American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-10, pp-164-172
www.ajer.org
Research Paper Open Access

Development of a Heat Recovery unit for Residential Applications

Menwer F. Alenezi[1] and SalemH. Alzaid[2]
[1]*The Public Authority for Applied Education and Training , Vocational Training Institute, Automotive Mechanic Department ,Kuwait.*
[2]*The Public Authority for Applied Education and Training , Vocational Training Institute, Automotive Mechanic Department ,Kuwait.*

Abstract
When considering the design for a heat recovery unit for residential applications, there are many possible configurations. The most fundamental design will be some form of heat exchanger that will use hot air to heat a cool fluid stream of water. The task is to design a unit for heating water flowing at 2.12 LPM by exactly 4 degrees centigrade from an initial temperature between 22.0and 24.0. Any deviations in this temperature change must be justified. The heat exchanger used for preliminary calculations is an unfinned counter flow heat exchanger; however, different con figurations will be explored throughout this report to determine the most efficient one with the smallest area of heat transfer.

The overall design of the unit has very few constraints, and any reasonable model can be considered. The only given design constraint is that the air or hot fluid must have an outlet diameter of 6 inches, and the warm air flow must exit at a velocity of 10 m/s and a temperature of 45 degrees centigrade. Some fair assumptions that were made are that the thermal properties will remain consistent, both fluid streams are fully developed, the kinetic and potential energy changes are negligible, and that no heat is lost to the surroundings. The preliminary design resulted in about 16% efficiency. For the initial calculations, the inlet and outlet diameter will be the same and any potential fouling factors will be ignored. The fouling factor, however, will be considered in later designs.

Date of Submission: 15-10-2023 Date of acceptance: 31-10-2023

I. Introduction

For this report, a heat recovery unit for residential application was used to design and analyze aheat exchanger. Devices like heat exchangers are used since they facilitate the exchange of heatbetween fluids having different temperatures without having to mix them, unlike mixingchambers where the fluids do mix. To analyze the heat transfer between the fluids, the overallheat transfer coefficient, U, is used, taking into account all the effects during heat transfer suchas convection and conduction. Heat transferred from the hot fluid to the wall is done byconvection through the wall by conduction and again by convection from the wall to the coldfluid. Thermal resistance through a tube wall can be negligible when the wall thickness of thetubes is small as it is in this case. With a quick literature search, numerous articles point out theuse of a heat recovery unit when looking at history; it is unclear when it was first invented.

Nevertheless, there are patents dating from 1983 by Rolf A. S. Kruse, Karl A. L. Gustavsson,Karl A. Jansson. At first glance, it may seem obsolete, but the critical function is recovering theheat.Itisessentialtolookbackonpatentstoknowwhichpathtofolloworsolelyforinspiration.

Furthermore, Heat recovery units are tremendously beneficial as they help recover most of theheat that is typically wasted and reduce heating requirements. This closed-cycle improvesefficiency when compared to old methods. A heat recovery unit circulates fresh hot air in ourhomes;italsokeepsoutmoistureandpollutants.Moistureandcontaminantsarecreatedbythings as simple as breathing and cooking. If humidity reaches excessive levels, it can causestructural damage. Our heat exchanger is a subunit of a complex architecture, but the generalpurpose is to heat fresh air without going stale. There are several different makes and models, butmost heat recovery units will gain back 80%-85% of the heat of the existing stream. They can beused in an independent heat recovery unit installation or a heat recovery with a furnace. Thesecond option is when our heat exchanger comes into play, replacing the furnace.

In this project, a heat exchanger is installed in the exhaust of the heat recovery unit, where thehot exhaust air will be utilized to heat cold water. A heat exchanger is to be designed andanalyzed to acquire the goal of warming the cold water 4C. Analytical and modeling methodswere applied using Fusion 360, and ANSYS. Designs were replicated in NX-10, but it wasincompatible with ANSYS. The heat exchanger design was done using Fusion 360 and wasimported to ANSYS to perform simulation and analyze results acquired and compare to theanalytical results. This project aims to demonstrate the application of a counterflow heatexchanger using analytical calculations and CFD software to validate our design. The finalmodel should be capable of heating water by 4 Celsius.

