Design of Heat Exchanger

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Abstract— This paper has been done to design a heat exchanger to pasteurize milk by steam in a dairy plant. Milk is to flow through a bank of 1.2 cm internal diameter tubes while steam condenses outside the tubes at 1 atm. Milk is to enter the tubes at 4°C, and it is to be heated to 72°C at a rate of 15 L/sec. We did all calculation processes to specify the tube length and the number of tubes, and the pump for the heat exchanger.

Keywords— Exchanger- pasteurize milk- tube length- pump-

I. INTRODUCTION

According to Y. A. Cengel in his book Heat Transfer: a Practical Approach, 2nd ed,

"Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperature while keeping them from mixing with each other. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants. Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix." (Cengel, 2007)

There are many applications for heat exchanger in industrial field. In food industrial, heat exchanger is being used to transfer heat from hot to cold or vice versa. Pasteurizing milk is one type of heat exchanger using in food applications. Design calculations are used to evaluate the efficiency of heat exchanger or to design new one for new purpose. By using this method, engineers can determine the rate of heat of both exit fluid cold and hot. Also, it can be used to estimate the power consumption.

Design a new heat exchanger is complicated process that is composed of many aspects. In this paper, we will discuss all the processes that involves in thermal side. Also, we will mention the characteristics of the material that we have picked up to be used in our design of this exchanger.

II. DESIGN CALCULATIONS FOR THE EXCHANGER

In heat exchanger design, the overall surface area of heat exchanger plays role in both inlet and outlet temperatures of product fluid and heating fluid. The flow rate of the fluid is also related to the surface area. Moreover, surface area plays a role in choosing the flow direction and pressure drop. Determining the total surface area, which is composed of tubes diameter, shell diameter and other geometrics, is important in heat exchanger designing.

Heat exchangers are named according to the direction of cold fluid and hot fluid to two kinds, Fig 1. Parallel flow is occurred in devices that the flow of both hot and could flow is moving in the same direction. In this case, usually the outlet temperature of heating fluid is more than the outlet temperature of cold fluid. Counter flow is existed when the cold and hot fluids are moving in the opposite direction of each other. In this case, the outlet temperature of cold fluid is sometimes more than the outlet temperature of heating fluid.

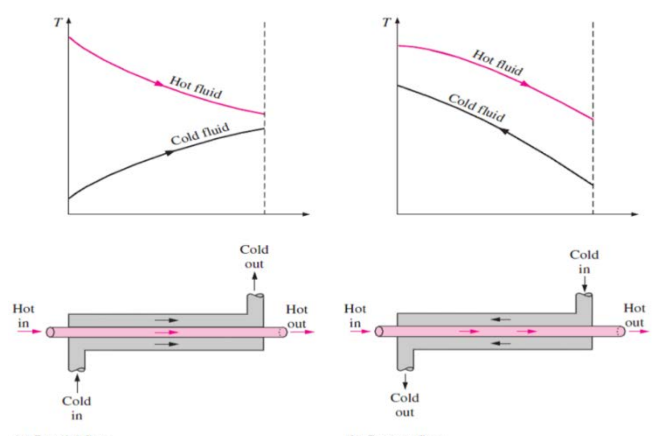


Fig 1, Parallel and counter flow configurations with corresponding temperature profiles (Cengel, 2007)

III. Materials involved

Stainless steel pipe and tubing are used for a variety of reasons: to resist corrosion and oxidation, to resist high temperatures for cleanliness and low maintenance costs, and to maintain the purity of materials which come in contact with stainless. The inherent characteristics of stainless steel tubing permit the design of thin wall piping systems without fear of early failure due to corrosion. The use of fusion welding to join such piping eliminates the need for threading.

Type 304 stainless is the most widely used analysis for general corrosive resistant tubing and pipe applications. It is used in chemical plants, refineries, paper mills, and food processing industries. Type 304 has a maximum carbon

content of 0.08%. It is not recommended to be used in temperature range between 800° F and 1650° F due to carbide precipitation at the grain boundaries which can result in inter-granular corrosion and early failure under certain conditions.

