Connecting Industry to Mathematics Instruction

NSF ATE Award # 1954291

Cream Capacity Increase
Student Activity Sheet

In partnership with

WAKE TECH

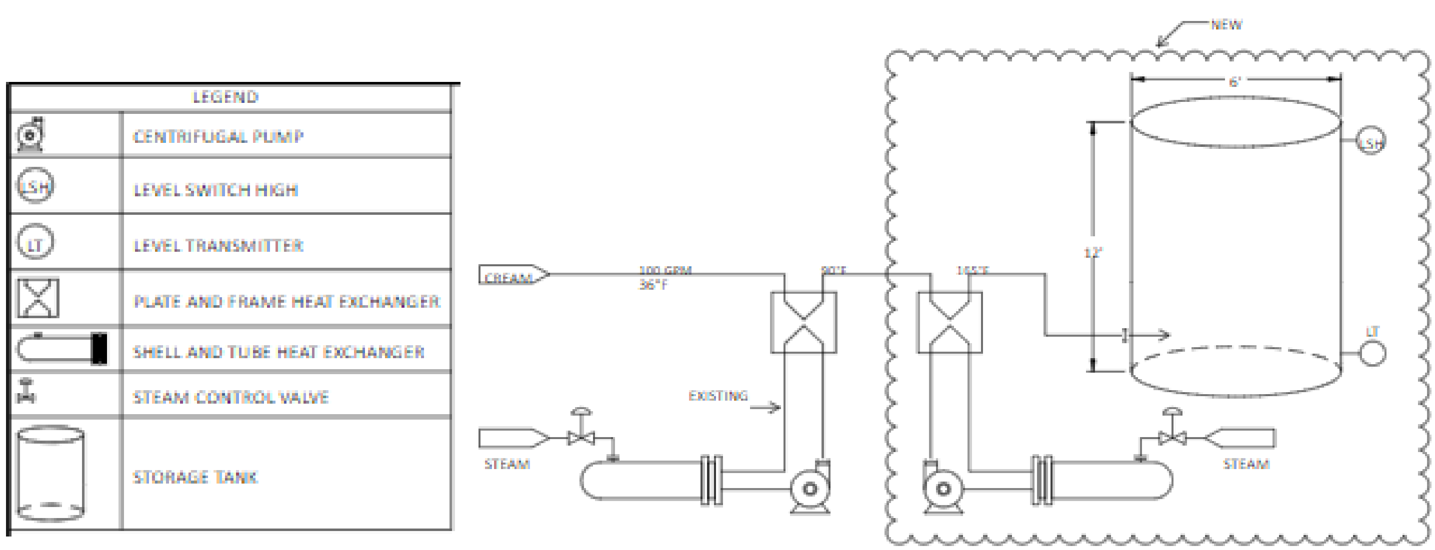
WAKE COUNTY PUBLIC SCHOOL SYSTEM

WakeEd PARTNERSHIP

Customer – Dairy processor in North Carolina. The plant processes regular fluid milk (all fat content grades), chocolate milk, buttermilk, and ice cream. Products get distributed to local grocery stores. A small amount goes to other processors.

Problem – Their demand for cream has picked up. They need to process much faster. To do so requires the plant to preheat the cream more than is being done now before it goes on to downstream pasteurization.

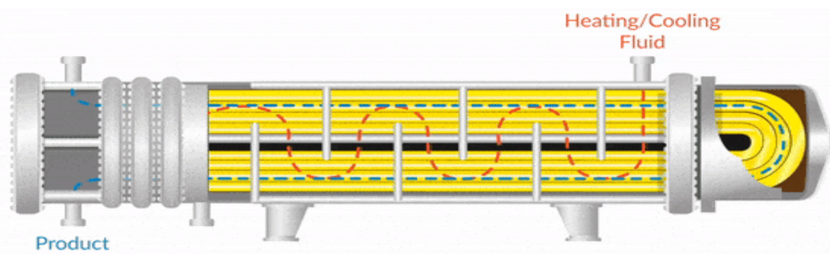
Solution –Utilize the existing equipment that is undersized but can be integrated with new equipment to meet this increased demand. The components inside the scalloped rectangle below are the new elements to be added to the existing equipment. As always, the most economical approach will usually be the one chosen!