Theoretical Background

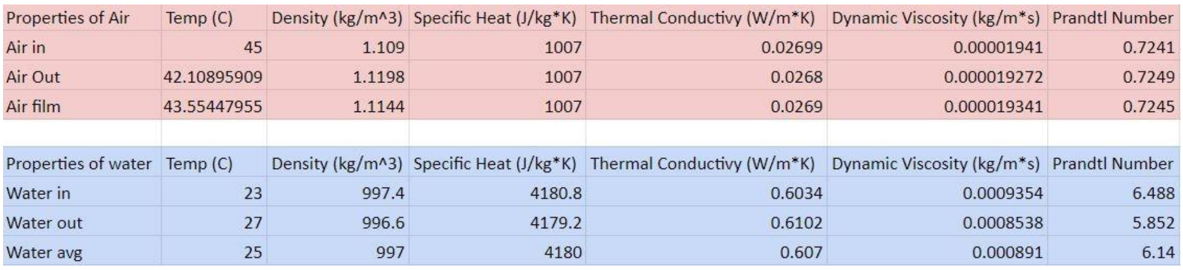
Heat recovery units come in different types of forms depending on what the unit needs to be usedfor, but they all contain a type of heat exchanger for it to be operable. When using heat recoveryunits for residential, it is important to be set up in the most convenient area. Heat recoverysystems are used for heat spaces, ventilating spaces, heating water, and industrial scale drying.

The way these types of systems work is hot fluid passes next to cold fluid and the heat transferson to the colder fluid hence the name heat exchanger. When putting a heat recovery unit in ahome or office, heat recovery units work just like a ventilation system where it involves a type ofheat exchanger that can sit on the roof, where it draws the cold air from the outside and warms itup with air that is being expelled from the inside.

It is known that a heat exchanger is the brain of a heat recovery unit. The role of heat exchangersis to cool or heat fluids in a system. When creating a heat exchanger for an application a lot ofproperties of the heat exchangers must be taken into consideration from the fluid being used, sizeofpipes,towhattypeoffittingsandwhattypeofmaterialwillbeusedforthepipingaswellasif it will have fins or not. When creating a heat recovery unit for a residential application havingan efficient heat exchanger in the system is needed to work properly.

There are two types of heat exchangers that are mostly used in different types of systems thatoperate very differently based on the direction of the flow of the fluid. The two types of heatexchangers that are the most common are parallel flow and counter flow, and for the heatrecovery unit it was decided that a counter-flow heat exchanger would be the best type of heatexchanger to use. The counter-flow heat exchanger works by having a stream of one of the fluidsin the opposite direction of the flow of the other fluid compared to the parallel where the fluidflows in the same direction. Since counter flow heat exchangers have the hot fluid going throughone side and the hot fluid through the other, it is more efficient because it minimizes the thermalstresses through the exchanger by the temperature difference being uniform between the twofluids, meanwhile the parallelflow exchanger has largetemperature differences atthe endswhich causes large thermal stresses. When creating a heat exchanger an important property iscross flow whether it is un-finned or finned. When a heat exchanger is finned tubular both fluidsare unmixed, and fins are guided in a direction transverse to the tube flow direction. When theheat exchanger is un-finned heat can be exchanged in all directions so that there's a chance thatthe fluid can mix.

Analytical Calculations



Properties of Air	Temp (C)	Density (kg/m^3)	Specific Heat (J/kg*K)	Thermal Conductivy (W/m*K)	Dynamic Viscosity (kg/m*s)	Prandtl Number
Air in	45	1.109	1007	0.02699	0.00001941	0.7241
Air Out	42.10895909	1.1198	1007	0.0268	0.000019272	0.7249
Air film	43.55447955	1.1144	1007	0.0269	0.000019341	0.7245

Properties of water	Temp (C)	Density (kg/m^3)	Specific Heat (J/kg*K)	Thermal Conductivy (W/m*K)	Dynamic Viscosity (kg/m*s)	Prandtl Number
Water in	23	997.4	4180.8	0.6034	0.0009354	6.488
Water out	27	996.6	4179.2	0.6102	0.0008538	5.852
Water avg	25	997	4180	0.607	0.000891	6.14

Table 1: Water and Air Properties

Calculating volume flow rate for water

$V=(2.12LPM)(\frac{1minute}{60seconds})(\frac{1m^{3}1}{000L})=0.00003533m^{3}/s$

Calculating for mass flow rate

$m_{water}=\rho * volumeflowrate=(997kg/m^{3})(0.00003533m^{3}/s)=0.03522401\text{kg/sec}$

