**Heat Exchanger Design**

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**ABSTRACT**

A characteristic of heat exchanger design is the procedure of specifying a design, heat transfer area and pressure drops and checking whether the assumed design satisfies all requirements or not. The purpose of this project is how to design the heat exchanger especially for shell-and-tube heat exchanger which is the majority type of liquid-to-liquid heat exchanger. General design considerations and design procedure are also illustrated in this paper. Fundamental heat transfer concepts and complex relationships involved in such exchanger are also presented in this paper.

This project addresses design of Heat Exchanger with the basics of thermal design, covering topics such as: shell and tube heat exchanger (STHE) components; classification of STHEs according to construction, Comparison of exchangers; data needed for design; tube side design; shell side design, including tube layout.

The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop.

**INTRODUCTION**

A heat exchanger is a device built for efficient [heat transfer](http://en.wikipedia.org/wiki/Heat_transfer) from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in [space heating](http://en.wikipedia.org/wiki/Space_heating), [refrigeration](http://en.wikipedia.org/wiki/Refrigeration), [air conditioning](http://en.wikipedia.org/wiki/Air_conditioning), [power plants](http://en.wikipedia.org/wiki/Power_plant), [chemical plants](http://en.wikipedia.org/wiki/Chemical_plant), [petrochemical plants](http://en.wikipedia.org/wiki/Petrochemical), [petroleum refineries](http://en.wikipedia.org/wiki/Oil_refinery), [natural gas processing](http://en.wikipedia.org/wiki/Natural_gas_processing), and [sewage treatment](http://en.wikipedia.org/wiki/Sewage_treatment). One common example of a heat exchanger is the [radiator](http://en.wikipedia.org/wiki/Radiator) in a car, in which the heat source, being a hot engine-cooling fluid, [water](http://en.wikipedia.org/wiki/Water), transfers heat to air flowing through the radiator (i.e. the heat transfer medium).

Heat transfer in heat exchanger usually involves convection in each fluid and conduction through the wall separating two fluids. The rate of heat transfer between two fluids at a location in heat exchanger depends on magnitude of temperature difference at that location which varies along heat exchanger.

**Applications of Heat Exchanger:**

Heat exchangers are used in various fields like-

* Automotive
* Commercial and Residential Heating/Cooling
* Aircrafts
* Manufacturing
* Cooling Electronics
* Power plant
* Petroleum refineries
* Natural gas processing
* Space heating
* Ventilation (HVAC)
* Radiators on internal combustion engines
* Boilers, condensers

In this project our aim is to design heat exchanger for the following problem-

**Problem Statement:**

* 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/s. Making reasonable assumptions, you are to specify the tube length and the number of tubes, and the pump for the heat exchanger.

To design heat exchanger of given problem so many point have to be considered like which heat exchanger is suitable for given problem, Selection Criteria of Heat Exchangers, counter flow or parallel flow, design steps and so on.

**Selection Criteria for Heat Exchangers:**

Following criteria should be considered while designing heat exchanger:

1. Upper-lower limit of pressure requirement

2. Thermal Performance

3. Temperature ranges

4. Mixture of different products

(Liquid/liquid, particulates or high-solids liquid)

5. Pressure Drops across the heat exchanger

6. Capacity of flowing fluid

7. Cost

8. Clean ability, routine maintenance and repair

9. Materials required for construction

10. Ease of future expansion

**Types of Heat Exchanger:**

There are different types of heat exchanger used in industry like:

1. Shell and Tube heat exchanger

2. Plate heat exchanger

3. Adiabatic wheel heat exchanger

4. Plate fin heat exchanger

5. Fluid heat exchanger

6. Waste heat recovery units

7. Dynamic scraped surface heat exchanger

8. Phase change heat exchanger

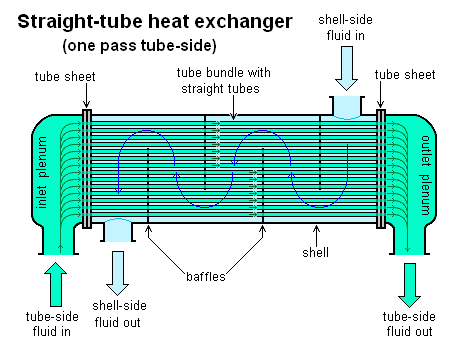
To design heat exchanger of given problem we used shell and tube heat exchanger:

