering.

Acknowledgments

I would like to acknowledge the help that I have received through the duration of this project. Professor Beardsley has helped immensely in figuring out the main objectives of this project, and helped in several key design aspects. Additionally, Professor Pringle and Dr. Johnson have helped greatly in their critiquing of this proposal. Also, I Matt Burvee was a great helping in helping to obtain materials for this project, and help to figure out some of the details in the manufacturing processes. Finally, I would like to acknowledge the CWU MET department as a whole, for providing the resources that make the completion of this project possible.

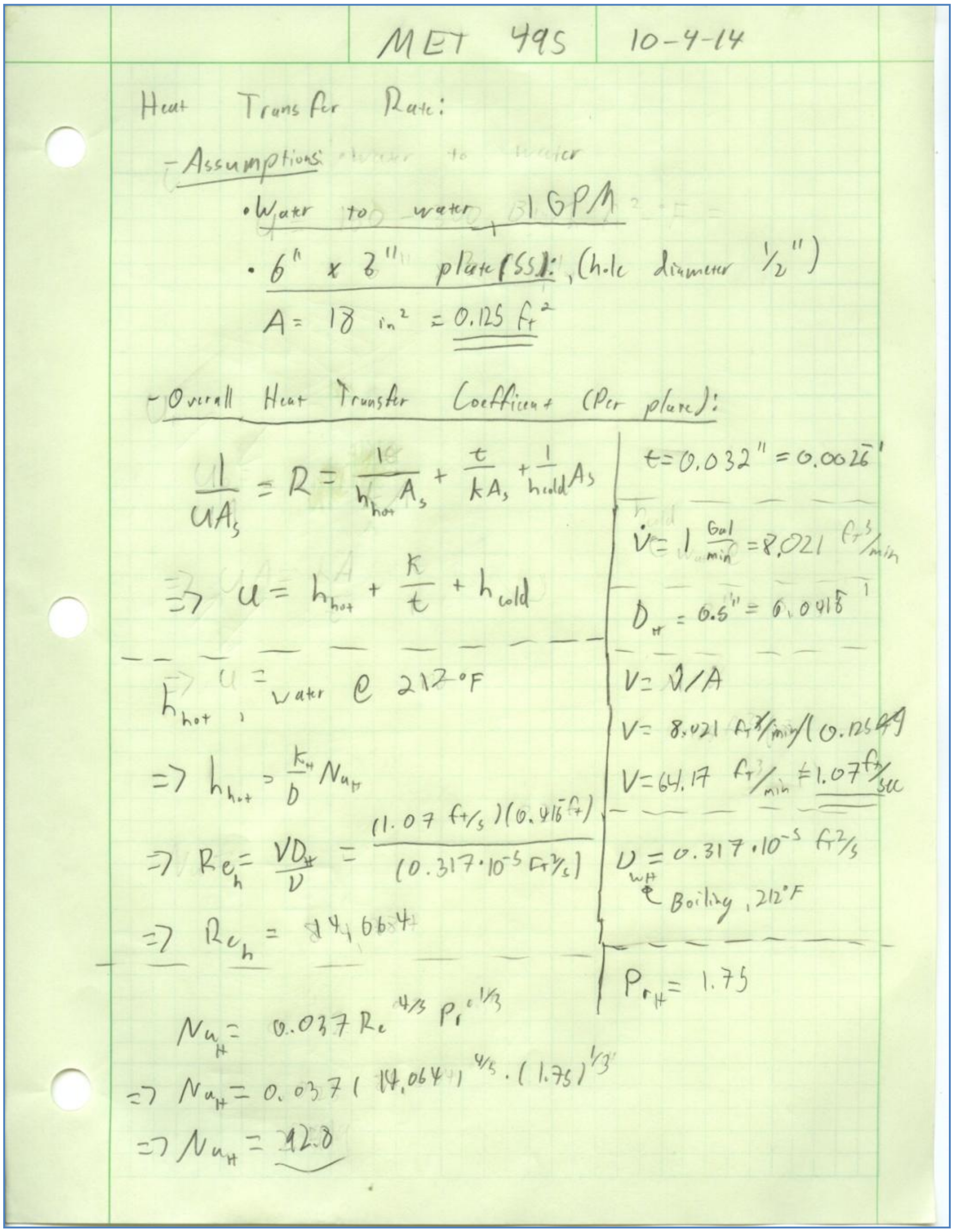
References

[1] Cengel, Y. Cimbala, J. Turner, R. (2011). *Fundamentals of Thermal Fluid Sciences*. McGraw-Hill.

[2] Diversified Silicone Products Inc. *Compression Force Graphs*. Retrieved from http://www.diversifiedsilicone.net/pdf/Compression_Force_Graphs2.pdf

Appendix A - Calculations

Initial calculations were done trying to calculate the exact overall heat transfer coefficient; U, in BTU/h-ft^2-°F. Due to the unpredictability associated with the fluids flowing in the heat exchanger, this analysis is not going to accurately predict the rate of heat transfer, although it will give a very broad ballpark estimate. *Fundamentals of Thermal-Fluid Sciences*[1] was utilized to find the appropriate equations for this analysis.



MET 495 10-4-14

Heat Transfer Rate:

- Assumptions:
  - Water to water, 1 GPM
  - 6" x 3" plate (SS), (hole diameter ½")

$A = 18\ in^2 = 0.125\ ft^2$

- Overall Heat Transfer Coefficient (Per plate):

$\frac{1}{UA_s} = R = \frac{1}{h_{hot} A_s} + \frac{t}{kA_s} + \frac{1}{h_{cold} A_s}$

$\Rightarrow U = h_{hot} + \frac{k}{t} + h_{cold}$

h_{hot}, water @ 212°F

$\Rightarrow h_{hot} = \frac{k_H}{D} Nu_H$

$\Rightarrow Re_h = \frac{VD_H}{\nu} = \frac{(1.07\ ft/s)(0.416\ ft)}{(0.317 \cdot 10^{-5}\ ft^2/s)}$

$\Rightarrow Re_h = 14{,}064$

$Nu_H = 0.037\, Re^{4/5}\, Pr^{1/3}$

$\Rightarrow Nu_H = 0.037(14{,}064)^{4/5} \cdot (1.75)^{1/3}$

$\Rightarrow Nu_H = 92.8$

$t = 0.032" = 0.0026'$

$\dot{V} = 1\ \frac{Gal}{min} = 8.021\ ft^3/min$

$D_H = 0.5" = 0.0416'$

$V = \dot{V}/A$

$V = 8.021\ ft^3/min / (0.125\ ft^2)$

$V = 64.17\ ft/min = 1.07\ ft/sec$

$\nu_{wH} = 0.317 \cdot 10^{-5}\ ft^2/s$ @ Boiling, 212°F

$Pr_H = 1.75$

MET 495 — 10-4-14

$$h_{hot} = \frac{k_H}{D} Nu_H$$

$k_H = 0.392 \frac{BTU}{h \cdot ft \cdot R}$

$$\Rightarrow h_{hot} = \frac{\left(0.392 \frac{BTU}{h \cdot ft \cdot R}\right)(92.8)}{(0.25\ ft)} = 146 \frac{Btu}{h \cdot ft^2 \cdot R}$$

h_{cold}, water @ 54 °F

$$\Rightarrow Re_c = \frac{V D_H}{\nu} = \frac{(1.07\ ft/s)(0.0416\ ft)}{1.407 \cdot 10^{-5}\ ft^2/s}$$

$$\Rightarrow Re_c = 3168$$

$\nu_{wc} = 1.407 \cdot 10^{-5}\ ft^2/s$ (@ ~54 °F)

$Pr = 9.44$

$k_c = 0.335 \frac{BTU}{h \cdot ft \cdot R}$

$$Nu_c = 0.332\, Re_c^{1/2}\, Pr^{1/3}$$

$$\Rightarrow Nu_c = 0.332(3168)^{1/2} \cdot (9.44)^{1/3}$$

$$\Rightarrow Nu_c = 39.5$$

$$h_{cold} = \frac{k_c}{D} Nu_c$$

$$\Rightarrow h_{cold} = \frac{0.335\ BTU/h \cdot ft \cdot R}{(0.25\ ft)}(39.5) = 52.9\ BTU/h \cdot ft^2 \cdot R$$

MET 445 10-4-11

$h_{hot} = 146 \ BTU/h \cdot ft^2 \cdot R$ | $k_{ss} = 8.6 \ \frac{BTU}{h \cdot ft \cdot R}$

$h_{cold} = 52.9 \ BTU/h \cdot ft^2 \cdot R$

$$\Rightarrow U = h_{hot} + \frac{k_{ss}}{n\,t} + h_{cold}$$

$$\Rightarrow U = 146 \ \frac{BTU}{h \cdot ft^2 \cdot R} + 52.9 \ \frac{BTU}{h \cdot ft^2 \cdot R} + \frac{8.6 \ BTU/h \cdot ft \cdot R}{(0.0025 \ ft)(20 \text{ plates})}$$