$m_{air}=\rho * velocity * Ac=(1.109kg/m^{3})(10m/s)((\pi/4)(0.1524m))=0.20229879kg/s$

Calculating for volume flow rate of air

$V=\frac{\rho}{massflowrate}=\frac{1.109kg/m^{3}}{0.20229879kg/s}=0.1824146925m^{3}/s$

Heat Transfer

$Q_{water}=massflowrate * Cp(Tout-Tin)_{water}=$
$=(0.03522401kg/sec)(4180J/kg*K)(27°C-23°C)=588.9454472\text{W}$

$Q_{air}=massflowrate * Cp(Tout-Tin)_{air}=$
$(0.20229879kg/s)(1007J/kg*K)(45°C-42.10895909°C)=588.9454472W$

Cc(water)=$massflowrate*Cp=(0.03522401kg/sec)(4180J/kg*K)=147.2363618W/K$
Cc(air)= $massflowrate*Cp=(0.20229879kg/s)(100el7J/kg*K)=203.7139792\ W/K$
Cmin=Cc(water)=147.2363618W/KCr =
Cmin/Cmax = 0.7227602267
$Q_{max}=Cmin(Thot,in-Tcold,in=(147.2363618W/K)(45°C-23=3239.19996W$

Effectiveness

$\varepsilon=Q/Q_{max}(100)=18.1818\%$

NTU

$NTU=\frac{1}{c-1}ln(\frac{\varepsilon-1}{\varepsilon c-1})=.2156455726$

Reynolds Number

$Re_{water}=\frac{4*massflowrate}{\pi Di\mu}=5355.94082(Turbulent)$
$Re_{air}=87385.14038(Turbulent)$

Nusselt Number

Using Table 7-1 from Heat and Mass Transfer Fundamentals and analyzing the range ofReynolds number for water, the equation used for Nusselt number is the following:

$Nu_{water}=0.193Re^{0.466}Pr^{1/3}=5355.94082$
$Nu_{air}=0.023Re^{0.8}Pr^{0.3}=215.9769787$

Heat transfer Coefficient

Using the Nusselt number equation to solve for h,

$$\text{Nu}_{\text{Cyl}}=\frac{hD}{k}\quad\therefore\text{h}=\frac{Nu_{Cyl}kD}{}$$

$h_{water}=4601.017186W/m2*Kh_{air}$
$=38.12192077W/m2*K$

Overall heat transfer coefficient

$u=\frac{1}{\frac{1}{h_{air}}+\frac{1}{h_{water}}}=37.80865557\text{W}/\text{m}^{2}*\text{K}$

LMTD

$$\Delta T1 \;= Thot{,}in - Tcold{,}out \quad = 18°C$$

$$\Delta T2 = Thot{,}out - Tcold{,}in = 19.10895909°C$$

$$TLM = \frac{\Delta T1 - \Delta T2}{ln(\Delta T/\Delta T2)} = 18.5489549$$

Surface Area

Using the equation for heat transfer to solve for the surface area

$$Q = UAs\Delta Tlm \qquad \therefore \quad As = \frac{Q}{U * \Delta Tlm} \quad = 0.8397777986\text{m}$$

Modeling Set Up

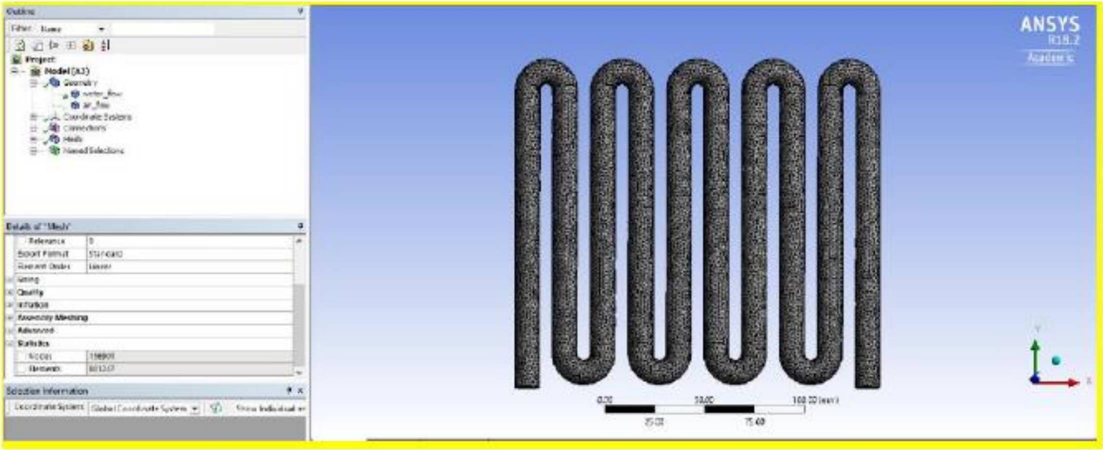
The heat exchanger was designed using Fusion 360 and was later imported into ANSYS toperform the simulation. As settings were modified during the setup process, many results anderrors were obtained.Multiple heat exchanger designs were attempted to achieve a temperaturedifference of 4 degrees celsius. The one below was the closest to achieving the 4 degrees. Thedifferent heat exchangers can be found in the appendix section of this report.