Type 316L as well as 304L is held to a maximum carbon content of 0.03%. This permits its use in welded assemblies without the need of final heat treatment. It is used extensively for pipe assemblies with welded fitting.

Other fields where stainless steel pipe and tubing are used are: aviation, electronics, automotive, cryogenic, marine, air conditioning and heating, medical, food preparation equipment, architectural and textiles.

IV. Calculation Processes

$$T_{in,Milk} = 4\ ^\circ C$$

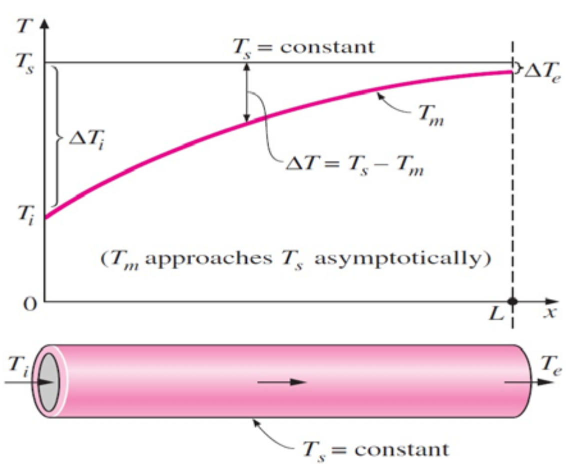
$$T_{out,Milk} = 72\ ^\circ C$$

$$\dot{m}_{total} = 15\ L/sec$$

$$d_i = 1.2\ cm$$

$$T_f = \frac{72+4}{2} \gg T_f = 38^\circ C$$

<u>We assumed that:</u>



1. The number of tubes is 30 tubes.
2. The properties of milk equal to the water properties.

$C_p = 4178.5\ \frac{J}{Kg.K}$

$Pr = 4.572$

$\rho = 993.7\ \frac{kg}{m^3}$

$K = 0.627\ \frac{W}{m.K}$

$A_c = \frac{\pi}{4} D_i^2$

$Ac = 1.131\ x\ 10^{-4}\ m^2$

$\mu = 0.759\ x\ 10^{-3}\ \frac{kg}{m.s}$

$v = \frac{\mu}{\rho}$ *"Kinematic viscosity"*

$v = 7.638\ x\ 10^{-7}\ \frac{m^2}{s}$

$$\dot{Q} = \dot{m}\, C_p\, (T_{C,Out} - T_{C,In})$$

From table

1 kg/sec = 1.0753 litter/sec

$$\dot{m}_{30\ tubes} = \frac{15}{1.0753} = 13.95\ kg/sec$$

$$\dot{m}_{one\ tube} = \frac{13.95}{30} = 0.465\ kg/sec$$

$$\dot{Q} = 0.465\ \frac{Kg}{s}\ x\ 4178.5\ \frac{J}{Kg.K}(72\ ^\circ C - 4\ ^\circ C)$$

$$\dot{Q} = 132.124\ Kw$$

$$\dot{m} = \rho\, V_{avg}\, A_c$$

$$V_{avg} = \frac{\dot{m}}{\rho \cdot A_c} \quad >> \quad V_{avg} = \frac{0.465}{993.7\ x\ 1.131\ x\ 10^{-4}}$$

$$V_{avg} = 4.138\frac{m}{s}$$

$$Re = \frac{V_{avg} \cdot D_i}{v} \quad >> Re = \frac{4.138\ x\ 1.2\ x\ 10^{-2}}{7.638\ x\ 10^{-7}}$$

$$Re = 65011.78 \quad >> \quad Re > 10{,}000$$

Since Reynolds number is more than 10,000, the flow is TURBULENT.