$$\Rightarrow U = 360.2 \ BTU/h \cdot ft^2 \cdot R$$

$$\dot{Q} = U A \Delta T_{lm}$$

$U = 360.2 \ BTU/h \cdot ft^2 \cdot R$

$A = 0.125 \ ft^2$

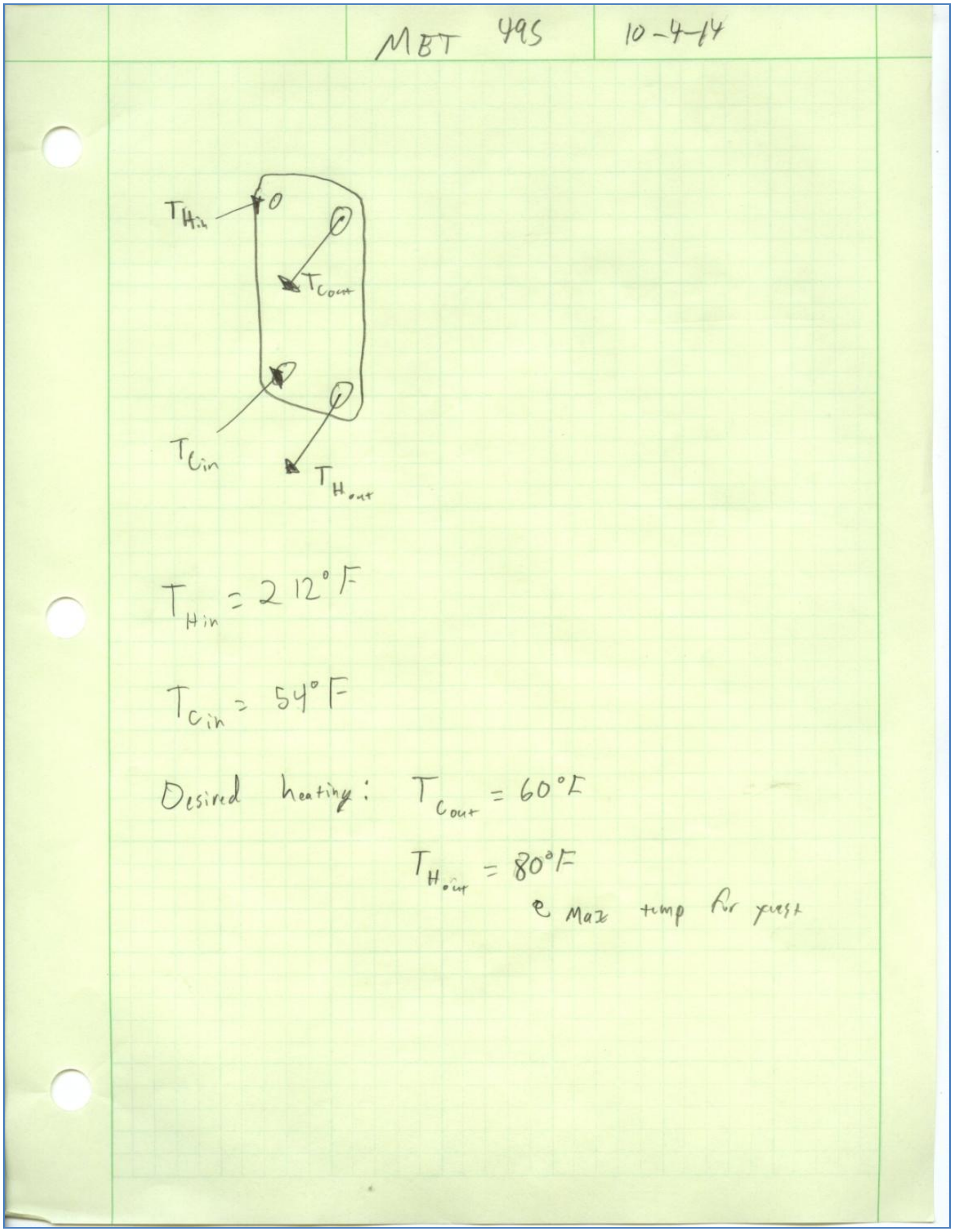
$$\Rightarrow \Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

$$\Rightarrow \Delta T_{lm} = \frac{(212°F - 80°F) - (60°F - 54°F)}{\ln(212°F - 80°F / 60°F - 54°F)} = 40.8°F$$

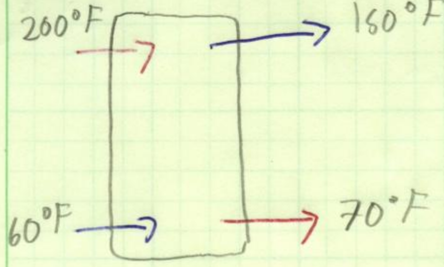
$$\dot{Q} = (360.2 \ BTU/h \cdot ft^2 \cdot R)(0.125 \ ft^2/\text{plate})(40.8°F)(20 \text{ plates})$$

$$\Rightarrow \dot{Q} = 36{,}740 \ BTU/h$$

Due to the difficulty of calculating the correct Reynolds number for both of the fluids, a second analysis was done, where the overall heat transfer coefficient, U, was taken from given values in *Fundamentals of Thermal-Fluid Sciences*. Specifically, Table 22-1 on page 932 was utilized to find a nominal U value. Additionally, more accurate temperature values were used.



MET 495



- Plate and Frame Heat Exchanger
- 7-½" x 3" plate
- 20 plates

Fundamentals of Thermal Fluid Sciences:

pg. 932

Overall Heat Transfer Coefficient, Water to Water:

$U = 180 - 300$ BTU/h-ft²-°F

$\Rightarrow U_{nom} = 225$ BTU/h-ft²-°F

- Assume U to be U_{nom}.

$\Delta T_{lm} = \Delta T_1 - \Delta T_2 / \ln(\Delta T_1 / \Delta T_2) = \dfrac{130\,°F - 90\,°F}{\ln(130/90)}$

$\Delta T_{lm} = \underline{109\ °F}$

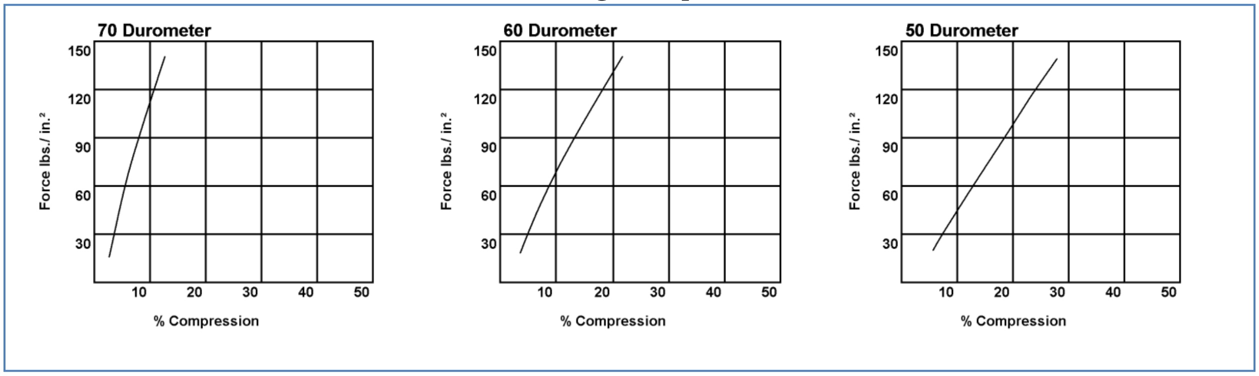
$A = (7\tfrac{1}{2}\ in \cdot 3\ in)\left(\dfrac{1\ ft^2}{144\ in^2}\right) = 0.156\ ft^2$

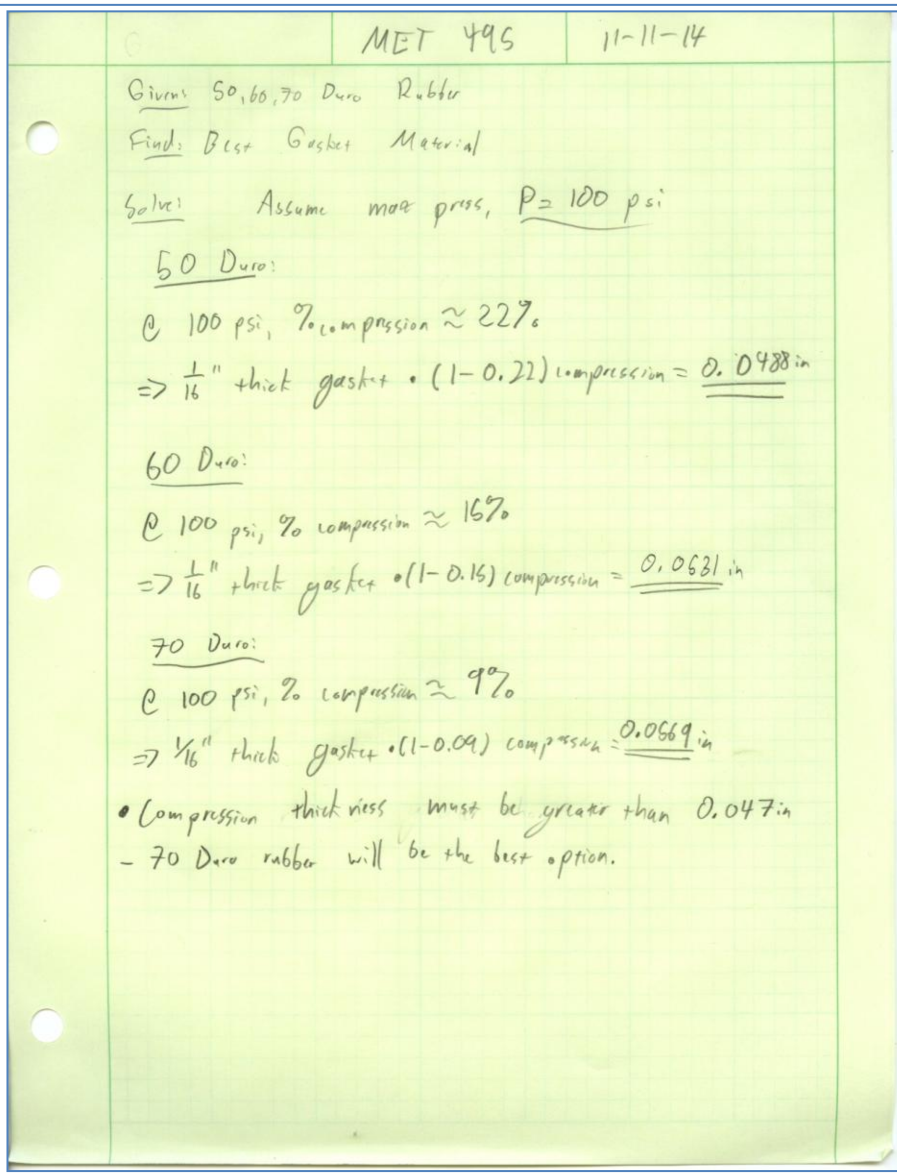
$A \cdot n = 0.156\ ft^2 \cdot 20 = \underline{3.125\ ft^2}$

$\dot{Q} = U A \Delta T_{lm} = (225\ BTU/h\text{-}ft^2\text{-}°F)(3.125\ ft^2)(109\ °F)$

$\boxed{\dot{Q} = 76{,}640\ BTU/h}$

The calculations below are for choosing the optimal durometer rubber.[2]