Relevance 0

Export Format Standard

Element Order Linear

Figure1. Applying mesh to outer fluid

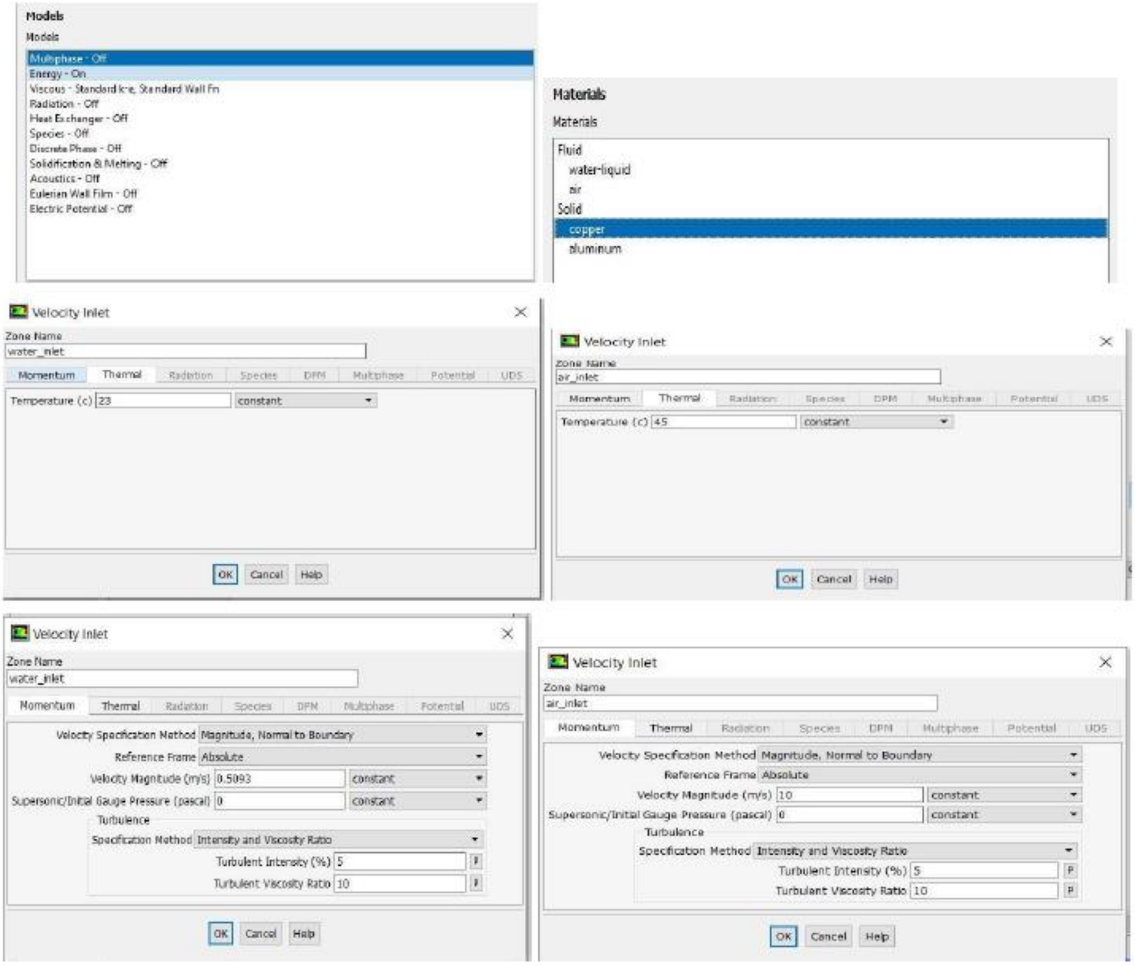


Relevance 0

Export Format Standard

Element Order Linear

Figure 2. Applying mesh to copper pipes and inner fluid



Models

Models

Multiphase - Off
Energy - On
Viscous - Standard k-e, Standard Wall Fn
Radiation - Off
Heat Exchanger - Off
Species - Off
Discrete Phase - Off
Solidification & Melting - Off
Acoustics - Off
Eulerian Wall Film - Off
Electric Potential - Off

Materials

Materials

Fluid
water-liquid
air
Solid
copper
aluminum

Velocity Inlet

Zone Name: water_inlet
Temperature (c): 23 constant

Velocity Inlet

Zone Name: air_inlet