Nusslet Number is:

$Nu = 0.023 Re^{0.8} Pr^n$ >>

$Nu = 0.023(65011.78)^{0.8}(4.572)^{0.4}$ >> *for heating, n is 0.4*

$$Nu = 299.34$$

From the equation $Nu = \frac{h_i \cdot D_i}{K}$ *then,*

$$h_i = \frac{Nu.K}{D_i} \quad >> \quad h_i = \frac{299.34 \times 0.627}{1.2 \times 10^{-2}}$$

$$\boldsymbol{h_i = 15640.515 \frac{W}{m^2.K}}$$

From the equation, $\dot{Q} = hA_s\Delta T_{lm} \quad >> \quad A_{s\,one\,tube} = \frac{Q}{h\Delta T_{lm}}$

$$\Delta T_e = T_s - T_{milk\ out} \quad >> \quad \Delta T_e = 100\ °C - 72\ °C = 28$$

$$\Delta T_i = T_s - T_{milk\ in} \quad >> \quad \Delta T_i = 100\ °C - 4.0\ °C = 96$$

$$\Delta T_{lm} = \frac{\Delta T_e - \Delta T_i}{\ln(\Delta T_e/\Delta T_i)} \quad >> \quad \Delta T_{lm} = \frac{28-96}{\ln(28/96)}$$

$$\Delta T_{lm} = 55.188$$

$$A_{s\,one\,tube} = \frac{Q}{h\Delta T_{lm}} \quad >> \quad A_s = \frac{132124.17}{15640.515 * 55.188}$$

$$\boldsymbol{A_s = 0.153\ m^2}$$

From the equation, $A_s = n\pi D_i L$ *where n=1*

$$L_{one\ tube} = \frac{A_s}{n\pi D_i} \quad >> \quad L = \frac{0.153}{\pi \times 1.2 \times 10^{-2}}$$

$$\boldsymbol{L = 4.058\ m}$$

The frication factor is:

$$f = 0.184\ Re^{-0.2} \quad >> \quad f = 0.184\ (65011.78)^{-0.2} \quad >>$$

$$\boldsymbol{f = 0.02}$$

$$\dot{W} = \dot{V}\Delta P$$

$$\Delta P = f\frac{L}{D}.\frac{\rho v_m^2}{2} \quad >> \quad \Delta P = 0.02\ \frac{4.058}{1.2 \times 10^{-2}}.\frac{993.7\,(4.138)^2}{2}$$

$$\boldsymbol{\Delta P = 57539.63}$$

$$\dot{V} = V_m.A_c n \quad >> \quad \dot{V} = 4.138 \times 1.131 \times 10^{-4} \times 30$$

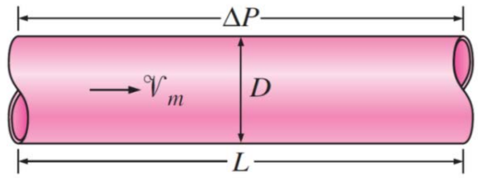
$$\boldsymbol{\dot{V} = 0.014 \frac{m^3}{s}}$$

$$\dot{W} = \dot{V}\Delta P \quad >> \quad \dot{W} = 0.014 \times 57539.63$$

$$\boldsymbol{\dot{W} = 805.554\ W}$$

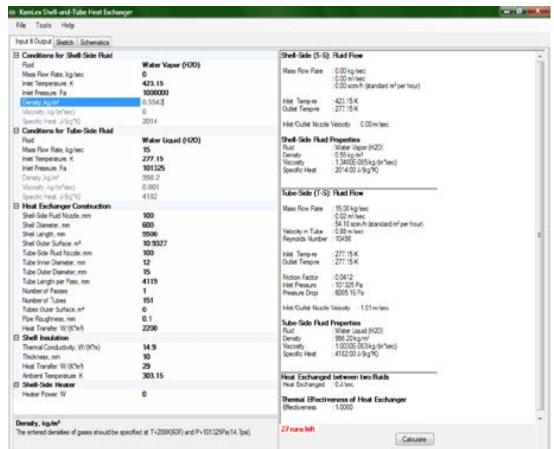
The power of pump is W/745.7 (Hp)