MET 495 11-11-14

Given: 50, 60, 70 Duro Rubber

Find: Best Gasket Material

Solve: Assume max press, P = 100 psi

50 Duro:

@ 100 psi, % compression ≈ 22%

=> 1/16" thick gasket • (1 − 0.22) compression = 0.0488 in

60 Duro:

@ 100 psi, % compression ≈ 16%

=> 1/16" thick gasket • (1 − 0.16) compression = 0.0631 in

70 Duro:

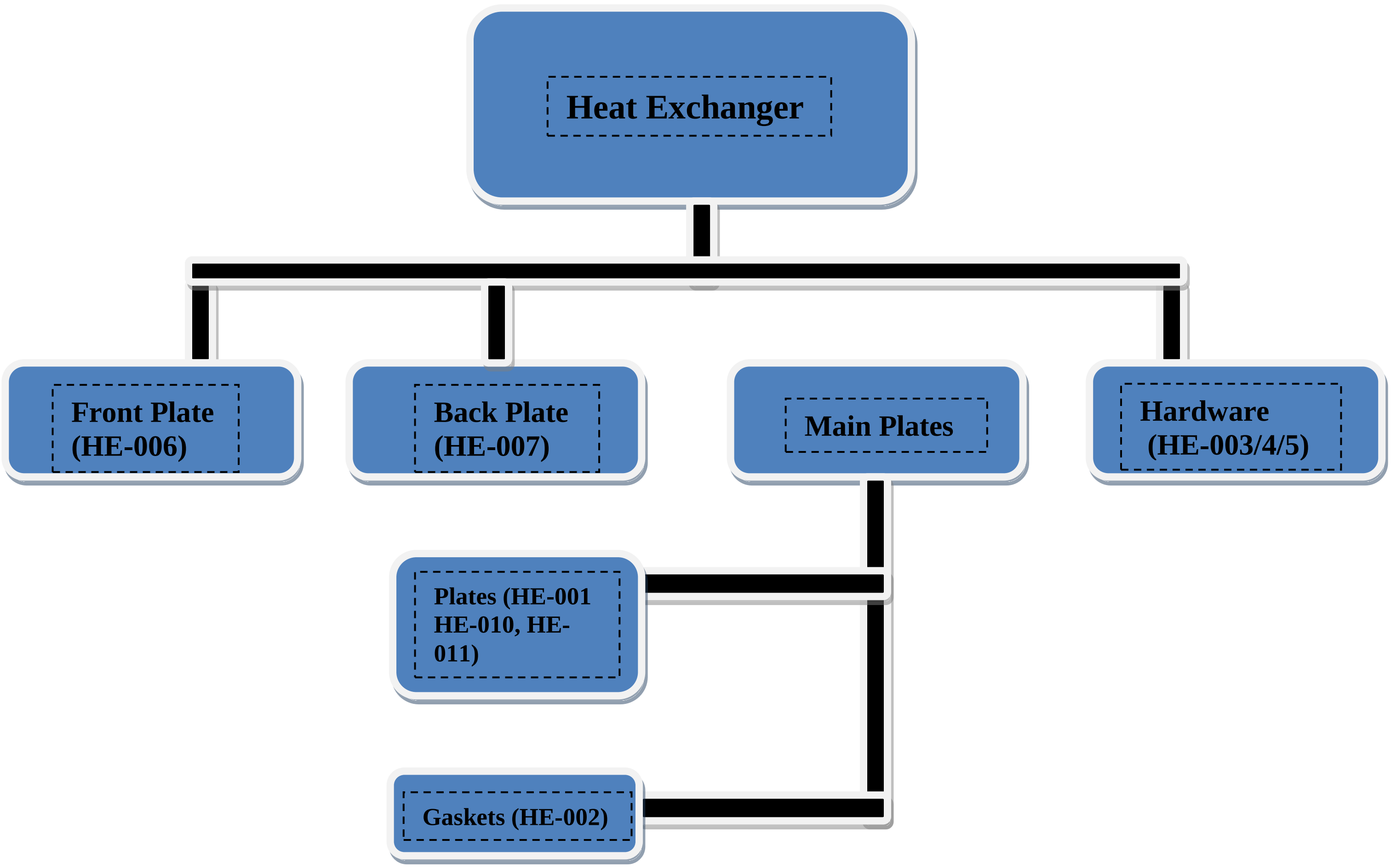
@ 100 psi, % compression ≈ 9%

=> 1/16" thick gasket • (1 − 0.09) compression = 0.0569 in

• Compression thickness must be greater than 0.047 in

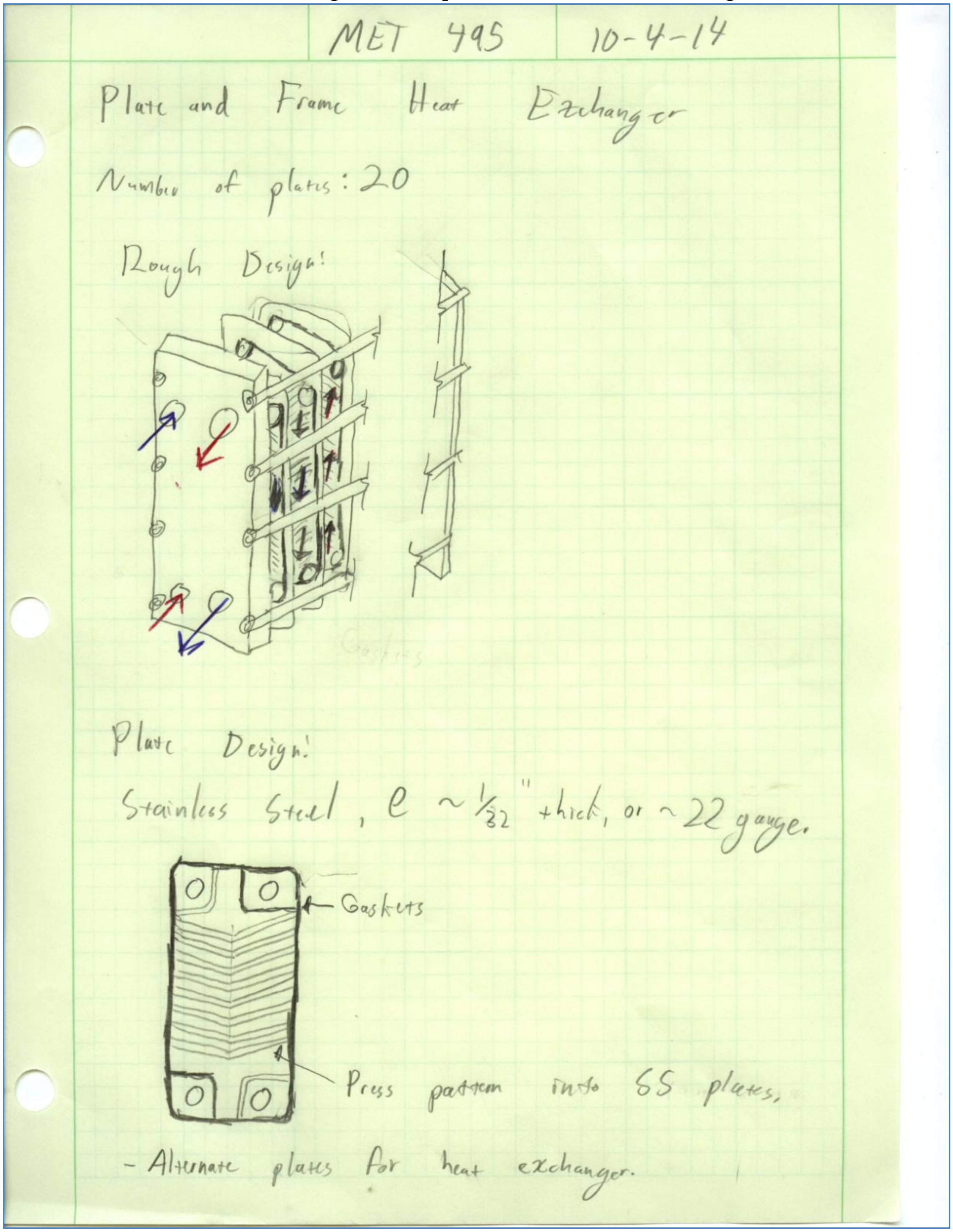
– 70 Duro rubber will be the best option.