Temperature (c): 45 constant

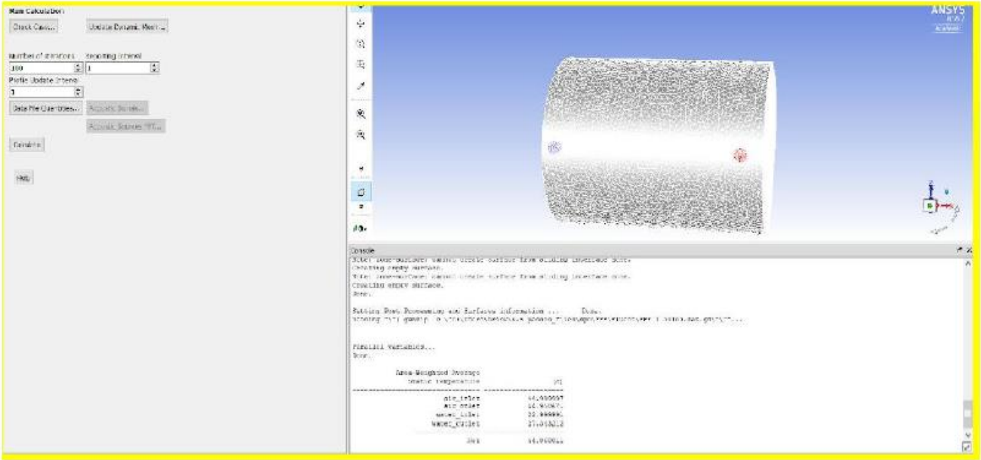
Velocity Inlet

Zone Name: water_inlet
Velocity Specification Method: Magnitude, Normal to Boundary
Reference Frame: Absolute
Velocity Magnitude (m/s): 0.5093 constant
Supersonic/Initial Gauge Pressure (pascal): 0 constant
Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity (%): 5
Turbulent Viscosity Ratio: 10

Velocity Inlet

Zone Name: air_inlet
Velocity Specification Method: Magnitude, Normal to Boundary
Reference Frame: Absolute
Velocity Magnitude (m/s): 10 constant
Supersonic/Initial Gauge Pressure (pascal): 0 constant
Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity (%): 5
Turbulent Viscosity Ratio: 10

