MEMO

To : Prof. Mary Hofle

From: Shishir Khanal, Matthew Wright, Sayler Massey

Date Submitted: November 6th, 2018

Subject: ME 4465 Design Summary for Project # 3 - Primary-Secondary Water loop System

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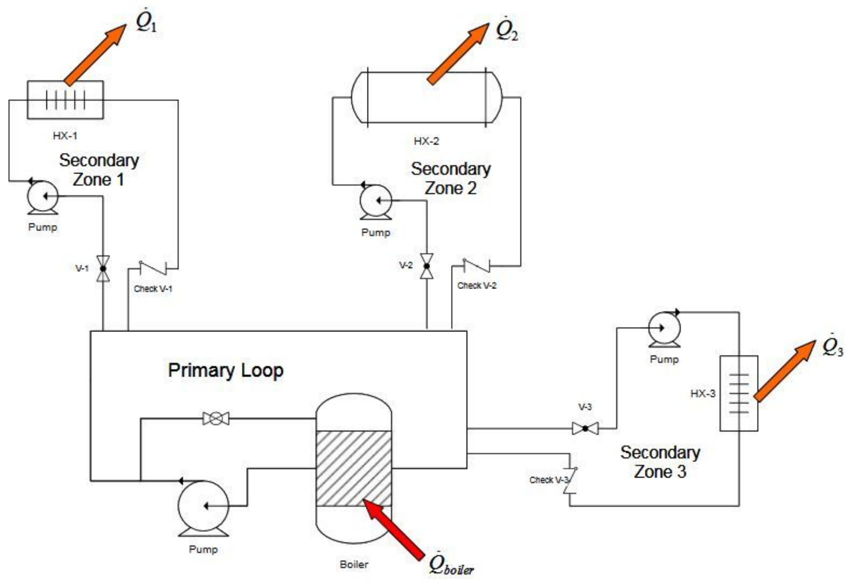
Introduction:

Our 'SMS' intern group of Hofle Heating & Cooling Corporation has been assigned to design a primary and secondary water pipe looping system which could be used to heat the water supplied in them for the commercial applications. This design documentation includes the calculations and coding iterations for the pipe design and it's parameters in all the primary and secondary loops, heat exchanger's parameters, heat exchanger selection and it's design in all 3 secondary loops, and the references used to get the facts required in the completion of the design.

System Requirements:

On the primary loop,under the given temperature, length and pressure, the design can have a maximum fluid velocity of 7ft/s. Similarly, in secondary zone -1, the loop's average temperature and amount of heat lost is provided, and the maximum flow velocity in the pipe can be 10 ft/s.

Also, in secondary zone -2, optimum flow velocity of 10 ft/s needs to heat potable water at a flow rate 5 gpm and drop it's temperature by 30 F. Finally, in secondary zone-3, the water flowing in the pipe needs to transfer 100,000 Btu/hr of heat to the air and its resulting drop in water temperature is 20 F, provided that the water can have an maximum fluid velocity of 10 ft/s.The outline of the loop design is provided below.



Objective:

The major objectives of the project is to design a piping system that would have a flow velocity below an optimum value and heat exchangers that would be able to make specific heat losses. In order to design the piping system, volumetric flow rate was to be calculated using the net heat change equation, the max allowable velocity could then be used in the volumetric flow rate equation to find the diameter of the pipe. For the heat exchanger design, air flow rate was either provided or calculated using the total heat change equation. Similarly, the type of heat exchanger was calculated using the Log Mean Temperature value. The size of the heat exchanger was calculated as a product of total heat exchange coefficient and surface area of heat exchanger.

Results:

Region of pipe	Pipe Diameter	Volumetric Flow Rate	Flow Velocity	Maximum Flow Allowed
Primary loop	0.3355 ft (4 in nom)	0.4679 ft^3/s	5.29 ft/s	7 ft/s
Secondary zone -1	0.2557 ft (3 in nom)	0.0457 ft^3/s	0.89 ft/s	10 ft/s
Secondary zone -2	0.256 ft (3 in nom)	0.0225 ft^3/s	0.497 ft/s	10 ft/s
Secondary zone -3	0.256 ft (3in nom)	0.0225 ft^3/s	0.4385 ft/s	10 ft/s

Table-1: Pipe diameter & fluid flow in Different loops

Zone	Flow Rate	Type	Size
Secondary zone -1	6.6 lbm/s	Counter flow	1780.5 Btu/hr °F
Secondary zone -2	1.38 lbm/s	Counter flow	2167.7 Btu/hr °F
Secondary zone -3	1.39 lbm/s	Counter flow	3202 Btu/hr °F

Table-2: Flow rate Type and size of Heat exchangers

In addition to these data, the total heat input by the boiler was found to be 450,000 Btu/hr , the starting temperature of the primary loop was taken as 194.5 ℉, and the heat removed from the hot water in heat exchanger on loop 2 was found to be 149400 btu/hr.

Conclusion:

In each secondary piping section our fluid velocity was slower than the maximum fluid velocity. For the primary section the fluid velocity was 5.29 ft/s with a maximum of 7 ft/s. The secondary zone-1 flow had a velocity of 0.89 ft/s, which was slower than the maximum of 10 ft/s. The secondary flow zone-2 had a velocity of 0.457 ft/s which was slower than the max of 10 ft/s . Finally, the third secondary zone had a velocity of 0.4385 ft/s which was slower than the max of 10 ft/s. The temperature of the water in the primary loop is 194.5 degrees fahrenheit, which is lower than the required temperature of 275 degrees fahrenheit. More information about the heat exchangers, water, and piping can be found in the above results section. Because each of the stated values were below the maximum allowable values our design passes all requirements.

Report

Requirements:

In the primary loop the maximum allowable length was 200 * Diameter of pipe chosen and the fluid velocity in the pipe cannot exceed 7 ft/s.

Similarly, in the secondary loop -1 the boiling water flowing through the tube could not have a velocity greater than 10 ft/s. Also, the water should transfer 200,000 Btu/hr heat to the air in the Heat Exchanger.

In secondary zone -2 , the maximum velocity of the water in the pipe should be 10 ft/s. Similarly, the heat exchanger should be designed such that the temperature of the boiling water drops by 30℉.

Finally, the velocity of fluid flow in the Secondary zone-3 cannot exceed 10 ft/s. The boiling water needs to transfer 100,000 Btu/hr to air.

Givens:

The maximum allowable temperature and pressure of water in the primary loop was given to be 275 ℉ and 50 psig respectively.

Then, for the secondary zone-1, mean water temperature was provided to be 180 ℉. The temperature drop of water in this region is provided to be 20 ℉. The entry and exit temperatures of the air is given as 50 ℉ and 85 ℉ respectively.