Appendix B – Drawing Tree

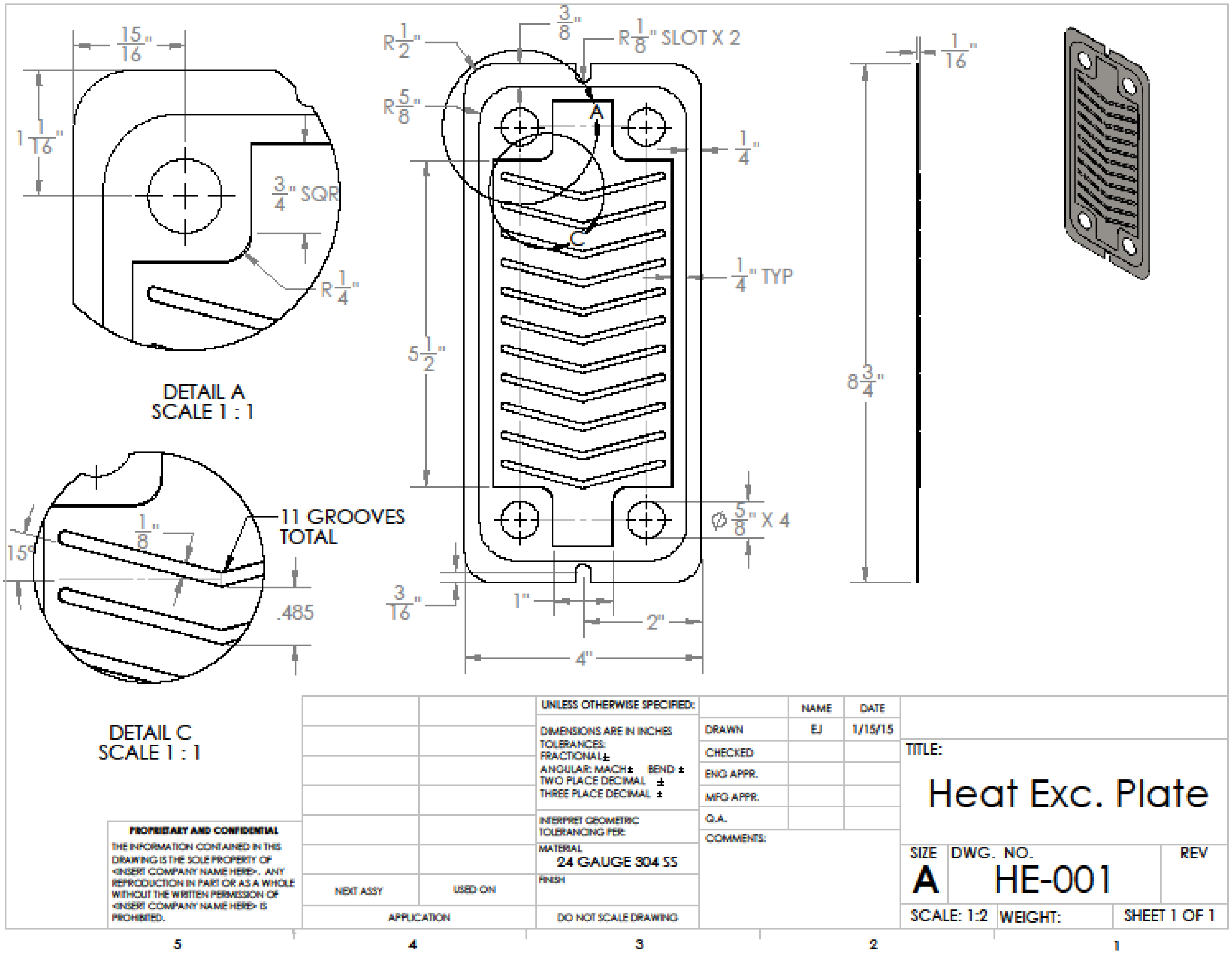


Appendix C - Drawings

Below are the initial designs for the plate and frame heat exchanger.



HE-001


DETAIL A
SCALE 1 : 1
DETAIL C
SCALE 1 : 1
11 GROOVES TOTAL
.485
15°
R 1/2"
R 5/8"
3/8"
R 1/8" SLOT X 2
1/4"
1/4" TYP
5 1/2"
8 3/4"
1/16"
3/4" SQR
R 1/4"
1 1/16"
15/16"
1/8"
Ø 5/8" X 4
3/16"
1"
2"
4"
A
C
PROPRIETARY AND CONFIDENTIAL
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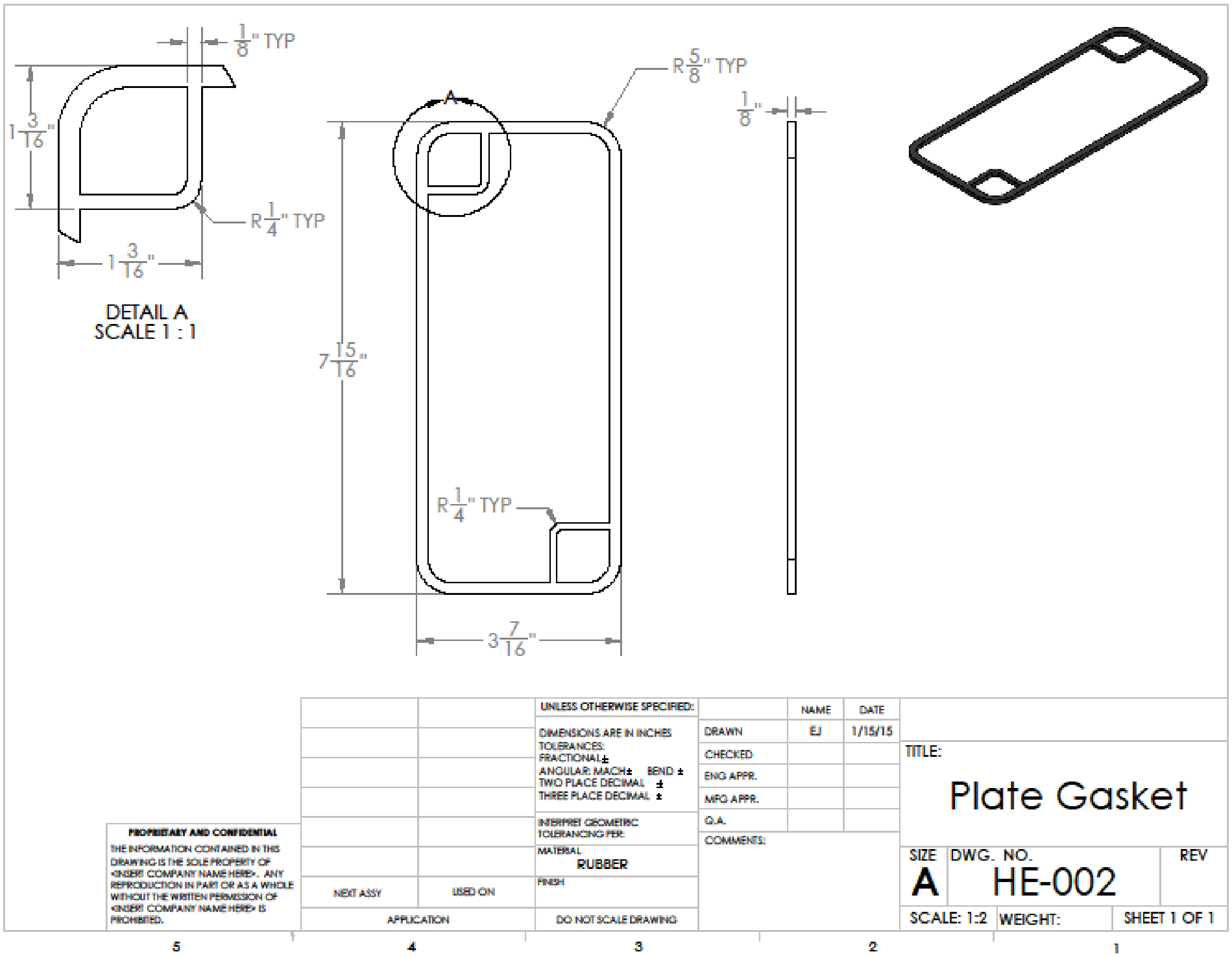
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
24 GAUGE 304 SS
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/15/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Heat Exc. Plate
SIZE
A
DWG. NO.
HE-001
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

HE-002


1/8" TYP
1 3/16"
R 1/4" TYP
1 3/16"
DETAIL A
SCALE 1 : 1
A
R 5/8" TYP
1/8"
7 15/16"
R 1/4" TYP
3 7/16"
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
RUBBER
FINISH
NAME
DATE
DRAWN
EJ
1/15/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Plate Gasket
SIZE
A
DWG. NO.
HE-002
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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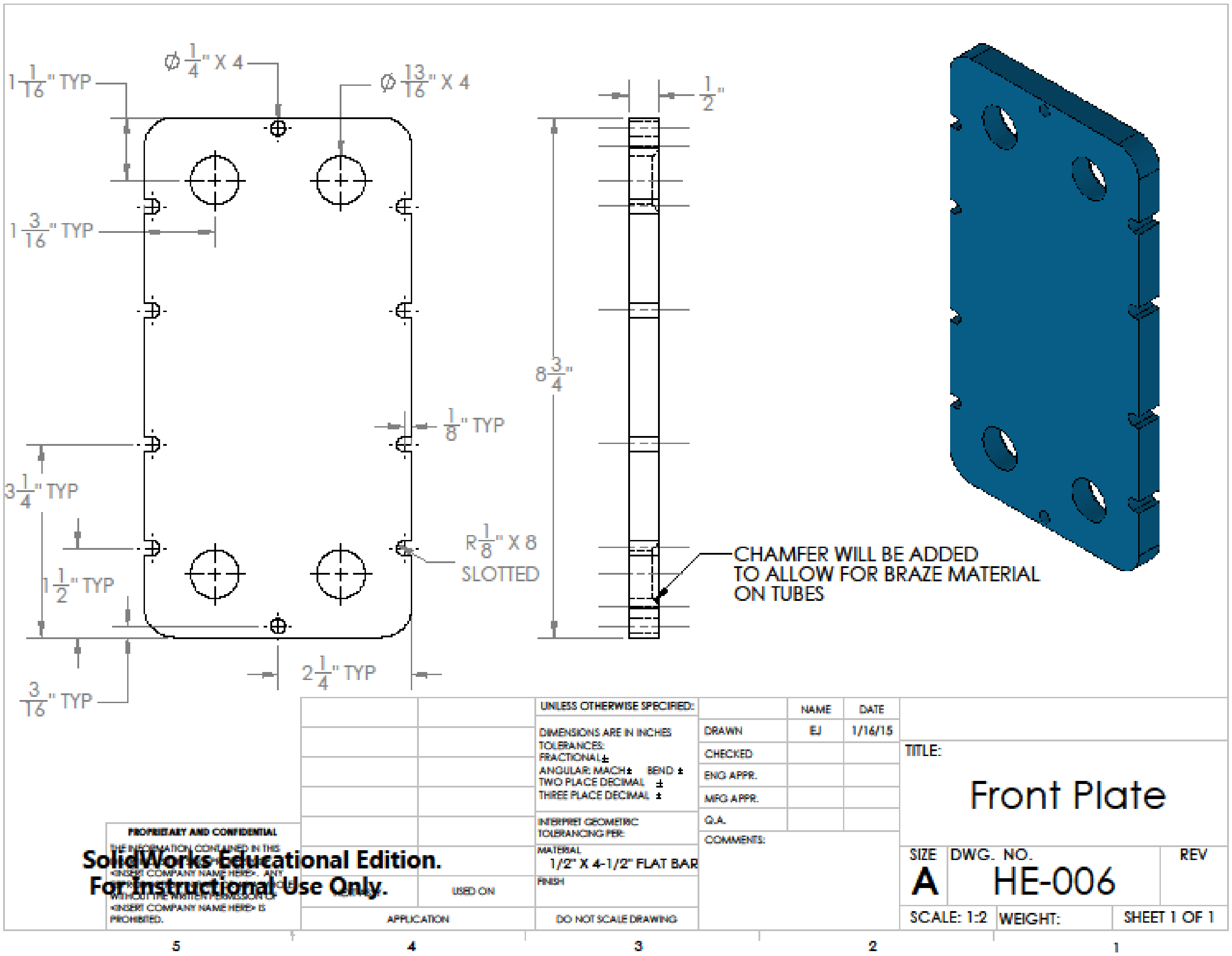
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
5
4
3
2
1