Design Components: Each item in the above legend needs to be carefully purchased or fabricated and assembled to be delivered to the Dairy. Notice that there are two different types of heat exchangers in the design. The shell and tube heat exchanger uses incoming steam that will be regulated by the steam control valve. This steam enters the shell and tube heat exchanger and will go through a phase change (change from gas to a liquid) that will heat the water that is also passing through the shell and tube heat exchanger. (See the animation below) The heated water will then be pumped into the Plate and Frame heat exchanger that is used to raise the temperature of the incoming cream.

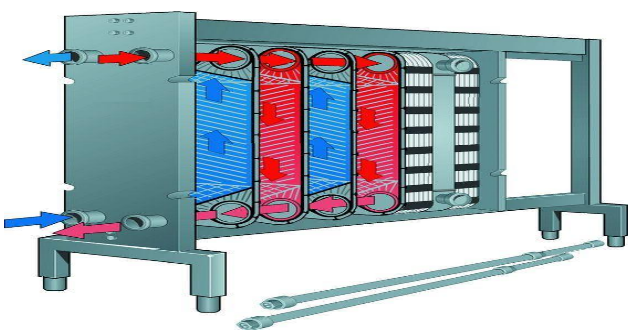
<u>Shell and Tube heat exchanger</u>

Steam going in the top right opening and water going in the bottom left opening and traveling through the tubes getting heated from the steam changes states from gas to liquid.



<u>Plate and Frame heat exchanger</u>

Hot water and Cream flowing through different pipes transferring heat energy from water to cream.



<u>Steam Control Valve</u>

The Steam Control Valve regulating the amount of steam entering the shell and tube heat exchanger is the most expensive single component in the design. They can range from $10,000 up to $50,000 depending on various parameters. The control value is like your car gas pedal, which regulates the amount of gasoline that goes to your car engine to accelerate or decelerate your speed. An example steam control value and the pump is shown below.

A control valve is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller. This enables the direct control of flow rate and the consequential control of process quantities such as pressure, temperature, and liquid level.

Centrifugal Pump

Determining the most economical steam control valve to purchase requires computing the heat energy needed to heat water that is then used to raise the cream to the desired temperature.

Now, design the new system to add to the existing system to bring the cream up to 165^{0}F.

Current operating data and given conditions

Cream flow rate = 100 gpm (gallons per minute)
Starting temp = 36 ^{o}F
Current final temp = 90 ^{o}F
New design final temp = 165 ^{o}F
Specific Gravity for cream is 1.023
Heat Capacity for cream is 0.89 BTU/(lb*^{0}F)
Latent Heat for steam at 30 psia is 945.2 BTU / pound
Latent Heat for steam at 40 psia is 933.6 BTU / pound
P1 = Pressure upstream of control value (known 35 psia)
P2 = Pressure downstream of control value
ΔP = Decrease in pressure across the control value (operates at 5 psia)

Technical Relationships:

Q = **ṁ** x **Cp** x Δ**T** , where **Q** = heat flow in BTU's/hr, **m** = cream flow rate in pounds/hour, **Cp** = Heat capacity for cream in BTU / (pound * ^{o}F), and Δ**T** = change in temp.

W = **Q** / **h$_v$** , where **W** = steam flow rate in pounds / hour and **h$_v$** = Latent Heat for steam at 35 psi , and **Q** = steam generated heat flow in BTU's/hr .

C$_v$ = **W** / (2.1 x sqrt (Δ**P** x (**P1** + **P2**)) , where **C$_v$** is a unitless number used by Control Value Manufacturers to size the correct value for the customer and **P** is pressure in psia (absolute pressure per square inch)

For each Task below, show your work to support all of your results. Include units on all computations and answers.