Also, mean water temperature for secondary zone 2 was given as 150 ℉. The flow rate of the potable water was provided to be 5 gpm with entry and exit temperatures were 50 ℉ and 110℉ respectively.

In the Secondary zone-3, the mean temperature of water was given as 120 ℉. The temperature drop of water in this region was given as 20 ℉.

Determine:

For all the 3 loops the diameter of the pipe needed to be determined. The process of the determination of the diameter included flow rate and flow velocity determination. For each of the secondary loops, the volumetric flow rate of the common piping was required. The starting temperature of the primary loop and the total heat input to the the boiler were needed.The type and size of the heat exchangers(HX) were required to be determined. The flow rate of HX-1 and Heat removed from water in HX-2 were also required.

Design Theory:

Note: All variables used are defined at the bottom of the design section.

1. **Determination of Boiler Parameters:**

First of all, the total rate of heat transfer required in the system was calculated. In order to find the boiler exit temperature, the total heat output of the boiler was calculated to find the total system need as shown below.

$$\dot{Q}_{total} = \dot{Q}_1 + \dot{Q}_2 + \dot{Q}_3 = 200{,}000 \frac{Btu}{hr} + 149040 \frac{Btu}{hr} + 100000 \frac{Btu}{hr}$$

$$\dot{Q}_{total} = 449040 \frac{Btu}{hr}$$

This value is rounded up to 450000 Btu/hr as a factor of safety. Once the total heat output is known the minimum pipe diameter can be found to handle it. An equation was used for the volume flow rate that is a function of heat transfer rate, density and change in temperature.

$$Q_p = \frac{Q}{\rho c_p \Delta T}$$

The density and cp value were an average taken from the max temperature given of 275 to the inlet of the first loop of 190 where ρ = 59.1575 lbm/ft^3 and $cp = 1.0095\ Btu/lbm\ R$. The change in temperature was found using iterations run using the difference of temperatures from the outlet temp starting at 275 degrees F to the inlet temperature of the first loop at 190 degrees F. A matrix of 20 values was created ranging from 85 to 4.5 degrees. These values were run to find the maximum volume flow rate that would be seen and the mass flow rate was found using the results and the following equation. Where

$$\dot{m} = \rho V A = \rho Q$$

Using the results from the iterations the corresponding Q (volume flow rate) was found for the mass flow rate and using that the minimum pipe diameter was calculated using the following equation.

$$Q = VA$$

The minimum diameter was found to be 3.5 inches. Using the nominal diameter from the Crane manual, the maximum velocity came out to be just under the 7ft/s maximum for the primary loop. The nominal pipe diameter was pushed up to 4 inches as a factor of safety as shown in the results.

Full list of iteration values is found in the appendix. The maximum pipe diameter and max velocity is shown below.

$Q_{max} = 1684.3 \frac{ft^3}{hr} = \underline{.4679 \frac{ft^3}{s}}$

$\dot{m} = \rho V A = \rho Q$

$\dot{m} = (59.1575 \frac{lbm}{ft^3})(88.65 \frac{ft^3}{hr}) = 5244.31 \frac{lbm}{hr} = \underline{1.47 \frac{lbm}{s}}$

from temperature difference iterations, largest $\dot{m}$ is $\underline{27.68 \frac{lbm}{s}}$

corresponding Q is $1684 \frac{ft^3}{hr}$

$\boxed{\text{Find: minimum } D \text{ using max allowable } V \text{ for pipe}}$

$Q = VA \Rightarrow .4679 \frac{ft^3}{s} = 7 \frac{ft}{s} (\frac{\pi}{4} D^2)$ $\quad .4679 \frac{ft^3}{s} = 5.49 D^2 \frac{ft}{s}$

$D^2 = .085 = .292 ft = \boxed{3.5 in}$

go up to nominal size of 4 inches $\quad D_{in}$ for shedule $40 = 4.026 in = .3355 ft$

check velocity

$.4679 \frac{ft^3}{s} = V(\frac{\pi}{4}(.3355 ft)^2$ $\quad \boxed{V = 5.29 \frac{ft}{s} < 7 \frac{ft}{s}}$

OK to use 4in nominal, $5.29 \frac{ft}{s}$ is the fastest velocity the main piping will see.

The hand calculations for the computation of these parameters are put in appendix 1 and 2 respectively.

2. **Determination of Pipe Diameter:**

Find: minimum D using max allowable V for pipe

$Q = VA \Rightarrow .4679\ \frac{ft^3}{s} = 7\ \frac{ft}{s}\left(\frac{\pi}{4}D^2\right) \qquad .4679\ \frac{ft^3}{s} = 5.49\ D^2\ \frac{ft}{s}$

$D^2 = .085 = .292\ ft = \boxed{3.5\ in}$

go up to nominal size of 4 inches D_{in} for schedule 40 = 4.026 in = .3355 ft

check velocity

$.4679\ \frac{ft^3}{s} = V\left(\frac{\pi}{4}(.3355\ ft)^2\right) \qquad \boxed{V = 5.29\ \frac{ft}{s} < 7\ \frac{ft}{s}}$

OK to use 4 in nominal, $5.29\ \frac{ft}{s}$ is the fastest velocity the main piping will see.

The total rate of heat transfer data was used to calculate the maximum volumetric flow rate. Using this flow rate the minimum diameter that would give the optimum flow rate was calculated. This value was compared in the nominal pipe diameter and the internal diameter was taken as the required diameter of pipe. After, that the flow velocity equation is used to get the final velocity of the flow. A sample of the calculation process is shown above. The hand calculations for the determination of the pipe diameter is shown in the appendices 2,4,5,6,7 and 8.

3. Determination of Flow in Common Piping:

Zone 6 Q_p 170→165 $T_{avg} \sim 167.5$ $\Delta T = 15$

$Q_s \sim$ 165→135 $T_{avg} \sim 150$ $\Delta T \sim 30$

Q_p

$C_p = 1.00075\ \frac{Btu}{lbm\ R}$

$\rho = 60.94\ \frac{lbm}{ft^3}$

$\boxed{Q_p - Q_s = 10.19\ \frac{gal}{min}}$

Q_s

$C_p = 1\ \frac{Btu}{lbm\ R}$

$\rho = 61.19\ \frac{lbm}{ft^3}$

The flow rate of the primary loop 'Q_p' and flow rate of secondary loop 'Q_s' were calculated using the equation 1 in the appendix. The difference in the temperatures of the section before the exit were taken for primary flow rate and that after the exit was taken for the secondary flow rate. The average temperature was used to find the density of the water specific heat capacity. And the difference between the 'Q_p' and 'Q_s' gave the volumetric flow rate in the common piping. Sample calculation in shown above. The hand calculations for the flow rate in common piping is provided in appendices 1 and 3.