HE-006



Ø 1/4" X 4
Ø 13/16" X 4
1 1/16" TYP
1 3/16" TYP
1/2"
8 3/4"
1/8" TYP
3 1/4" TYP
R 1/8" X 8
SLOTTED
1 1/2" TYP
2 1/4" TYP
3/16" TYP
CHAMFER WILL BE ADDED
TO ALLOW FOR BRAZE MATERIAL
ON TUBES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
1/2" X 4-1/2" FLAT BAR
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Front Plate
SIZE
A
DWG. NO.
HE-006
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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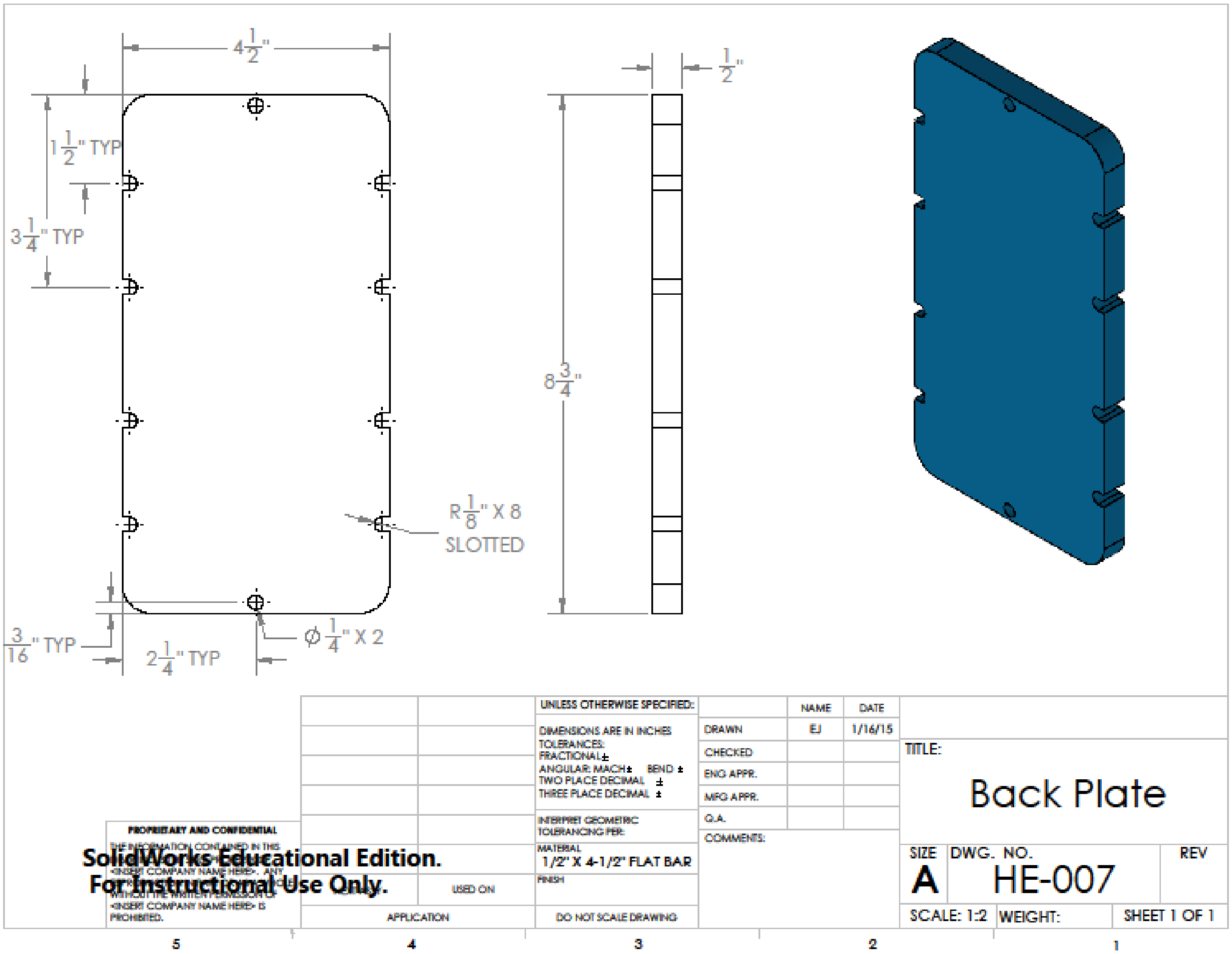
USED ON
APPLICATION
5
4
3
2
1

HE-007



4 1/2"
1/2"
1 1/2" TYP
3 1/4" TYP
8 3/4"
R 1/8" X 8
SLOTTED
3/16" TYP
2 1/4" TYP
Ø 1/4" X 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/2" X 4-1/2" FLAT BAR
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Back Plate
SIZE
A
DWG. NO.
HE-007
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
USED ON
APPLICATION
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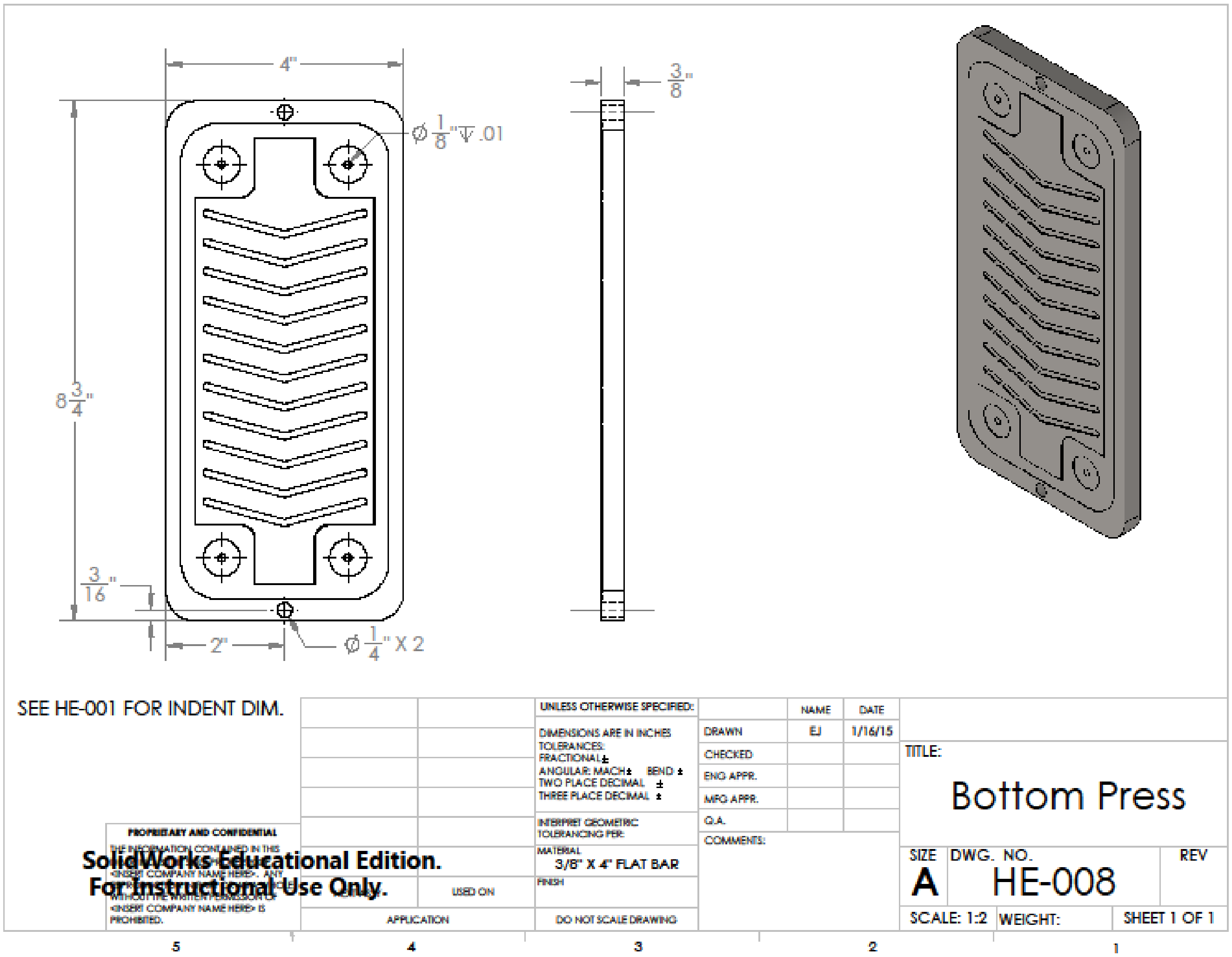
5
4
3
2
1