Figure 3. Simulation Conditions



Number of Iterations: 100
Reporting Interval: 1
Profile Update Interval: 1

Figure 4. Running Calculations

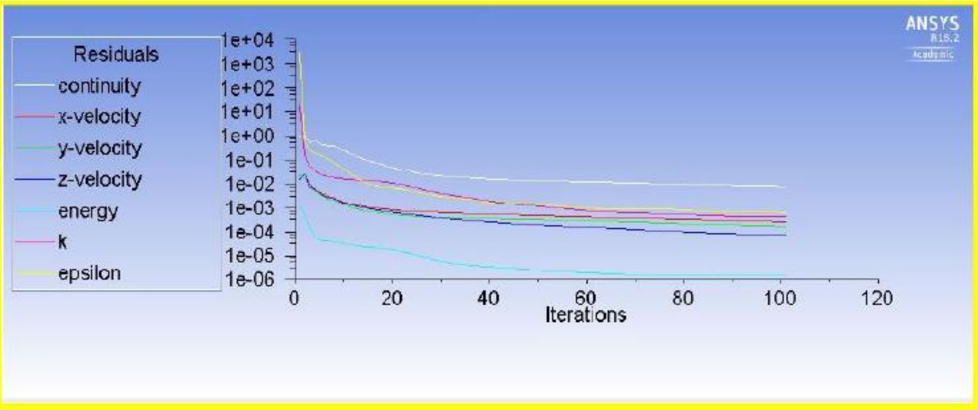


Figure 5. Iterations

II. Results

ANSYS simulation was performed on three different CAD models with three different numbersof passes (17, 11, and 10). There were technical limitations on geometry and design whensimulating ANSYS, which made our initial theoretical design impossible to simulate on thesoftware. The following results are the velocity, pressure, and temperature contours retrieved fromsimulating the 10 tubbed CAD design, which represents the most accurate simulation whencompared to our analytical calculations.

Velocity Contour:

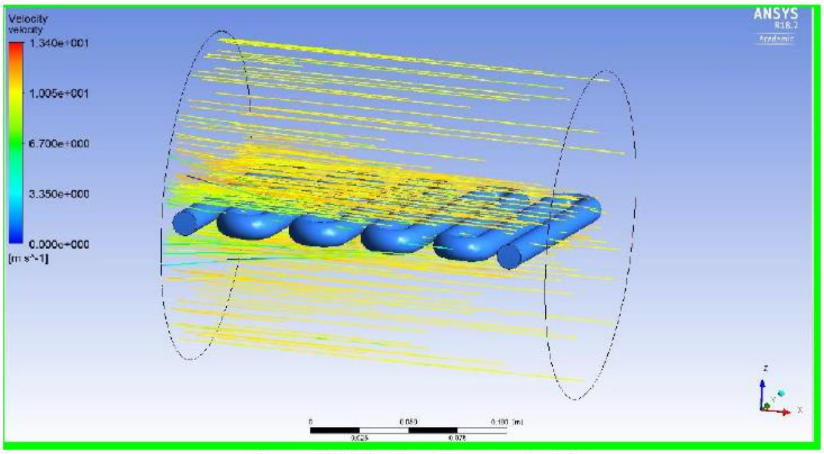


Figure 6.Velocity Contour (m/s)

Computational Fluid Dynamics (CFD) simulations were carried out to simulate the air flowthrough the test subject. We know that the performance of the heat exchanger is greatly affectedby the distribution of air that passes through it and the features within the duct and theorientation of the heat exchanger.

Simulation shows air flowing inside the heat exchanger in a range between 0 m/s and 13.1 m/s,which agrees with the 10 m/s initial velocity declared in the set up.

Pressure Contour:

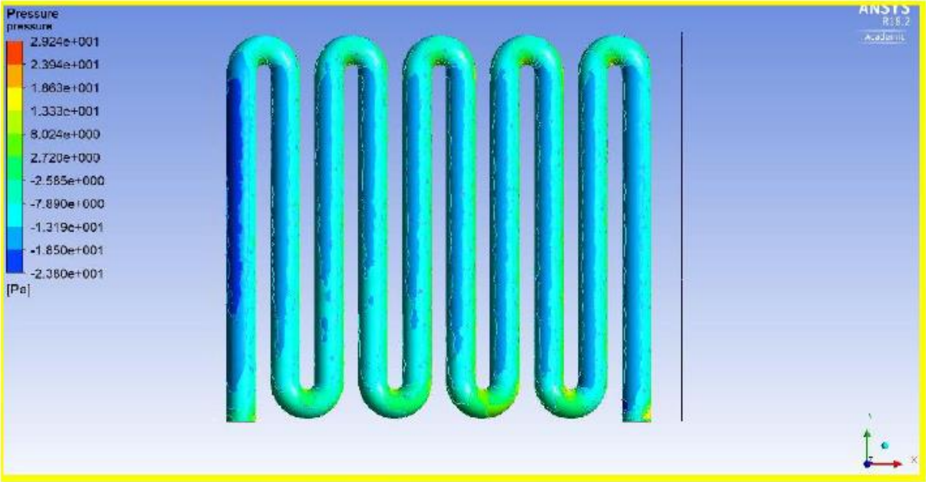


Figure 7. Pressure Contour (Pa)

The pressure contour obtained from ANSYS confirms that pressure does not remain constant inheat exchangers. This can be attributed to the fact that the fluid flowing inside the tube willcreate friction that leads to unavoidable pressure drop. Our simulation shows a range in pressurebetween -23.8 Pa and 29.2 Pa.