4. **Determination of type and size of Heat Exchangers:**

Heat exchanger 1: Air $\dot{Q}$ = 200,000 Btu/hr T_{cin} = 50°F T_{cout} = 85°F ← given

∴ ΔT_c = 85 - 50°F = 35°F C_p = 0.2404 Btu/lbm°F pg 953 app A15E heat trans.

$\dot{Q} = \dot{m} C_p \Delta T_c$ ← eqn 1-18 pg 13 Heat transfer

200,000 Btu/hr = $\dot{m}$ · 0.2404 Btu/lbm°F · (85-50°F) = 23769.9 lbm/hr

=> 23769.9 lbm/hr · 1 hr / 3600s = 6.6 lbm/s air is cold, water is hot

Water: $\dot{Q} = \dot{m} C_p \Delta T$ T_{hin} = 180°F + 20°F/2 = 190°F T_{hout} = 180°F - 10°F/2 = 170°F

$C_{p\,water}$ = 1.002 Btu/lbm R ← pg 947 app A-9 E heat transfer

∴ 200,000 Btu/hr = $\dot{m}$ · 1.002 Btu/lbm R · (20°R) = 9980 lbm/hr · 1hr/3600s = 2.77 lbm/s

$\dot{Q} = UA_s \Delta T_{lm}$ ← eqn 11.3 pg 654 heat transfer and $\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$

eqn 11.25 pg 664 heat transfer. We are choosing a counter flow heat exchanger

due to its high efficiency. ∴ $\Delta T_1 = T_{hin} - T_{cout}$ $\Delta T_2 = T_{hout} - T_{cin}$

ΔT_1 = 190°F - 85°F = 105°F ΔT_2 = 170°F - 50°F = 120°F

∴ $\Delta T_{lm} = \frac{105°F - 120°F}{\ln(105°F/120°F)}$ = 112.33°F

and plugging each into eqn 11.3 =>

200,000 Btu/hr = UA_s · 112.33°F ∴ UA_s = 1780.5 Btu/hr°F ← size of HX #1

Mass flow rate of the water was calculated for the two different fluids intermixing in the heat exchanger. The equation 2,

$$Q = m_{Fr} * c_p * \Delta T$$

was used for the purpose.Total heat input of the boiler was used for the ‘Q’, the ‘ΔT’ was either calculated as a difference between the exit and entry temperatures or provided in the statement and specific heat of water at 'ΔT' was obtained from the Ref Book [2]. The ΔT's were used in the calculation of log mean temperature using the equation 3. Using this equation required the specification of type of heat exchanger. Counterflow Heat Exchanger was chosen for better efficiency.

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})}$$

Finally, the eqn 4 was used to determine the size($U * A_s$) of the heat exchanger. A sample calculation is shown above. The appendices 9, 10 and 11 contains detailed calculations for the HX's 1,2 and 3 respectively.

Appendix:

Equations

$$Q_p = \frac{Q}{\rho c_p \Delta T}$$ -- [1]

$Q_H = m_{Fr} * c_p * \Delta T$ -- [2]

$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})}$ (for Counter flow)--- [3]

$Q_H = U * A_s * \Delta T_{LM}$ --- [4]

$$Q = VA$$ -- [5]

$$\dot{m} = \rho VA = \rho Q$$ --- [6]

$Q_{conv} = h * A * (T - T(surr))$ --- [7]

$Q_{cond} = k * A * \frac{T_1 - T_2}{\Delta x}$ --- [8]

Q_p = Rate of Heat Transfer
Q = Volumetric Flow Rate
ρ = density of the fluid
c_p = specific heat of liquid
Q_H = Heat transfer rate in the HX
ΔT_{LM} = Log Mean Temperature Difference
U = Total heat transfer constant
A = Surface Area
$\dot{m}$ = mass flow rate
h= convective heat transfer coefficient
k = conductive heat transfer coefficient
Δx =distance between the points of interest

Primary loop | Matthew Wright

$T_{max} = 275°F$ @ 50psig $V_{max} = 7 ft/s$

$\dot{Q}_{total} = \dot{Q}_1 + \dot{Q}_2 + \dot{Q}_3 = 200{,}000\frac{Btu}{hr} + 149040\frac{Btu}{hr} + 100000\frac{Btu}{hr}$

$\dot{Q}_{total} = 449040\frac{Btu}{hr}$

Max temp = 275
Min temp = 110

$\dot{Q} = \dot{m}c_p\Delta T$

$Q_p = \frac{\dot{Q}}{\rho c_p \Delta T_p}$

T	cp
275	1.025
190	1.004
170	1.001
165	1.0005
135	.999
130	.999
110	.999

$c_{p\,avg} = 1.004$

$\Delta T = 165$

60.69

Find flow in common piping 275 190

Zone 1

$Q_p = \frac{200{,}000\frac{Btu}{hr}}{58.09(1.0215)(85)}$

ρ_{avg} 275+190
58.09
$\rho_{avg} = 58.09$
$c_{p\,avg} = 1.0215$

} interpolation Table A-9E

$Q_p = 39.65\frac{ft^3}{hr}$

$\Delta T = 275 - 190 = 85$

$= 4.94\frac{gal}{min}$

$Q_s = \frac{200{,}000}{60.57(1.0025)(20)}$

ρ_{avg} 190-170 $= 60.57\frac{lbm}{ft^3}$
$c_{p\,avg} = 1.0025$

$\Delta T = 20°F$

$Q_s = 164.69\frac{ft^3}{hr} = 20.53\frac{gal}{min}$

$Q_p - Q_s = 4.94 - 20.53 = -15.59\frac{gal}{min}$ Reverse flow at this temperature

Q_p flows from 275 to 190

App-1: Hand calculation for Primary loop(1/3)

Primary loop Matthew Wright

$T_{avg} = \frac{275+190}{2} = 235.5°F$

$\Delta T = 85°F$

$C_{p\,avg} = 1.0095 \frac{Btu}{lbm\,R}$ } avg values

$\rho_{avg} = 59.1575 \frac{lbm}{ft^3}$

Push Q up to 450,000 to take into account extra losses

$Q = \frac{\dot{Q}}{\rho c_p \Delta T}$

$Q = \frac{450{,}000 \frac{Btu}{lbm}}{(59.1575 \frac{lbm}{ft^3})(1.0095 \frac{Btu}{lbm\,R})(85)} = 88.65 \frac{ft^3}{hr} = 11.05 \frac{gal}{min} = .025 \frac{ft^3}{s}$

$Q_{max} = 1684.3 \frac{ft^3}{hr} = \underline{.4679 \frac{ft^3}{s}}$

$\dot{m} = \rho VA = \rho Q$

$\dot{m} = (59.1575 \frac{lbm}{ft^3})(88.65 \frac{ft^3}{hr}) = 5244.31 \frac{lbm}{hr} = \underline{1.47 \frac{lbm}{s}}$

from temperature difference iterations, largest $\dot{m}$ is $\underline{27.68 \frac{lbm}{s}}$

corresponding Q is $1684 \frac{ft^3}{hr}$

Find: minimum D using max allowable V for pipe

$Q = VA \Rightarrow .4679 \frac{ft^3}{s} = 7 \frac{ft}{s} \left(\frac{\pi}{4} D^2\right) \quad .4679 \frac{ft^3}{s} = 5.49 D^2 \frac{ft}{s}$

$D^2 = .085 = .292 ft = \boxed{3.5 in}$

go up to nominal size of 4 inches Din for schedule 40 = 4.026 in = .3355 ft

check velocity

$.4679 \frac{ft^3}{s} = V\left(\frac{\pi}{4}(.3355 ft)^2\right) \quad \boxed{V = 5.29 \frac{ft}{s} < 7 \frac{ft}{s}}$

OK to use 4 in nominal, $5.29 \frac{ft}{s}$ is the fastest velocity the main piping will see.