HE-008



4"
3/8"
Ø 1/8" ⊽ .01
8 3/4"
3/16"
2"
Ø 1/4" X 2
SEE HE-001 FOR INDENT DIM.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
3/8" X 4" FLAT BAR
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bottom Press
SIZE
A
DWG. NO.
HE-008
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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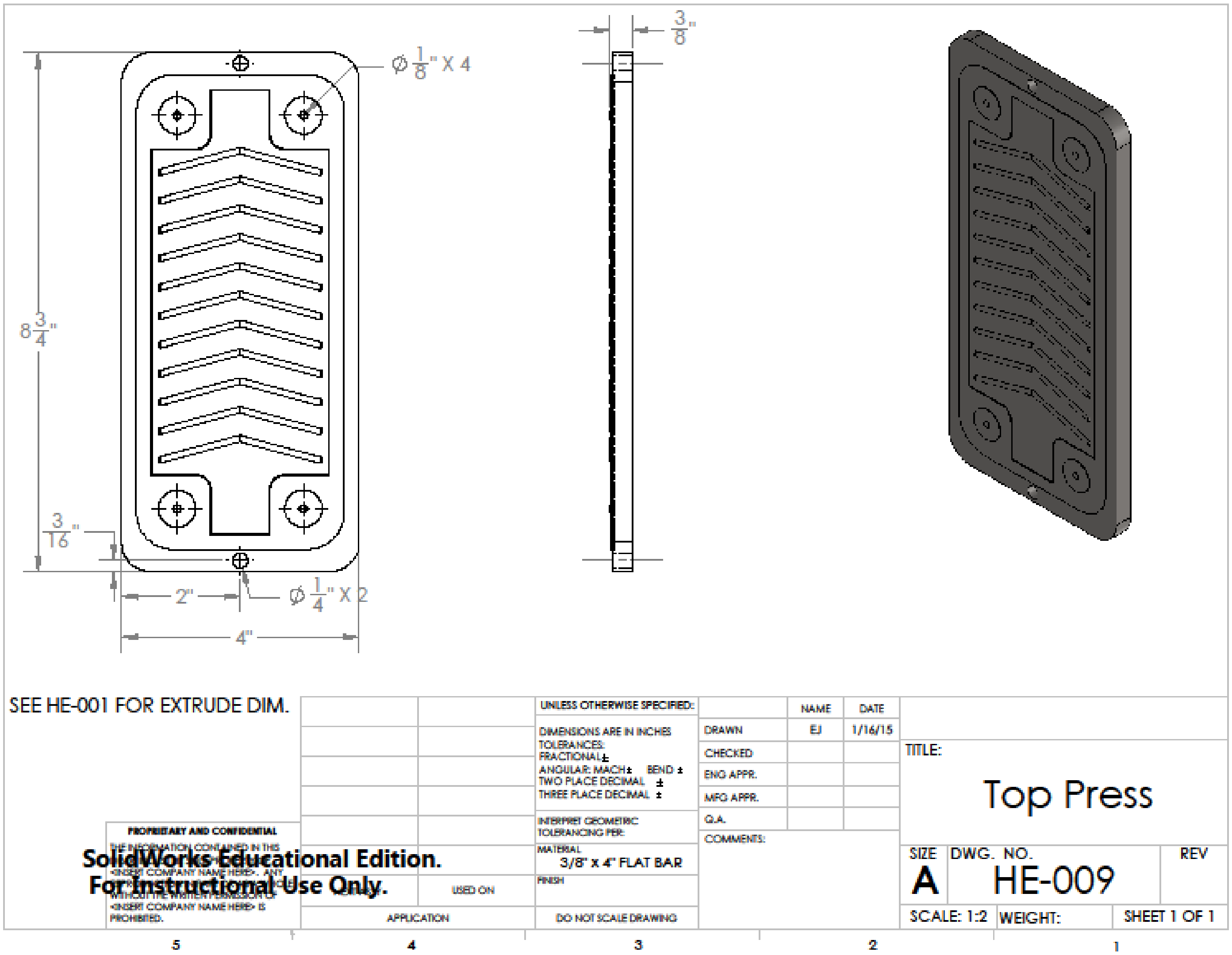
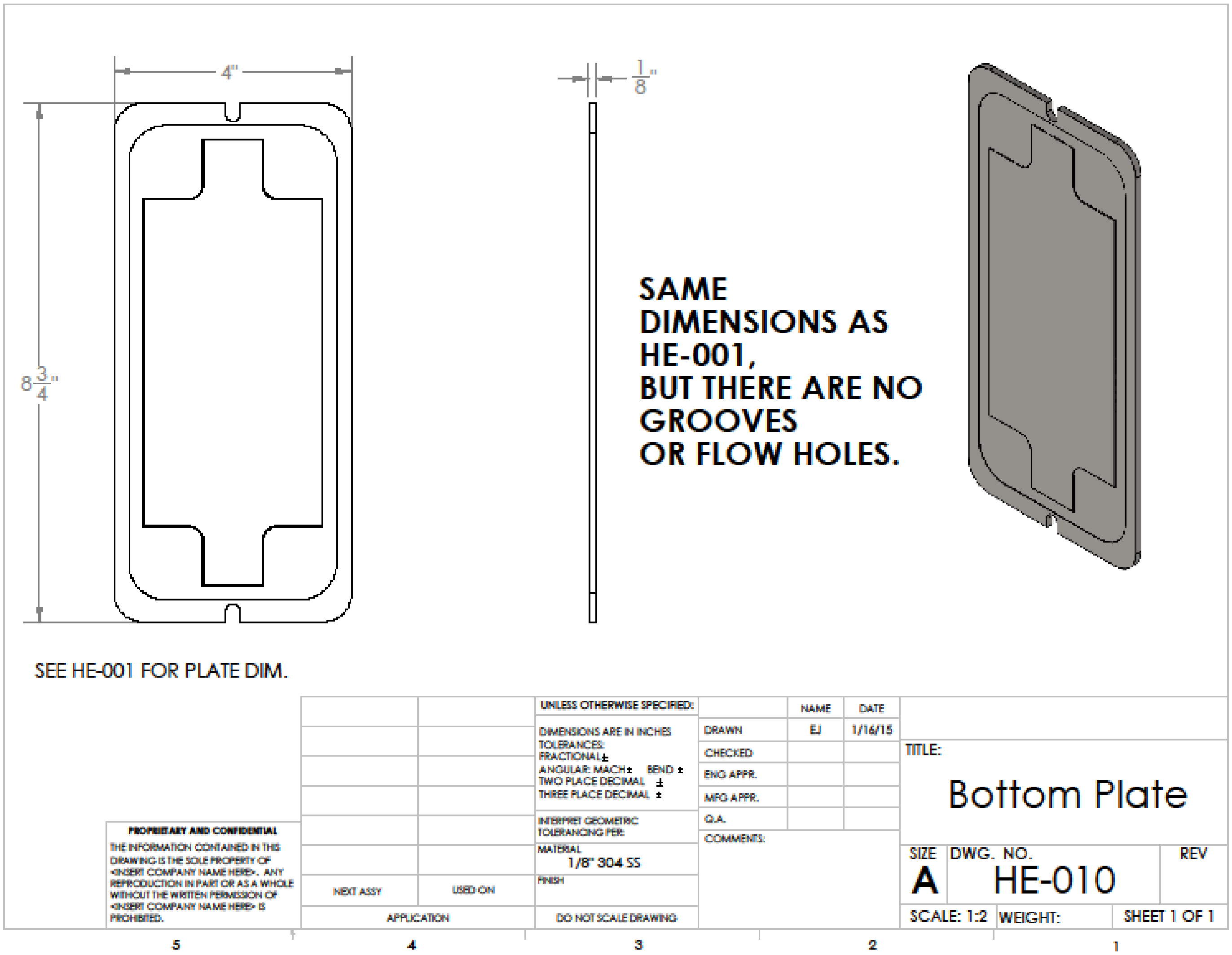
5
4
3
2
1

HE-009


Ø 1/8" X 4
3/8"
8 3/4"
3/16"
2"
Ø 1/4" X 2
4"
SEE HE-001 FOR EXTRUDE DIM.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
3/8" X 4" FLAT BAR
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Top Press
SIZE
A
DWG. NO.
HE-009
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
SolidWorks Educational Edition.
For Instructional Use Only.
USED ON
APPLICATION
5
4
3
2
1

HE-010


4"
1/8"
8 3/4"
SAME DIMENSIONS AS HE-001, BUT THERE ARE NO GROOVES OR FLOW HOLES.
SEE HE-001 FOR PLATE DIM.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/8" 304 SS
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bottom Plate
SIZE
A
DWG. NO.
HE-010
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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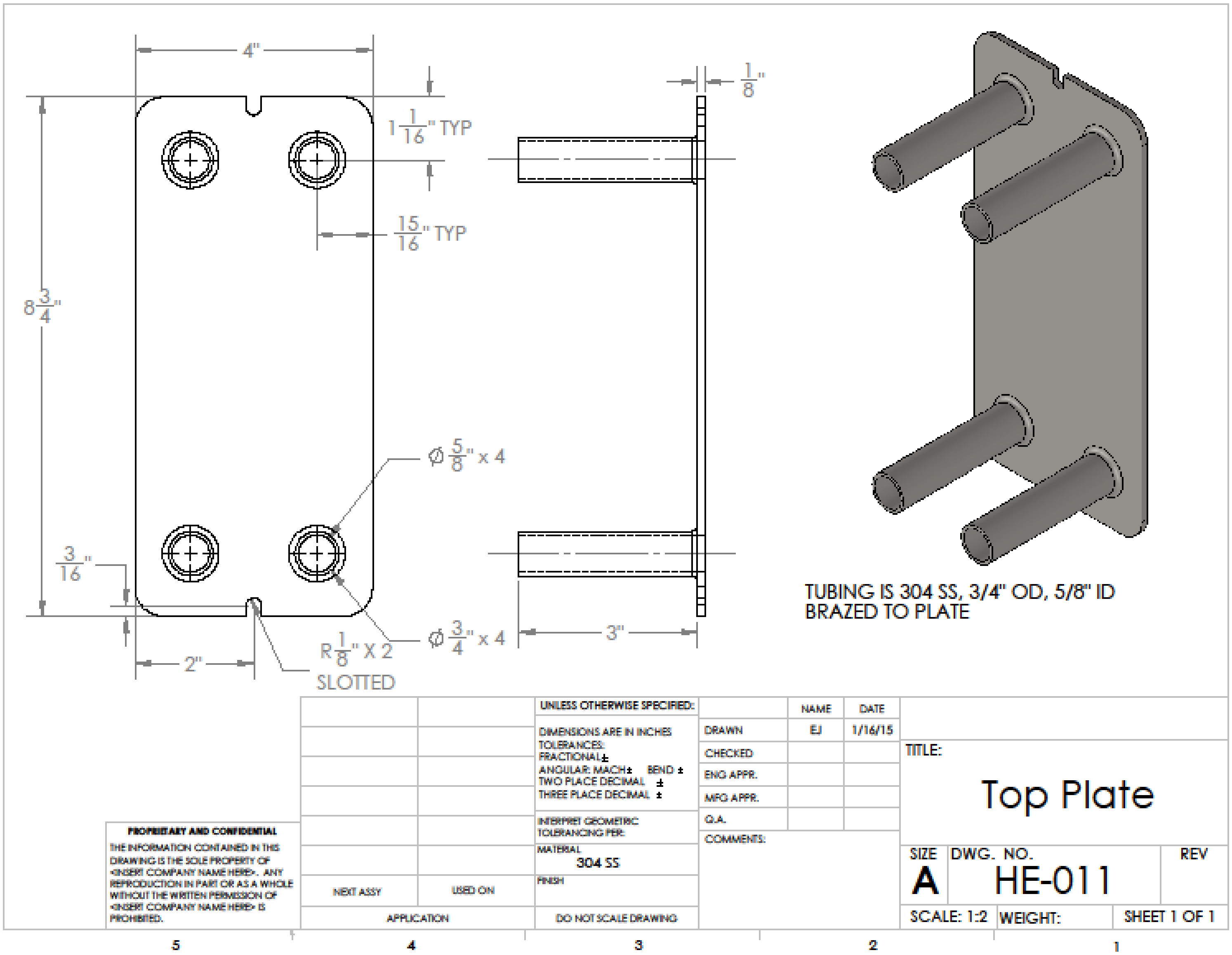
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1