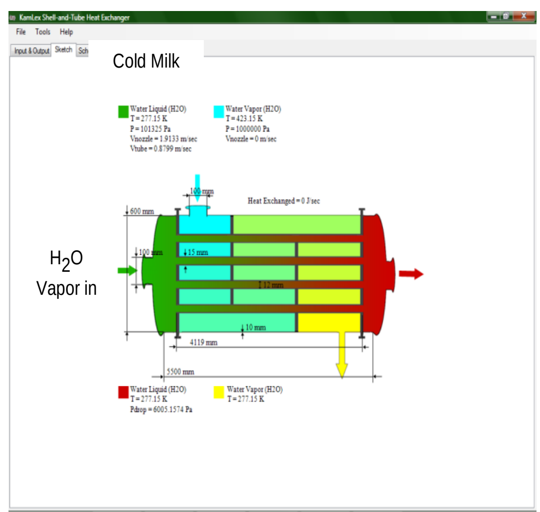
The power of pump is 1.08 hp

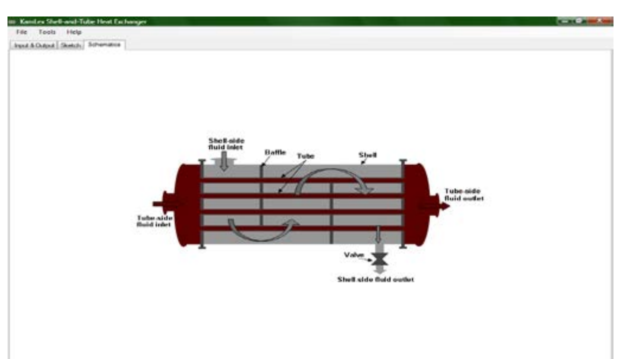


$$\textit{Pressure drop: } \Delta P = f\frac{L}{D}\frac{\rho \mathcal{V}_m^2}{2}$$

V. Calculate the Size of Heat Exchanger







VI. Conclusion

The calculation of thermal design assistance in the design and operation efficiency of heat exchangers. Is usually used routinely LMTD method to estimate the changes in temperature in the fluid and the size of heat exchangers. The method is based on the assumption that the properties of liquids LMTD constant along the heat exchanger (but we did not use LMTD due to lack of knowledge steam temperature in/ out of our system). To overcome these assumptions, the design calculations must be performed using computational techniques. Estimated coefficient of heat transfer surface could be the most difficult design because of its dependence on the flow of fluid and thermal properties, and flow conditions and heat exchanger engineering, and surface roughness. Can modern tools such as computational fluid dynamics to help determine the values of surface heat transfer coefficient.

VII. NOMENCLATURE

A	area of heat exchange surface (m2)
Cp	specific heat of fluid (J/kg _C)
F	correction factor (dimensionless)
H	surface heat transfer coefficient (W/m2 K)
K	thermal conductivity (W/m K)
L	length of a cylindrical tube (m)
LMTD	log mean temperature difference (_C)
$\dot{m}$	mass flow rate (kg/sec)
Q	heat flow rate (W)
Re	Reynolds number (dimensionless)
Pr	Prandtl number (dimensionless)
Rt	total thermal resistance of heat exchange surface (K/W)
Rf	fouling factor (m2 K/W)
T	temperature (Celsius or Kelvin)
ΔT_{lm}	log mean temperature difference
U	overall heat transfer coefficient (W/m2 K)

VIII. Microsoft Excel Calculations

The Microsoft Excel used to make formats that can help in calculation in this design.

For n tubes	
Q=	142069
tubes # =	30
V rate (l/s) =	15
mass flow rate (kg/s)	0.5
Ac (m2)	0.000113097
V ave =	8.897789051
Re # =	139792.4438
Nu # =	552.2774139
h (W/m2 . K) =	28856.49487
As (m2) =	0.089209497
L (m) =	2.366355403
f=	0.017207631
DP=	133477.8842
Volume rate (m3/s) =	0.030189487
W (W) =	4029.628853
Power ofPump (hp) =	5.403820374

IX. References

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3. Singh, P. P. (2007). Thermal Design of Heat Exchangers. University of Idaho, Moscow, Idaho, U.S.A.