App-2: Hand calculation for Primary loop(2/3)

Primary loop common piping   Matthew Wright $\frac{3}{3}$

Zone 2 Q_p $170 \rightarrow 165$ $T_{avg} = 167.5$ $\Delta T = 15$

$Q_s = 165 \rightarrow 135$ $T_{avg} = 150$ $\Delta T = 30$

Q_p

$C_p = 1.00075 \frac{Btu}{lbm\,R}$

$\rho = 60.94 \frac{lbm}{ft^3}$

$\boxed{Q_p - Q_s = 10.19 \frac{gal}{min}}$

Q_s

$C_p = 1 \frac{Btu}{lbm\,R}$

$\rho = 61.19 \frac{lbm}{ft^3}$

Zone 3 Q_p $135 \rightarrow 130$ $T_{avg} = 132.5°F$

Q_s $130 \rightarrow 110$ $T_{avg} = 120°F$

Q_p

$C_p = .999 \frac{Btu}{lbm\,R}$

$\rho = 61.4225 \frac{lbm}{ft^3}$

$\boxed{Q_p - Q_s = 30.52 \frac{gal}{min}}$

Q_s

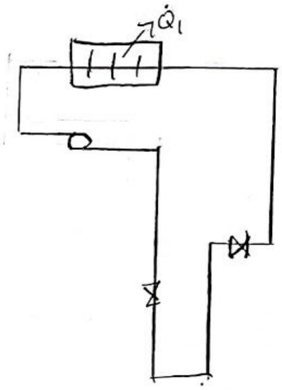
$C_p = .999 \frac{Btu}{lbm\,R}$

$\rho = 61.71 \frac{lbm}{ft^3}$

App-3: Hand calculation for Primary loop(3/3)

$V_{max} = 10 ft/s$

$23779.8 \frac{lb}{hr} \cdot \frac{1 \ hr}{3600 s} = 6.6 \frac{lb}{s}$



$\dot{Q}_w = \dot{m} C_{p_{water}} \Delta T$

$\dot{m} = \frac{\dot{Q}}{C_p \Delta T}$ $\Delta T = 20°F$

C_{pw} @ 180°F $= 1.002 \frac{Btu}{lbm \cdot R}$

$\dot{m} = \frac{200000 \frac{Btu}{hr}}{1.002 \frac{Btu}{lbm R}(20°F)}$

$\dot{m} = 9980 \frac{lbm}{hr} \cdot \frac{1 \ hr}{3600 s} = 2.77 \frac{lbm}{s}$ water

Solve for h

Need to find Nu, Pr, Ray, Re, K first Properties need to be found as well

Properties of water @ 180°F

Assuming $T_s = T_{avg} = 180°$

Kinematic viscosity $(\nu) = 3.827 \times 10^{-6} ft^2/s$

Density: $60.57 \frac{lbm}{ft^3}$

Dynamic viscosity $(\mu) = 7.707 \times 10^{-6} \frac{lb \cdot s}{ft^2}$

Thermal conductivity (K) : .388 $\frac{Btu}{h ft R}$

Prandtl number : 2.15

$\beta = .567 \times 10^{-3}$

Find minimum diameter $V_{max}: 10 ft/s$

$\frac{\dot{m}}{\rho} = Q$ $Q = VA$ $\frac{2.77 \frac{lbm}{s}}{60.57 \frac{lbm}{ft^3}} = \boxed{.0457 \frac{ft^3}{s} = 20.51 \frac{gal}{min} = Q}$ volume flow rate

$.0457 \frac{ft^3}{s} = 10 ft/s \left(\frac{\pi D^2}{4}\right)$ $D_{min} = .076 ft = .9156 in$

nominal size = 1 in

App-4: Hand calculation for Secondary loop-1(1/2)

2/2

Secondary loop 1 | Matthew Wright

check velocity

1.049 = inside diameter (crane manual)
= .0874 ft

$$V = \frac{Q}{A} = \frac{.0457 \frac{ft^3}{s}}{\frac{\pi}{4}(.0874ft)^2}$$

$$\boxed{V = 7.62 ft/s < 10 \frac{ft}{s} \quad \checkmark}$$

V is less than the maximum allowed for the loop so any pipe 1" or greater will work for the system.

will choose 3in nominal pipe. Inside diameter is 3.068 in = .2557 ft

Find velocity for 3in pipe

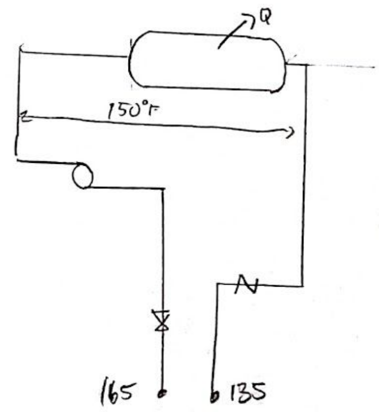
$$V = \frac{Q}{A} = \frac{.0457 ft^3/s}{\frac{\pi}{4}(.2557ft)^2}$$

$$\boxed{V = .89 \frac{ft}{s}}$$ well below V_{max}

3in pipe was chosen to achieve a balance between U and As for the heat exchanger as well to reduce the jump in pipe size from the secondary to the primary loop diameter of 4in.