HE-011


4"
1/8"
1 1/16" TYP
15/16" TYP
8 3/4"
Ø 5/8" x 4
3/16"
Ø 3/4" x 4
R 1/8" X 2
SLOTTED
2"
3"
TUBING IS 304 SS, 3/4" OD, 5/8" ID
BRAZED TO PLATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
304 SS
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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NAME
DATE
DRAWN
EJ
1/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Top Plate
SIZE
A
DWG. NO.
HE-011
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

Appendix D – Parts List

Item Number	Description	Quantity
HE-001	*Heat Exchanger Plates*	20
HE-002	*Plate Gaskets*	20
HE-003	*Alignment Shaft*	2
HE-004	*1/4" UNC Bolts - 4"*	8
HE-005	*1/4" UNC Nuts*	8
HE-006	*Heat Exchanger Front Plate*	1
HE-007	*Heat Exchanger Back Plate*	1
HE-008	*Bottom Press Plate*	1
HE-009	*Top Press Plate*	1
HE-010	*Bottom HE Plate*	1
HE-011	*Top HE Plate*	1

Appendix E – Budget

Item Number	Material/Description	Supplier	Supplier Part I.D.	Unit Price	Quantity	Estimated Price	Actual Price
HE-001	*SS 304 (24" x 24" - 24 Gauge)*	CWU	#4-304	$29.07	1	$29.07	Donated
HE-002	*70 Duro Rubber (12" x 24")*	Rubber Sheet Roll	70-1/8	$9.24	3	$27.72	$27.72
HE-003	*1018 Round, 1/4" - 24"*	CWU	1018-0.166	$1.00	1	$1.00	$1.00
HE-004	*¼" Bolt*	Bolt Depot	#139	$0.71	8	$5.68	$5.68
HE-005	*¼" Nut*	Bolt Depot	#2563	$0.08	8	$0.64	$0.64
HE-006/7	*A36 - 1/2" Thick* *½" x 4-1/2" – 24"*	CWU	A36-6.72	$28.70	1	$28.70	Donated
HE-008/9	*A36 – 3/8" Thick* *½" x 4" – 24"*	CWU	A36-5.112	$28.70	1	$22.52	Donated
HE-010/11	*SS 304 (12" x 12" - 1/8")*	CWU	#8-304	$25.61	1	$25.61	Donated
HE-011_T	*SS 304 ¾" OD 5/8" ID Tube-12"*	CWU	WSST-304	$6.64	1	$6.64	Donated
HE-002P	*3D Printed Gasket Stencil*	CWU	HE-002P	$8.80	1	$8.80	$8.80
					Total Price:	**$156.38**	**$43.84**

Appendix F – Schedule

Heat Exchanger

ID #	ACTIVITY	WEEK START	FINISH	ESTIMATED HOURS	ACTUAL HOURS
	Proposal				
1a	**Outline**	1	3	4	4
1b	**Introduction**	2	4	2	2
1c	**Design & Analysis**	4	12	10	14
1d	**Methods & Construction**	4	6	4	6
1e	**Testing Methods**	4	6	3	2
1f	**Budget and Scheduling**	6	-	2	6
			Subtotals:	25	34
	Analysis				
2a	**Heat Transfer Rates**	6	8	3	6
2b	**Bolt Statics**	6	7	1	1
2c	**Gasket Compression**	7	9	2	4
			Subtotals:	6	11
	Drawings				
3a	**HE-001**	9	10	1.5	1
3b	**HE-002**	9	10	1.5	1
3c	**HE-006**	11	12	1.5	0.5
3d	**HE-007**	11	12	1.5	0.5
3e	**HE-008**	11	12	1.5	0.5
3f	**HE-009**	11	12	1.5	0.5
3g	**HE-010**	11	12	1.5	0.5
3h	**HE-011**	11	12	1.5	0.5
			Subtotals:	12	5
	Material Purchasing				
4a	**Order Steel**	13	16	2	1
4b	**Order Gaskets**	13	16	2	1.5
4c	**Purchase DAP Adhesive**	13	16	1	0.5
			Subtotals:	5	3
	Construction				
5a	**Construct Press Plates**				
5ai	Generate CNC Code for Plates	20	21	4	10
5aii	Cut Stock to Size	21	22	1.5	0.3
5aiii	CNC Top and Bottom Plates	21	22	3.5	8
5b	**Construct HE Plates**				
5bi	Shear Plates to Dim.	21	23	3.5	0
5bii	Punch Alignment Holes	22	23	2.5	0
5biii	Press Plates	23	24	5	1
5biiii	Punch Flow Holes	23	24	1.5	1.4
5c	**Construct Gaskets**				
5ci	3D Print Stencil	20	21	1.5	1.2
5cii	Cut Gaskets	20	21	3.5	6
5d	**Construct Spines**				
5di	Cut Stock to Size	24	25	1	0.4
5dii	Drill Alignment and Flow Holes	24	25	3.5	4.4
5e	**Attach Gaskets to Plates/Assemble**	26	27	4	4
			Subtotals:	35	42.7
	Documentation				
6a	**Update Proposal**	17	21	4.5	8
6b	**Machining Documentation**	20	22	1.5	2
6c	**Progress Reports**	21	27	2	3
			Subtotals:	8	13
	Testing				
7a	**Test for Leakage**	30	31	1.5	4
7b	**Run Comparison Testing**	32	33	2.5	0
7c	**Run HE Testing**	33	34	4	7
7d	**Document Testing Results**	35	37	3.5	2
			Subtotals:	11.5	13
			Totals:	102.5	121.7

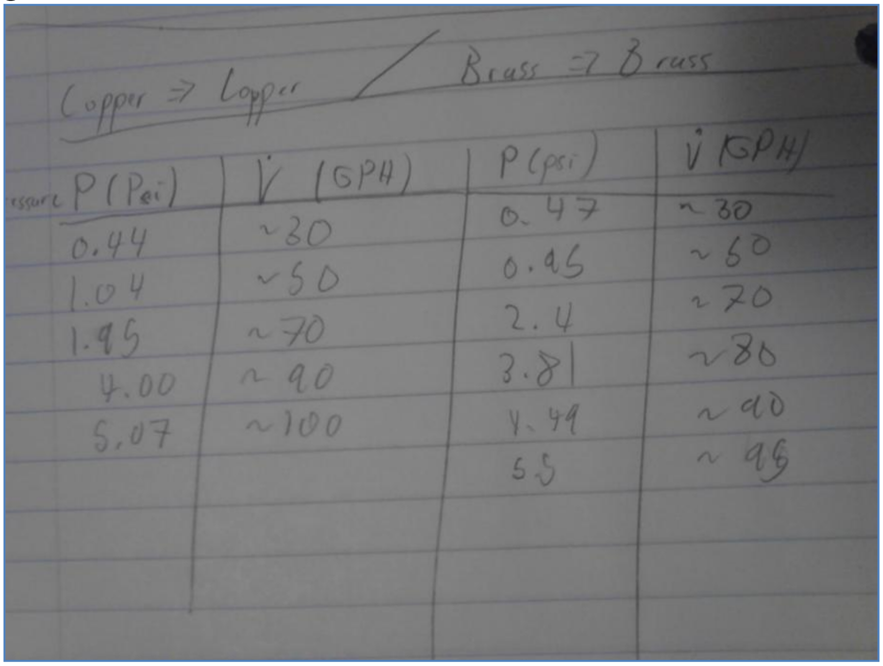
Week	Date	Month
1	9/15/2014	September
2	9/22/2014	
3	9/29/2014	
4	10/6/2014	October
5	10/13/2014	
6	10/20/2014	
7	10/27/2014	
8	11/3/2014	November
9	11/10/2014	
10	11/17/2014	
11	11/24/2014	
12	12/1/2014	December
13	12/8/2014	
14	12/15/2014	
15	12/22/2014	
16	12/29/2014	
17	1/5/2015	January
18	1/12/2015	
19	1/19/2015	
20	1/26/2015	
21	2/2/2015	February
22	2/9/2015	
23	2/16/2015	
24	2/23/2015	
25	3/2/2015	March
26	3/9/2015	
27	3/16/2015	
28	3/23/2015	
29	3/30/2015	
30	4/6/2015	April
31	4/13/2015	
32	4/20/2015	
33	4/27/2015	
34	5/4/2015	May
35	5/11/2015	
36	5/18/2015	
37	5/25/2015	

Appendix G – Expertise and Resources

The resources available from Central Washington University allowed for this project to be completed. Hogue Technology building's machine shop was utilized for the machining of parts required to make this system, and parts essential to the operation of this system. Additionally, the expertise of Matt Burvee proved to be essential in the completion of the machining operations for this project.

Appendix H – Evaluation Sheet

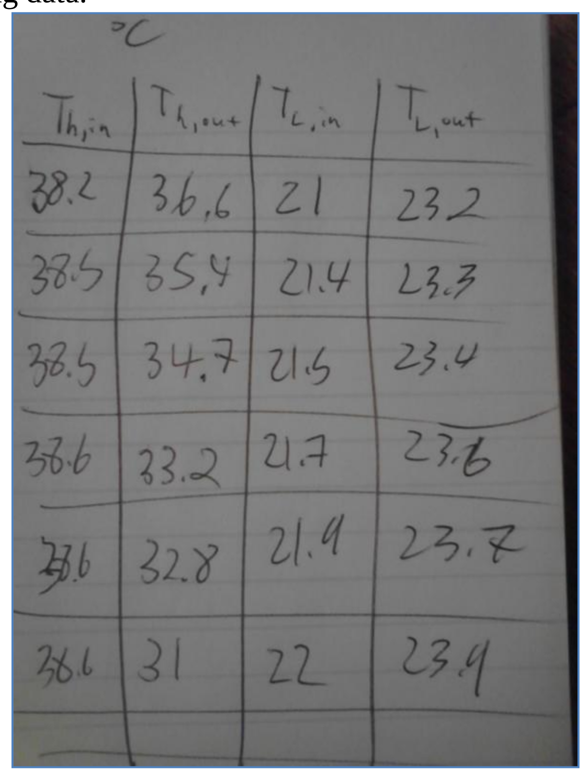
Leakage testing data.