**Why shell and tube heat exchanger?**

Shell and tube heat exchanger in their various construction modification are probably the most widespread and commonly used basic heat exchanger in the process industry The reason for this general acceptance are several. Shell and tube heat exchanger provides a comparatively large ratio of heat transfer area to volume and weight. It provides this surface in form which is relatively easy to construct in a wide range of size and which is mechanically rugged enough to withstand normal shop fabrication stresses, shipping and field erection stresses and normal operating conditions. There are many modification of the basic configuration, which can be used to solve special problems. The shell and tube heat exchanger can easily clean, and those component most subject to failure-gasket and tubes-can be easily replace. Finally good design methods exits and the expertise and shop facilities for the successful design and construction of shell and tube exchanger are available throughout the world.

**Shell and tube heat exchanger:**

Shell and tube heat exchangers consist of a series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and Tube heat exchangers are typically used for high pressure applications (with pressures greater than 30 bar and temperatures greater than 260°C). This is because the shell and tube heat exchangers are robust due to their shape. Shell and Tube heat exchanger as shown in fig.



There are several thermal design features that are to be taken into account when designing the tubes in the shell and tube heat exchangers. These include:

* **Tube diameter:** Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and the fouling nature of the fluids must be considered.
* **Tube thickness:** The thickness of the wall of the tubes is usually determined to ensure:
  + There is enough room for corrosion
  + That flow-induced vibration has resistance
  + Axial strength
  + Availability of spare parts
  + Hoop strength (to withstand internal tube pressure)
  + Buckling strength (to withstand overpressure in the shell)
* **Tube length:** Heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including the space available at the site where it is going to be used and the need to ensure that there are tubes available in lengths that are twice the required length (so that the tubes can be withdrawn and replaced). Also, it has to be remembered that long, thin tubes are difficult to take out and replace.
* **Tube pitch:** When designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter which leads to a more expensive heat exchanger.
* **Tube corrugation**: This type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.
* **Tube Layout:** Refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (30°), rotated triangular (60°), square (90°) and rotated square (45°). The triangular patterns are employed to give greater heat transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.
* **Baffle Design:** [Baffles](http://en.wikipedia.org/wiki/Baffle_(heat_exchanger)) are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating.

The most common type of baffle is the segmental baffle. The semicircular segmental baffles are oriented at 180 degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundles. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo economic optimization it is suggested that the baffles be spaced no closer than 20% of the shell’s inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag.

The other main type of baffle is the disc and donut baffle which consists of two concentric baffles, the outer wider baffle looks like a donut, whilst the inner baffle is shaped as a disk. This type of baffle forces the fluid to pass around each side of the disk then through the donut baffle generating a different type of fluid flow.

**Advantages of Shell and Tube Heat Exchanger:**

* Condensation or boiling heat transfer can be accommodated in either the tubes or the shell, and the orientation can be horizontal or vertical.
* The pressures and pressure drops can be varied over a wide range.
* Thermal stresses can be accommodated inexpensively.
* There is substantial flexibility regarding materials of construction to accommodate corrosion and other concerns. The shell and the tubes can be made of different materials.
* Extended heat transfer surfaces (fins) can be used to enhance heat transfer.
* Cleaning and repair are relatively straightforward, because the equipment can be dismantled for this purpose.

**FLOW ARRANGEMENT:**

Because heat exchangers come in so many shapes, sizes, makes, and models, they are categorizing according to common characteristics. One common characteristic that can be used to categorize them is the direction of flow the two fluids have relative to each other. The three categories are:-

* Counter-flow heat exchangers
* Parallel-flow heat exchangers
* Cross low heat exchanger