Temperature Contour:

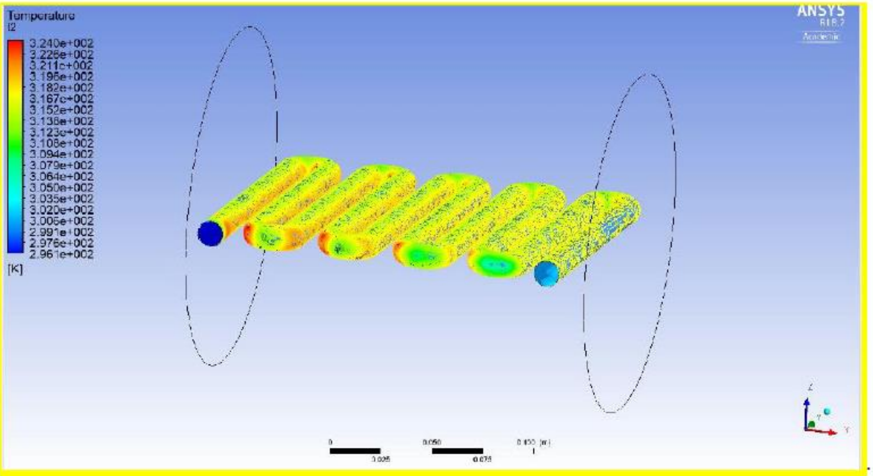


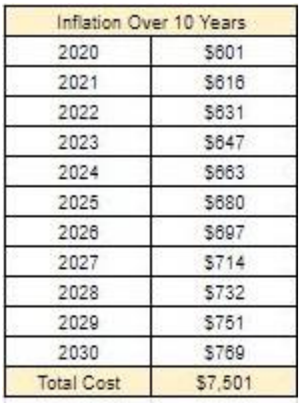
Figure 8. Temperature Contour (K)

The temperature contour shows a minimum temperature of 296.1 K located at the water inlet ofthe pipe. The water outlet shows a temperature in a blue gradient, which can be estimated to bebetween 299 K and 300 K, proving that this design successfully heats water by 4 degrees.

Costs

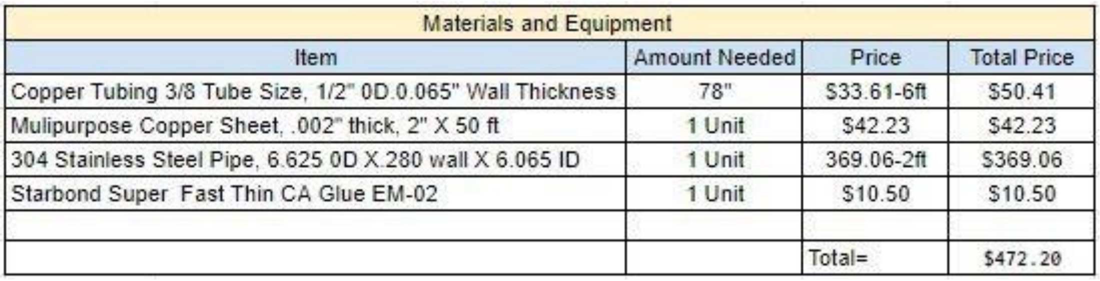
		# of Days	# of Hrs	Price $/kWhr	Q Air kW	Cost per Month	Cost per Season
🟪	January	31	744	0.1111	0.588	48.6031392	Winter
🟪	February	28	672	0.1111	0.588	43.8996096	141.105888
🟦	March	31	744	0.1111	0.588	48.6031392	Spring
🟦	April	30	720	0.1111	0.588	47.035296	149.0975136
🟦	May	31	744	0.1222	0.588	53.4590784	Summer
🟨	June	30	720	0.1222	0.588	51.734592	158.6527488
🟨	July	31	744	0.1222	0.588	53.4590784	Fall
🟨	August	31	744	0.1222	0.588	53.4590784	152.2289664
🟩	September	30	720	0.1222	0.588	51.734592	
🟩	October	31	744	0.1222	0.588	53.4590784	
🟪	November	30	720	0.1111	0.588	47.035296	
🟪	December	31	744	0.1111	0.588	48.6031392	
Total in 1 Year		365	8760			601.0851168	

Figure 9. Cost of One Year



Inflation Over 10 Years	
2020	$601
2021	$616
2022	$631
2023	$647
2024	$663
2025	$680
2026	$697
2027	$714
2028	$732
2029	$751
2030	$769
Total Cost	$7,501