App-5: Hand calculation for Secondary loop-1(2/2)

Secondary loop 2 | Matthew Wright | $\frac{1}{2}$



$\dot{Q} = \dot{m} c_p \Delta T$

$\dot{Q} = 41.4 \frac{Btu}{s} \frac{3600\,s}{1\,h} = 149040 \frac{Btu}{hr}$

$c_p @ 150° = 1 \frac{Btu}{lbm R}$

$\rho = 61.19 \frac{lbm}{ft^3}$

$\Delta T = 30°F$

$\nu = 4.746 \times 10^{-6} \frac{ft^2}{s}$

$149040 \frac{Btu}{hr} = \dot{m}(1)(30°F)$

$\dot{m} = 4968 \frac{lbm}{hr} \frac{1\,hr}{3600\,s}$

$\underline{\dot{m} = 1.38 \frac{lbm}{s}}$

$\frac{\dot{m}}{\rho} = Q \qquad Q = VA$

$\boxed{Q = .0225 \frac{ft^3}{s} = 10.09 \frac{gal}{min}}$

$Q = V \frac{\pi}{4} D^2$

$D^2 = \frac{Q}{V} \left(\frac{4}{\pi}\right)$

$D^2 = \frac{.0225 \frac{ft^3}{s}}{10 \frac{ft}{s}} \left(\frac{4}{\pi}\right) = .00286$

$D = \sqrt{.00268} = .0535 ft = .64 in$ pipe

$D_{min} = .64 in$ next nominal $D = .75 in$

$D_{in} = \underline{.824 inches} = .0687 ft$

check velocity

$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(D^2)} = \underline{6.09 \frac{ft}{s} < 10 \frac{ft}{s}}$

any pipe over .75in nominal will work

App-6: Hand calculation for Secondary loop-2(1/2)

Secondary loop 2	Matthew Wright		2/2

Choose 3in pipe $\Rightarrow$ .256ft

Check velocity

$V = \frac{Q}{A} = \frac{.0225 \frac{ft^3}{s}}{\frac{\pi}{4}(.256ft)^2}$ $\boxed{V = .497 \frac{ft}{s}}$

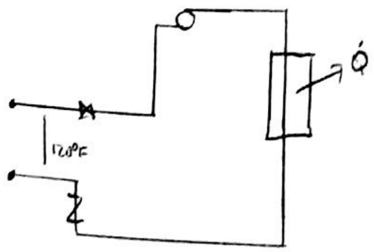
3 inch pipe was chosen to match other loop and keep change from secondary to primary piping minimal.

App-7: Hand calculation for Secondary loop-2(2/2)

Secondary loop 3

Matthew Wright

1/1



$\dot{Q} = 100{,}000 \frac{Btu}{hr}$

$\dot{Q} = \dot{m} C_p \Delta T$

$\Delta T = 20°$

$120°F$

$C_p = .999$

$\rho = 61.71 \frac{lbm}{ft^3}$

$100000 \frac{Btu}{hr} = \dot{m}(.999)(20°F)$

$\dot{m} = 5000 \frac{lbm}{hr} = 1.39 \frac{lbm}{s}$

$\nu = 6.067 \times 10^{-6} \frac{ft^2}{s}$

volume flow rate

$\frac{\dot{m}}{\rho} = Q = \boxed{.0225 \frac{ft^3}{s} = 10.09 \frac{gal}{min} = Q}$

$D = .6424$ in Nominal is .75in

$D_{in} = .824$in

$V = 6.09 \frac{ft}{s} < 10 \frac{ft}{s}$

$D_{min} = .824$in

$V = \frac{Q}{\frac{\pi}{4} D^2}$

Reynolds number $= \frac{VD}{\nu}$

choosing 3in nominal pipe

$\boxed{V = .4384 \frac{ft}{s}}$

App-8: Hand calculation for Secondary loop-3

Dayler Massey eqns | project #3 | 11/1/18 | 1/3

Heat exchanger 1: <u>Air</u> $\dot{Q} = 200{,}000$ Btu/hr $T_{cin} = 50°F$ $T_{cout} = 85°F$ ← given

$\therefore \Delta T_c = 85 - 50°F = 35°F$ $C_p = 0.2404$ Btu/lbm°F pg 953 app A-15E heat trans.

$\dot{Q} = \dot{m} C_p \Delta T_c$ ← eqn 1-18 pg 13 Heat transfer

$200{,}000$ Btu/hr $= \dot{m} \cdot 0.2404$ Btu/lbm°F $\cdot (85-50°F) = 23769.9$ lbm/hr

$\Rightarrow 23769.9$ lbm/hr $\cdot$ 1 hr / 36000 = $\underline{6.6}$ lbm/s Air is cold, water is hot

<u>Water:</u> $\dot{Q} = \dot{m} C_p \Delta T$ $T_{hin} = 180°F + \frac{20°F}{2} = 190°F$ $T_{hout} = 180°F - \frac{10°F}{2} = 170°F$

$C_{p,water} = 1.002$ Btu/lbmR ← pg 947 app A-9E heat transfer

$\therefore 200{,}000$ Btu/hr $= \dot{m} \cdot 1.002$ Btu/lbmR $\cdot (20°R) = 9980$ lbm/hr $\cdot$ 1hr/3600s $= \underline{\underline{2.77}}$ lbm/s

$\dot{Q} = UA_s \Delta T_{lm}$ ← eqn 11.3 pg 654 heat transfer and $\Delta T_{lm} = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$

eqn 11.25 pg 664 heat transfer. We are choosing a <u>counter flow heat exchanger</u>

due to its high efficiency. $\therefore \Delta T_1 = T_{hin} - T_{cout}$ $\Delta T_2 = T_{hout} - T_{cin}$

$\Delta T_1 = 190°F - 85°F = 105°F$ $\Delta T_2 = 170°F - 50°F = 120°F$

$\therefore \Delta T_{lm} = \dfrac{105°F - 120°F}{\ln(105/120°F)} = \underline{112.33°F}$

and plugging each into eqn 11.3 $\Rightarrow$

$200{,}000$ Btu/hr $= UA_s \cdot 112.33°F$ $\therefore UA_s = \underline{\underline{1780.5}}$ Btu/hr°F ← size of HX #1

App-9: Hand calculation for Heat exchanger Design in loop 1

<u>Heat exchanger #2:</u> using eq. 11.3 $\dot{Q} = \dot{m} C_p \Delta T$ as long as we ignore losses (as per instruction) $\dot{Q}_{hot} = \dot{Q}_{cold}$ $\therefore$ $\dot{m}_h C_{p_h} \Delta T_h = \dot{m}_c C_{p_c} \Delta T_c$

cold is potable water, hot is heated water.