Task 1: Determine total Heat Flow currently needed to raise cream from 36 °F to 90 °F by:

A. determining **m**, the cream flow rate in pounds/hour
B. finding the heat capacity value (**Cp**) for cream
C. determining **Q ,** the heat flow rate of steam

Task 2: Determine total Heat Flow needed to raise cream from 36 °F to 165 °F.

Task 3: Determine Heat Flow needed in the new addition.

Task 4: Determine the Steam Flow Rate needed in the new addition to meet the required Heat Flow in the new addition.

Task 5. Compute C_v and use the table of control valve sizes to determine which value to purchase using the smallest size in the Equal Percentage column option.

Flow coefficients

Flow Characteristic	LV - Linear PV - Equal percentage MV - Modified parabolic 1R, 2R, 3R, 4R - Low noise 1, 2, 3 and 4 st 1K, 2K, 3K – Anti-cavitation 1,2 and 3 stag

	Body size (inch)	**LV**	**PV**	**MV**	**1R**
Flow coefficient - C_v	1"	19	17	11	18
	1½"	38-23	34-22	20-12	18-33
Types	2"	63-30	52-26	40-12	22-63
85-51	3"	130-88	118-57	120-32	38-125
85-61	4"	215-105	200-95	150-20	52-190
85-71	6"	410-155	390-140	310-64	350-104
	8"	870-260	820-210	820-118	665-400

Task 6. The Dairy customer prefers the tank shown below, rather than the single cylindrical tank. If the tank completely fills, determine the cream weight the tank must support in pounds. Tank radius is 3 feet and total height is 8 feet with the cylindrical height of 6 feet.

Task 7. A switch in the tank (LSH) is being read several times each second by the process control computer (PLC). When the cream level gets too high, the liquid cream will cover the probes on the switch. When this happens, an electric current pass through the liquid to an input (I:1) on the PLC. Internally, the input (I:1) flips from a 0 to 1 and will signal to sound an alarm. Start with an empty tank. Suppose the cream begins to flow into the tank at 10 gpm and this rate continues until the tank is completely full. However, after 2 minutes from beginning to fill the tank, cream begins to be withdrawn from the tank at 5 gpm. How long will it take to completely fill the tank and sound the alarm?

Task 8: Complete the formulas in the [excel template]() with initial values to check your results for tasks 1-4. Then use the Excel template to answer the following design options. (Below questions also in the excel sheet)

A. What valve would be needed if the Product Flow rate increased from 100 gal/min by 50%?
B. What is the maximum Product Flow rate in gal/min that would allow you to use the original designed control value?
C. What if the Dairy customer desired a higher rate of production and it is determined that a final cream temp of 185 degrees F would meet that demand. At the initial cream flow rate, would the Control Valve Size need to be increased?
D. What would be the highest final temp we could raise the cream up to and not have to increase the size of the control valve?

Task 9: OIL CAPACITY INCREASE - A New Customer

Determine the size of the most economical steam control valve that can be purchased to use in the new added system for the new customer to increase their production. Explain each step of your solution process and clearly state your control valve size recommendation.

Customer – Bakery snack processor in North Carolina. The plant processes several different varieties of fried snack cakes.

Problem – Due to a successful marketing campaign, their product demand has picked up. They need to process much faster. To do so requires the plant to preheat cooking oil more than is being done now before it goes on to the fryers.

Solution – Working with MG Newell technical sales and engineering, a plan has been proposed that would address this issue. It utilizes existing equipment that is undersized but can be integrated with new equipment to meet this increased demand. As always, the most economical approach will usually be the one chosen!

Design elements – the following refer to the process drawing and will require design calculations. Included below are the current conditions along with the new specifications.

<u>Current operating data</u>

Oil flow rate = 50 gpm

Starting temp = 60 ^{o}F

Heat Exchanger exit temp = 100 ^{o}F

Oil heat capacity = 0.49 BTU / (pound * ^{o}F)

Oil specific gravity = 0.91

<u>New specification</u>

Heat oil to 180 F before it goes into the fryer where it will be further heated.