Figure 10. Total Life Cycle Cost



Materials and Equipment			
Item	Amount Needed	Price	Total Price
Copper Tubing 3/8 Tube Size, 1/2" 0D.0.065" Wall Thickness	78"	$33.61-6ft	$50.41
Mulipurpose Copper Sheet, .002" thick, 2" X 50 ft	1 Unit	$42.23	$42.23
304 Stainless Steel Pipe, 6.625 0D X.280 wall X 6.065 ID	1 Unit	369.06-2ft	$369.06
Starbond Super Fast Thin CA Glue EM-02	1 Unit	$10.50	$10.50
		Total=	$472.20

Figure 11. Initial Costs

The total cost was calculated using the residential electricity rates in El Paso. To get the monthlycost, Qair was multiplied with the hours of the month, and then multiplied by the rate.Theaverage costs during the summer months are 12.22 ¢/kWhr and in the winter it is 11.11 ¢/kWhr.To calculate the costs over a span of 10 years, inflation was taken into consideration. In the finalreport, maintenance costs will also be included

Safety Considerations

Heat exchangers are essential equipmentfor a manufacturing plant. However, heat exchangersoperation and maintenance contain potential safety hazards to prevent any accidents, even death.Safety is a crucial part of the design and building to prevent accidents and also life cost of theheat exchanger.According to frankieidson.com, an injury lawyer, “Every year in the US .,power tool injuries result in approximately 400,00 emergency rooms visits”. Toreduce the risksof getting hurt the adequate personal protective equipment (PPE) should be used by every teammember. Safety goggles protect the eyes from residue from pipes being cut,helmets as well toget protection from flying objects ,gloves to protect hands from hot surfaces and sharp objects. Itis also imperative to always be a supervisor in case of accidents and never operate a machine orheat exchanger by yourself.

III. Conclusion

In this project, a heat recovery unit was created and simulated for the purpose of heating water4°C. Waterand air entered the heat recovery unit at 23°C and45°C respectively. All initialproperties were collected at those temperatures to help calculate both mass flow rates. Once thatwas calculated, the heat transfer, effectiveness, and NTU were calculated. The NTUwas used todetermine the Reynolds and Nusselt number. The heat transfer coefficient and LMTD were thencalculated to find the surface area. Multiple heat exchangers of different sizes were created to get aheat increase of 4°C. The final CAD design consisted of ten tubes and nine 180- elbows. Thisspecific heat exchanger size was the one that yielded the closest increase to 4°C. However, thefinal temperature at the water outlet is 27.3C. The reason for not getting exactly 4C could’ve been caused for numerous reasons including mesh size, number of iterations, and quality.

References

[1]. Administrator,E.(2020,January31).Whatisthedifferencebetweenparallelflow,counterflow and cross flow heatexchangers?Enerquip.

[2]. https://www.enerquip.com/2018/03/12/whats-the-difference-between-parallel-flow-counter-flow-and-crossf low-heat-exchangers/

[3]. Çengel, Y. A., Cimbala, J. M., & Turner, R. H. (2017). Fundamentals of thermal-fluid sciences. New York, NY: McGraw-HillEducation.

[4]. ElPaso,TXElectricityRates.(2020).RetrievedJuly13,2020,fromhttps://www.electricitylocal.com/states/texas/el-paso/

[5]. EngineeringToolBox,(2003).ConvectiveHeatTransfer.[online]RetrievedJune25,2020Fromhttps://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html.

[6]. Heat Transfer. (n.d.). Eng Fsu. Retrieved June 25, 2020, fromhttp://www.eng.fsu.edu/%7Eshih/eml3015/lecture%20notes/heat-transfer.htm

[7]. Heat Transfer Mechanisms. (n.d.). Engr Colostate. Retrieved June 25, 2020, fromhttps://www.engr.colostate.edu/%7Eallan/heat_trans/page4/page4f.html#:%7E:text=Convection%20heat%20transfer%20is%20energy,solid%20temperature%20difference%20Ts%2DTf.

[8]. Hire Orlando Workplace Injury Lawyers: Frank M. Eidson P.A. (2020, May 01). Retrieved July 14, 2020, fromhttps://www.frankeidson.com/practice-areas/workers-compensation/workplace-accidents/power-tool-accidents/