<u>cold:</u>

$\dot{V} = 5$ gpm and @ 80°F (MWT of potable water) $= 0.01607\ ft^3/lbm \leftarrow$ A-9E Heat trans.

$$\therefore \frac{5\,gal}{min} \cdot \frac{1\,min}{60\,s} \cdot \frac{0.133681\,ft^3}{1\,gal} \cdot \frac{1\,lbm}{0.01607\,ft^3} = \dot{m}_c = 0.693\ lbm/s$$

$T_{ci} = 50°F$ $T_{ce} = 110°F$ $C_{p_c} = 0.999\ Btu/lbmR \leftarrow$ A-9E Heat trans.

$$\therefore \dot{Q} = \dot{m}_c C_{p_c} \Delta T_c \ (1\text{-}18) = 0.693\ lbm/s \cdot 0.999\ Btu/lbmR \cdot (110°F - 50°F) = 41.5\ Btu/s$$

$$41.5\ Btu/s \cdot \frac{3600\,s}{hr} = \underline{149400\ Btu/hr} = \dot{Q} \text{ for HX 2}$$

<u>Hot water:</u> $\dot{Q} = \dot{m}_h C_{p_h} \Delta T_h \ (1\text{-}18)$ $C_{p_h} = 0.999\ Btu/lbmR \leftarrow$ A-9E

$\Delta T = 30°F \leftarrow$ given $\Rightarrow 41.5\ Btu/s = \dot{m}_h \cdot 0.999\ Btu/lbmR \cdot 30°R = \underline{1.38\ lbm/s} = \dot{m}_h$

<u>size:</u> $\dot{Q} = UA_s \Delta T_{lm}$ (11.3) $\Delta T_{lm} = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$ (11.25)

again using a counterflow HX for efficiency $\therefore$

$\Delta T_1 = T_{hin} - T_{cout}$ = $T_{hi} = 150°F + \frac{1}{2}(30°F) = 165°F$ $T_{ce} = 110°F$

$\therefore \Delta T_1 = 165 - 110°F = 55°F$ $\Delta T_2 = T_{he} - T_{ci}$ $T_{he} = 150 - \frac{1}{2}(30°F) = 135°F$

$$\therefore \Delta T_2 = 135°F - 50°F = 85°F \quad \text{and} \quad \Delta T_{lm} = \frac{55°F - 85°F}{\ln(55°F/85°F)} = \underline{68.92°F}$$

$$\therefore UA_s = \dot{Q}/\Delta T_{lm} = 149400\ Btu/hr / 68.92°F = \underline{2167.7\ Btu/hr°F}$$

App-10: Hand calculation for Heat exchanger Design in loop 2

Heat exchanger #3

$\dot{Q}_{conv} = hA_s(T_s - T_\infty)$ ← 1.24 Heat trans. $T_\infty = 70°F$, a comfortable room temperature

$\dot{Q}_{cond} = kA_s\left(\frac{T_1 - T_2}{\Delta x}\right)$ ← 1.21 heat trans.

and $\frac{1}{hA_s} = \frac{1}{UA_s}$ ← eqn thermodynamics

plugging 1.24 into , $\frac{1}{hA_s} = \frac{T_s - T_\infty}{\dot{Q}}$. therefore $UA_s = \frac{\dot{Q}}{T_s - T_\infty}$

For a pipe filled with hot water and small fins it can be approximated that $T_s = T$ @ the end of the fin. Therefore we approximate T_s as T_2 and $\dot{Q}_{cond} = \dot{Q}_{conv}$ solving 1.21 for T_2 and saying $\Delta x = r_2 - r_1$ or pipe thickness and $A_s = 2\pi r_2(L)$

$T_1 - \frac{\dot{Q}_{cond} \cdot (r_2 - r_1)}{k(2\pi r_2 L)} = T_2$, where r_2 is the outer radius and r_1 is the inner radius.

we know T_1 = water temp = 120°F, $\dot{Q} = 100{,}000$ Btu/hr, $\underbrace{r_2 = 1.75\text{in}, \text{in}, r_1 = 1.534\text{in}}_{\text{crane manual}}$ and L is approx. 4 feet , k for steel = 314 Btu·in/hr·°F·ft² ← A-5E Heat trans

$\therefore T_2 = 120°F - 100{,}000\ \text{Btu/hr} \cdot (1.75\text{in} - 1.534\text{in}) / 314\ \text{Btu·in/hr°F ft}^2 / \left(\frac{2\pi \cdot 1.75\text{in}}{12\ \text{in}} \cdot 4\text{ft}\right)$

$= T_s = 101.23°F$

therefore $UA_s = \frac{100000\ \text{Btu/hr}}{101.23°F - 70°F} = \underline{\underline{3202\ \text{Btu/hr°F}}}$

hot water

$\dot{Q}_3 = \dot{m}_h c_{p_h} \Delta T_h = 100{,}000\ \text{Btu/hr} \cdot \dot{m}_h \cdot \overset{\sim\ \text{A-9E}}{1.00\ \text{Btu/lbm°R}} \cdot \overset{\text{given}}{20°R}$

$\therefore \dot{m}_h = 5000\ \text{lbm/hr} \cdot 1\ \text{hr}/3600\text{s} = 1.39\ \text{lbm/s}$

Boiler

$\dot{Q}_{boiler} = \dot{Q}_1 + \dot{Q}_2 + \dot{Q}_3 = 200{,}000\ \text{Btu/hr} + 149400\ \text{Btu/hr} + 100000\ \text{Btu/hr}$

$= 449400\ \text{Btu/hr} = \underline{\underline{450000\ \text{Btu/hr}}}$ to account for minor heat losses

App-11: Hand calculation for Heat exchanger Design in loop 3

```
%Matthew Wright
% Loop 1
clear
clc
Qdot = 200000 %[BTU/hr]
Cp = 1 % [BTU/lbm*R]
deltaT = 20 %Degrees F
Mdot = Qdot/(Cp*deltaT) %[lbm/hr]
Mdotsec = Mdot/3600 %[lbm/s]

%solve for the minimum pipe diameter with the maximum allowable veloctiy
rho = 60.57;
Q = Mdotsec/rho %[ft^3/s]
Vmax = 10; %[ft/s]
D = (sqrt(Q/(Vmax*(pi/4)))*12) % minimum pipe diameter [inches]
%Nominal size of 1 in
%Check velocity
Din = 1.049/12 %[feet]
V = Q/((pi/4)*Din^2)

%Velocity using a 3in nominal pipe
D3in = 3.068/12 %[ft]
V3in = Q/((pi/4)*D3in^2) %[ft/s]



%Reynolds number
mu = 4.746*10^-6 %[ft^2/s] 150 degrees F
Re = (V*D)/mu
if Re > 10^4
    fprintf('Can use the Dittus Boelter equation to find Nusselt number')
else
  fprintf('Cannot use Dittus Boelter equation')
end
```

App-12: Loop-1 Code

```matlab
%Matthew Wright
% Loop 2
clear
clc
Qdot = 149040 %[BTU/hr]
Cp = 1 % [BTU/lbm*R]
deltaT = 30 %Degrees F
Mdot = Qdot/(Cp*deltaT) %[lbm/hr]
Mdotsec = Mdot/3600 %[lbm/s]

%solve for the minimum pipe diameter with the maximum allowable veloctiy
rho = 61.19;
Q = Mdotsec/rho %[ft^3/s]
Vmax = 10; %[ft/s]
D = (sqrt(Q/(Vmax*(pi/4)))*12) % minimum pipe diameter [inches]

%Check velocity
Din = .824/12 %[feet]
V = Q/((pi/4)*Din^2)

%Velocity using a 3in nominal pipe
D3in = 3.068/12 %[ft]
V3in = Q/((pi/4)*D3in^2) %[ft/s]



%Reynolds number
mu = 4.746*10^-6 %[ft^2/s] 150 degrees F
Re = (V*D)/mu
if Re > 10^4
    fprintf('Can use the Dittus Boelter equation to find Nusselt number')
else
  fprintf('Cannot use Dittus Boelter equation')
end
```