Copper ⇒ Copper / Brass ⇒ Brass

Pressure P (Psi)	$\dot{V}$ (GPH)	P (psi)	$\dot{V}$ (GPH)
0.44	~30	0.47	~30
1.04	~50	0.95	~60
1.95	~70	2.4	~70
4.00	~90	3.81	~80
5.07	~100	4.49	~90
		5.5	~95

Second temperature testing data.



°C

$T_{h,in}$	$T_{h,out}$	$T_{L,in}$	$T_{L,out}$
38.2	36.6	21	23.2
38.5	35.4	21.4	23.3
38.5	34.7	21.5	23.4
38.6	33.2	21.7	23.6
38.6	32.8	21.9	23.7
38.6	31	22	23.9

Appendix I – Testing Data

Below is the data set for the first trial taken with the heat exchanger. This data includes the temperature inputs and outputs, along with the flow rates of each flow path. Note that after this trial, the system was taken apart and the gaskets were sealed to prevent a small internal leak. The second table has the data taken from the second round of testing, although this data was not as usable as that of the first test, due to the hoses leaking profusely during testing.

Time (s)	$T_{H,In}$ (°C)	$T_{H,Out}$ (°C)	$T_{L,In}$ (°C)	$T_{L,Out}$ (°C)	$V_{H,Out}$ (GPM)	$V_{L,Out}$ (GPM)
30	39	32.7	22.3	26	1	1.6
60	40.6	33.9	22.7	26.8	1	1.7
90	41.5	34.6	23.1	27.6	1	1.8
120	42	35	23.5	28.6	1	1.7
150	42.3	35.3	23.9	29.8	1	1.7
180	42.5	35.5	24.3	30	1.1	1.8
210	42.5	35.7	24.9	31	1.1	1.7
240	42.5	35.8	25.1	32	1.1	1.7

Time (s)	T H,In (°C)	T H,Out (°C)	T L,In (°C)	T L,Out (°C)
30	38.2	36.6	21	23.2
60	38.5	35.4	21.4	23.3
90	38.5	34.7	21.5	23.4
120	38.6	33.2	21.7	23.6
150	38.6	32.8	21.9	23.7
180	38.6	31	22	23.9

This data set is from the original leakage test, where on both ends of the input/output of the heat exchanger, pressure and flow rate were measured. The first data set Copper-Copper (Hot), indicates that this is the hot water flow channel, and the Brass-Brass (Cold) data set is the flow path for the cooling water. The flow rate was measured, along with back pressure on the system.

Copper-Copper (Hot)		Brass-Brass (Cold)	
Pressure (psi)	Flow rate (GPH)	Pressure (psi)	Flow rate (GPH)
0.44	30	0.47	30
1.04	50	0.95	50
1.95	70	2.4	70
4	90	3.81	80
5.07	100	4.49	90
		5.5	95

Appendix J – Testing Report

Introduction:

For the testing of this heat exchanger, the main requirement was that the hot water came out to an acceptable cooler temperature. The exact temperature of this hot water would vary based on the application. The main data of interest from this testing is the temperature values of the input and outputs ports. Specifically, of those four values, the hot output temperature is the most critical, since that is what would ideally be a specific value. Ideally, the system would take ~200 °F hot water and take it down to ~70°F. However, obtaining a large amount of near boiling water was difficult, so the testing was done using hot tap water, at ~110 °F to test the feasibility of this heat exchanger. Ideally this system would be able to take that ~110 °F water to ~70 °F. However, the cooling water reached room temperature faster than anticipated, and the system was being cooled by ~70 °F. The data for this testing was taken using thermocouples attached to each output port, and connected to multimeters to allow the temperature values to be recorded during testing. In addition to this, both outputs had flow meters attached, to measure the flow rate out of the system. As for the schedule, the testing was somewhat late, and took place a few weeks later than originally planned for.

Approach:

The main resources for the testing of this project was all of the hosing equipment, the pump used for the cooling water, the cold water tank, thermocouples, multimeters, pressure gauge, and the flow meters. All of this was supplied by Professor Beardsley. During testing, data was recorded off the thermocouples, along with the data from the flow rate meters being recorded. Additionally, the first test had back pressure readings, which were recorded using a multimeters, and the values were written down at different flow rates.

The main testing procedures were somewhat simple. To begin, all of the hoses were attached to the proper ports, and thermocouples were attached to each output port. Additionally, flow meters were attached to eat output hose for a flow path. From here, the cool water would be run through a pump, and circulate through the system, then the hot water would be turned on, from the faucet. After all of this, data would be recorded for several minutes, until the temperatures reached equilibrium. The main operational limitations of this system were temperature and pressure. The entire system was rated for ~200 °F, and 100 psi max. For the most part, all of the recorded data was accurate and precise, the thermocouples were well insulated and there should not have been much of a temperature differential between the actual water temperature, and the temperature read by the thermocouples. All of the data from the testing can be found in Appendix I.

Test Procedures:

The testing for this project was performed in the senior project room in Hogue. Multiple days in April and May data was collected, usually in the afternoon for several hours. Setting the system up itself took around 30 minutes, and cleaning up after, mainly draining all the water from the hoses and heat exchanger, took around 20 minutes. For the most part, there were no major safety risks. The only possible safety concerns were being scalded by hot water, which did not happen, or the gaskets blowing out and shooting how water out, which also didn’t happen. Overall, the testing for this system went somewhat smooth. The biggest problem was the actual hoses used, as they tended to leak quite a bit, especially during the last testing session.

Deliverables:

The heat exchanger system worked, although not quite to the extent that was desired. Ideally, the system would have taken 200 °F water down to ~70 °F. In actuality the system was able to take 120 °F water down to around 90 °F, although the cooling water was room temperature. Calculating the heat transfer for this system, a value of ~8500 BTU/h is found. Ideally, the system would have been able to transfer 76,000 BTU/h. However, this project was able to meet several other success criteria listed in the fall quarter. The system ended up weighing only 19.2 pounds, compared to the 20 pounds initially listed. Eight bolts were utilized to clamp the gaskets together, and the system was water-proof.

Overall, this system was a success in many ways, and could use further advancement. Additional plates should be added to the system, and the plate thickness should be sized down, to allow for more plates for the same cost, and ease of manufacturing. The thinner plates would also allow for them to be pressed much easier, and more effectively. If this project were to be picked up by a student in the future to work on a plate redesign, it should be able to meet the original heat transfer requirements, while utilizing the older parts as well.

Report Appendix:

Main data sheet used to record data:

Time	$T_{H,In}$ (°C)	$T_{H,Out}$ (°C)	$T_{L,In}$ (°C)	$T_{L,Out}$ (°C)	$V_{H,Out}$ (GPM)	$V_{L,Out}$ (GPM)

Gantt chart with testing section:

	Testing				
7a	**Test for Leakage**	30	31	**1.5**	**4**
7b	**Run Comparison Testing**	32	33	**2.5**	**0**
7c	**Run HE Testing**	33	34	**4**	**7**
7d	**Document Testing Results**	35	37	**3.5**	**2**
			Subtotals:	**11.5**	**13**

Appendix K - Resume

ERIC M. JOHNSON

1500 N. Glen Drive, Apt. 3 (509)-439-2404
Ellensburg, WA 98926 Johnsonerm@gmail.com

Education

Central Washington University September 2011 - June 2015
B.S. in Mechanical Engineering Technology **GPA: 3.77**
Sample Courses: Thermodynamics, Fluid Mechanics, Heat Transfer, Statics, Dynamics, Mechanics of Materials, Materials Science, Machine Design I-II, Engineering Economics, Finite Element Analysis.
Minor in Mathematics
Courses: Calculus I-IV, Linear Algebra, Differential Equations

Honors

- Passed the Mechanical Fundamentals of Engineering (FE) Exam May 2015
  Washington State Engineer-in-Training (EIT) License No. 34473
- Recipient of a CWU Undergraduate Research Fellowship Grant January 2014

Professional Experience

Mechanical Engineer **June 2014 – November 2014**
Industrial Technologies International
Yakima, WA

- Assisted in the design and analysis of a four tier hydraulic press system, used in modular housing panel applications.
- Designed a roller chain drive that utilized a pneumatic airbag system to allow the roller chain tracks to recede into the press tables.
- Utilized SolidWorks for modeling and Finite Element Analysis.
- Supervised on-going work in the machine shop, and ensured that parts met drawing specifications.
- Maintained contact with local distributors, and ordered specified parts and materials on a regular basis.

Research Assistant **September 2012 – March 2014**
Central Washington University Physics Department
Ellensburg, WA

- Assisted in far-infrared laser research, specifically looking into emission generated by methanol isotopologues.
- Research from this investigation generated 34 new far-infrared emissions, and was published in the IEEE Journal of Quantum Electronics: *New Optically Pumped Far-Infrared Laser Emissions From* $^{13}CD_3OH$, $^{13}CD_3OD$, CD_3CN, *and* $^{13}CD_3I$.
- Performed routine operation and maintenance of a high powered CO_2 laser.
- Fabricated small parts required for continued operations in the laser lab.

Professional Affiliations

- American Society of Mechanical Engineers (ASME)
- Society of Manufacturing Engineers (SME)
- American Foundry Society (AFS)
- Vice President: CWU Electric Vehicle (EV) Club

Technical Skills

- **Computers**:
    - **Microsoft Office**: Word, Excel, PowerPoint, Outlook
    - **Modeling:** AutoCAD, SolidWorks (CSWA), Rhinoceros
    - **Programming**: Java, Visual Basic, Mathematica, Studio 5000 (PLCs)
- **Machining**:
    - Basic Machining (Lathe, Mill, Drill Press, Hand Tools)
    - CNC Machining (Mastercam X8)