App-13: Loop 2 code

```
%Matthew Wright
% Loop 3
Qdot = 100000 %[BTU/hr]
Cp = 1 % [BTU/lbm*R]
deltaT = 20 %Degrees F
Mdot = Qdot/(Cp*deltaT) %[lbm/hr]
Mdotsec = Mdot/3600 %[lbm/s]

%solve for the minimum pipe diameter with the maximum allowable veloctiy
rho = 61.71;
Q = Mdotsec/rho
Vmax = 10; %[ft/s]
D = (sqrt(Q/(Vmax*(pi/4)))*12) % minimum pipe diameter [inches]

%Check velocity
Din = .824/12 %[feet]
V = Q/((pi/4)*Din^2) %[ft/s]

%Velocity using a 3in nominal pipe
D3in = 3.068/12 %[ft]
V3in = Q/((pi/4)*D3in^2) %[ft/s]



%Reynolds Number
mu = 6.067*10^-6; %[ft^2/s] 120 degrees F
Re = (V*D)/mu
if Re > 10^4
    fprintf('Can use the Dittus Boelter equation to find Nusselt number')
else
  fprintf('Cannot use Dittus Boelter equation')
end
```

App-14: Loop 3 Code

```
%Matthew Wright
% Main loop interations for flow rate at different temps
% Find flow in primary piping from boiler exit
clear
clc
Qdot = 450000;
Cp = 1.0095;
rho = 59.1575;
%rho = 60.57;
Ts = 190;
Thot = linspace(275,190,20);
deltaT = (Thot-Ts);
Qp = (Qdot./(rho.*Cp.*deltaT)) % [ft^3/hr]

%solve for the mass flow rates at different temperatures

mdot = (rho.*Qp)/3600  %[lbm/s]

%Finding pipe diameter
%Q=VA
Q = Qp/3600
V = 7 %[ft/s]
D = 2*sqrt(pi.*V.*Q)./(pi.*V)

%Check Velocity
%Miniumim diameter comes out to be 3.5in exactly, check the velocity to see
%what happens
D3in = 3.548/12 %[ft]
Vmax = Q./((pi./4).*D3in.^2) %[Water velocity range with 3in nominal pipe
%The max velocity for the 3.5in nominal pipe is just under the 7ft/s maximum

%Will boost the nominal size to 4in to ensure it wont go over 7ft/s
Dmin = 4.026/12 %[ft]  inner diameter of 4in nominal pipe
Vm = Q/((pi/4)*Dmin^2) %[Water velocity range with 4in nominal pipe]

%max velocity is 5.29ft/s
```

App-15: Code to calculate flow in primary piping

Qp [ft^3/hr] = 1.0e+03 *| 0.0886 0.0936 0.0991 0.1053 0.1123 0.1203 0.1296 0.1404 0.1531 0.1684
0.1871 0.2105 0.2406 0.2807 0.3369 0.4211 0.5614 0.8422 1.6843 Inf

Mdot [lbm/s] = 1.4567 1.5377 1.6281 1.7299 1.8452 1.9770 2.1291 2.3065 2.5162 2.7678 3.0754
3.4598 3.9540 4.6130 5.5356 6.9196 9.2261 13.8391 27.6782 Inf

Q [ft^3/s] = 0.0246 0.0260 0.0275 0.0292 0.0312 0.0334 0.0360 0.0390 0.0425 0.0468 0.0520
0.0585 0.0668 0.0780 0.0936 0.1170 0.1560 0.2339 0.4679 Inf

V = 7 [ft/s]

D [ft] = 0.0669 0.0688 0.0708 0.0729 0.0753 0.0780 0.0809 0.0842 0.0880 0.0923 0.0972
0.1031 0.1103 0.1191 0.1305 0.1459 0.1684 0.2063 0.2917 Inf

D3in = 0.2957 [ft]

Vmax [ft/s] = 0.3587 0.3786 0.4009 0.4259 0.4543 0.4867 0.5242 0.5679 0.6195 0.6814 0.7572
0.8518 0.9735 1.1357 1.3629 1.7036 2.2715 3.4072 6.8145 Inf

Dmin =0.3355 [ft]

Vm [ft/s] = 0.2785 0.2940 0.3113 0.3308 0.3528 0.3780 0.4071 0.4410 0.4811 0.5292 0.5880
0.6616 0.7561 0.8821 1.0585 1.3231 1.7641 2.6462 5.2924 Inf

>>

Primary Loop Iterations

Iterations of temp range from 275 to 190 degrees F resulting in a temp change ranging from 85 to 4.4

```
%Matthew WrightP
%Flow in common piping
clear
clc
 %------------------------------ Secondary zone 1------------
%275 to 190 degrees varying
Qdot1 = 200000;
Cpp1 = 1.0095;
rhop1 = 59.1575;
Ts = 190;
Thot = linspace(275,190,20);
deltaT1 = (Thot-Ts); %[degrees F]
Qpp1 = (Qdot1./(rhop1.*Cpp1.*deltaT1)); % [ft^3/hr]

%flow in secondary piping 190 to 170
Cps11 = 1.0025;
rhos11 = 60.57; %[lbm/ft^3]
deltaTs11 = 20;
Qs11 = (Qdot1/(rhos11*Cps11*deltaTs11));  %[Ft^3/hr]

% flow in common piping
Qcp1 = Qpp1-Qs11  %[ft^3/hr]
Qppg = Qpp1/8.021; % changes ft^3/s to gallons per minute
Qsg11 = Qs11/8.021;   % changes ft^3/s to gallons per minute
Qcp2 = Qppg-Qsg11 %[gal/min]


% --------------------------------------Secondary Zone 2----------

%170 to 165
Qdot2 = 149040; %[Btu/hr]
Cp2 = 1.00075; % [Btu/lbm*R]
rho2 = 60.94; %[lbm/ft^3]
deltaT1 = 15; %[degrees F]
Qp2 = (Qdot2/(rho2*Cp2*deltaT1)); % [ft^3/hr]
Qpg2 = Qp2/8.021;

% temp range from 165 to 135
Cp22 = 1;
rho22 = 61.19; %[lbm/ft^3]
deltaT22 = 30; %[degrees F]
Qs22 = (Qdot2/(rho22*Cp22*deltaT22)); % [ft^3/hr]
Qsg22 = Qs22/8.021;   %[gal/min]

%flow rate of second loop common piping
Qcp3 = Qp2-Qs22 %[ft^3/hr]
Qcp4 = Qpg2-Qsg22 %[gal/min]
%Qs-Qp

 %----------------------------------- Secondary zone 3-----------------
% 135 to 130
Qdot3 = 100000; %[Btu/hr]
rho3 = 61.4225; %[lbm/ft^3]
Cp3 = .999; %[Btu/lbm*R]
deltaT3 = 5;
```

App-16: Code for flow in common Piping(1/2)

```
Qp3 = (Qdot3/(rho3*Cp3*deltaT3)); % [ft^3/hr]
Qpg3 = Qp3/8.021;

%130 to 110
rho33 = 61.71;
Cp33 = .999;
deltaT33 = 20;
Qs33 = (Qdot3/(rho33*Cp33*deltaT33)); % [ft^3/hr]
Qsg33 = Qs33/8.021;

%flow rate of the common piping
Qcp5 = Qp3-Qs33 %[gal/min]
Qcp6 = Qpg3-Qsg33 %[ft^3/hr]

HeatTransfer = [Qdot1; Qdot2 ;Qdot3];
VFR = [-15.62; Qcp4; Qcp6];
List = {'Loop1'; 'Loop2'; 'Loop3'};
list = {'heat transfer rate (Qdot) [Btu/hr]';'volumetric flow rate common
piping (gal/min)'};
Units = {'[Btu/hr]  [gal/min]';'[Btu/hr]  [gal/min]';'[Btu/hr]  [gal/min]'}
%T = table(list,heatTransfer,VFR)
T = table(List,HeatTransfer,VFR,Units)
```

App-17: Code to calculate flow in piping (2/2)

```
%Code By Sayler Massey
%Heat Exchanger #1
%Given information
Qdot=200000;
Tcin=50;
Tcout=85;
%solve for mdot cold
deltc=Tcout-Tcin;
Cpcold=0.2404;
mdotcold=Qdot/Cpcold/deltc
%solve for mdot hot
Thin=180+20/2;
Thout=180-20/2;
delth=Thin-Thout;
Cpcold=1.002;
mdothot=Qdot/Cpcold/delth
%solve for delta T log mean
delt1=Thin-Tcout;
delt2=Thout-Tcin;
deltlm=(delt1-delt2)./log(delt1/delt2);
%solve for UAs
UAs=Qdot/deltlm
```

App-18: Code for Heat Exchanger -1

```
%Code By Sayler Massey
%Heat Exchanger #2
%Solve for Qdot
mdotc=0.693;
Tcin=50;
Tcout=110;
Cpc=0.999;
Qdot=mdotc*Cpc*(Tcout-Tcin);
%Converts Qdot to Btu/hr
Qdothr=Qdot*3600;
%Solve for mdot hot
Cph=0.999
delth=30
mdoth=Qdot/Cph/delth
%Size / UAs
Thin=150+0.5*30;
Thout=150-.5*30;
delt1=Thin-Tcout;
delt2=Thout-Tcin;
deltlm=(delt1-delt2)./log(delt1/delt2);
%solve for UAs
UAs=Qdothr/deltlm;
```

App-19: Code for Heat Exchanger -2

```
%Code By Sayler Massey
%Heat Exchanger #3
%Solve for UAs
T1=120;
Qdot=100000;
r2=1.75;
r1=1.534;
l=4;
k=314;
T2=T1-(Qdot*(r2-r1)/k/(2*pi*r2/12*l));
%Solve for mdot hot
Cph=1.00;
delt=20;
mdoth=Qdot/Cph/delt;
```

App-20: Code for Heat Exchanger -3

```
%Code By Sayler Massey
%Boiler
Q1=200000;
Q2=149400;
Q3=100000;
Qdotboiler=Q1+Q2+Q3
```

App-21: Code for Boiler

■ Table B.1

Physical Properties of Water (BG Units)[a]

Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight[b], γ (lb/ft^3)	Dynamic Viscosity, μ (lb·s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Surface Tension[c], σ (lb/ft)	Vapor Pressure, p_v [lb/in.^{2}(abs)]	Speed of Sound[d], c (ft/s)
32	1.940	62.42	3.732 E − 5	1.924 E − 5	5.18 E − 3	8.854 E − 2	4603
40	1.940	62.43	3.228 E − 5	1.664 E − 5	5.13 E − 3	1.217 E − 1	4672
50	1.940	62.41	2.730 E − 5	1.407 E − 5	5.09 E − 3	1.781 E − 1	4748
60	1.938	62.37	2.344 E − 5	1.210 E − 5	5.03 E − 3	2.563 E − 1	4814
70	1.936	62.30	2.037 E − 5	1.052 E − 5	4.97 E − 3	3.631 E − 1	4871
80	1.934	62.22	1.791 E − 5	9.262 E − 6	4.91 E − 3	5.069 E − 1	4819
90	1.931	62.11	1.500 E − 5	8.233 E − 6	4.86 E − 3	6.979 E − 1	4960
100	1.927	62.00	1.423 E − 5	7.383 E − 6	4.79 E − 3	9.493 E − 1	4995
120	1.918	61.71	1.164 E − 5	6.067 E − 6	4.67 E − 3	1.692 E + 0	5049
140	1.908	61.38	9.743 E − 6	5.106 E − 6	4.53 E − 3	2.888 E + 0	5091
160	1.896	61.00	8.315 E − 6	4.385 E − 6	4.40 E − 3	4.736 E + 0	5101
180	1.883	60.58	7.207 E − 6	3.827 E − 6	4.26 E − 3	7.507 E + 0	5195
200	1.869	60.12	6.342 E − 6	3.393 E − 6	4.12 E − 3	1.152 E + 1	5089
212	1.860	59.83	5.886 E − 6	3.165 E − 6	4.04 E − 3	1.469 E + 1	5062

[a]Based on data from *Handbook of Chemistry and Physics*, 69th Ed., CRC Press, 1988. Where necessary, values obtained by interpolation.

[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 32.174$ ft/s^2.

[c]In contact with air.

[d]Based on data from R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

App-22: Physical Properties of water

References:

- **Textbook:**
    - Munson, Bruce Roy, et al. Fundamentals of Fluid Mechanics. John Wiley & Sons, Inc., 2013. [1]
    - Cengel. Heat and Mass Transfer. 2015. 5th edition [2];

        -Eqn1.18(Pg-13), Eqn 11.3(Pg-654), Eqn 11.25(Pg-),Eqn(1.24), Eqn(1.21)
- **Pipe Sizing Data**
    - Crane Manual
- **Equation References**
    - [1].Class Notes
    - Equation [2] Volumetric flow rate. Heat and Mass Transfer 5th edition, Muson, pg 661
- **Heat Exchangers**
    -