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| |  | | --- | |  |   Although ordinary heat exchangers may be extremely different in design and construction and may be of the single- or two-phase type, their modes of operation and effectiveness are largely determined by the direction of the fluid flow within the exchanger.  **1. Counter-Flow Heat Exchangers:**  The most common arrangements for flow paths within a heat exchanger are counter-flow and parallel flow. A counter-flow heat exchanger is one in which the direction of the flow of one of the working fluids is opposite to the direction to the flow of the other fluid.  flickr:2090037059  Figure represents the directions of fluid flow in the counter-flow exchangers.  The **counter-flow heat exchanger** has **three** significant **advantages** over the parallel flow design.  **1.** The more uniform temperature difference between the two fluids minimizes the thermal stresses throughout the exchanger. **2**. The outlet temperature of the cold fluid can approach the highest temperature of the hot fluid (the inlet temperature). **3.** The more uniform temperature difference produces a more uniform rate of heat transfer throughout the heat exchanger. **4**. Under comparable conditions, more heat is transferred in a counter-flow arrangement than in a parallel flow heat exchanger.  **2. Parallel-Flow Heat Exchangers:**  Parallel flow, as illustrated in Figure, exists when both the tube side fluid and the shell side fluid flow in the same direction. In this case, the two fluids enter the heat exchanger from the same end with a large temperature difference. As the fluids transfer heat, hotter to cooler, the temperatures of the two fluids approach each other.  In this type the hottest cold-fluid temperature is always less than the coldest hot-fluid temperature.  parallel flow heat exchanger  The temperature profiles of the two heat exchangers indicate **two** major **disadvantages** in the **parallel-flow design**.  **1.** The large temperature difference at the ends causes large thermal stresses. The opposing expansion and contraction of the construction materials due to diverse fluid temperatures can lead to eventual material failure.  **2.** The temperature of the cold fluid exiting the heat exchanger never exceeds the lowest temperature of the hot fluid. This relationship is a distinct disadvantage if the design purpose is to raise the temperature of the cold fluid.  The design of **a parallel flow heat exchanger** is **advantageous** when two fluids are required to be brought to nearly the same temperature.  **3. Cross Flow Heat Exchanger:**  Cross flow, as illustrated in Figure, exists when one fluid flows perpendicular to the second fluid; that is, one fluid flows through tubes and the second fluid passes around the tubes at 90° angle. Cross flow heat exchangers are usually found in applications where one of the fluids changes state (2-phase flow). An example is a steam system’s condenser, in which the steam exiting the turbine enters the condenser shell side, and the cool water flowing in the tubes absorbs the heat from the steam, condensing it into water. Large volumes of vapor may be condensed using this type of heat exchanger flow.  cross flow heat exchanger  Whether parallel or counter-flow, heat transfer within the heat exchanger involves both conduction and convection. One fluid (hot) convectively transfers heat to the tube wall where conduction takes place across the tube to the opposite wall. The heat is then convectively transferred to the second fluid. Because this process takes place over the entire length of the exchanger, the temperature of the fluids as they flow through the exchanger is not generally constant, but varies over the entire length, as indicated in. The rate of heat transfer varies along the length of the exchanger tubes because its value depends upon the temperature difference between the hot and the cold fluid at the point being viewed.  As mention above advantages of counter flow over parallel and cross low heat exchanger, **we use counter flow heat exchanger for our** **design** because  is the most efficient when comparing heat transfer rate per unit surface area. The efficiency of a counter flow heat exchanger is maximum.   |  |  | | --- | --- | |  |  | |

**CALCULATION OF HEAT EXCHANGER DESIGN**

**Data of milk**:

**Note: We assume number of tubes = 3**

Density of milk () = 1030 Kg/

Volume flow rate () = 15 L/sec = 0.0015/sec

Volume flow rate of each tube = 15/3= 5L/sec= 0.005/sec

So, mass flow rate of each tube () = = 5 kg/sec

Inlet temperature (Ti) = 4

Outlet temperature (To) = 72

Thermal conductivity of milk () = 0.559 W/m

Specific heat () = 2.18 KJ/Kg

Viscosity () = 4.3 /sec

Internal Diameter of pipe = 1.2cm = 0.012m

**Data of steam (at 1atm):**

Inlet temperature (Ti) = 100

Specific heat () = 1.89 KJ/Kg

Density of steam () = 0.5884 Kg/

To design heat exchanger we use **NTU** (**Number of Transfer Units**) method.

Reynolds number can be calculated as-

**= …………………………….. (1)**

==

Velocity in each tube () = / =

From Eq.1

Which is greater than 4000. Therefore flow is turbulent.

Now, we find **Nusselt Number** and **Prandtl number**

Also,

Heat transfer coefficient,

Now, **Heat transfer rate,**

Also,

But,

**So, Length of Tubes = 0.12m**

We select Material of tube as a stainless steel so, roughness

**Now we will find pressure:**

**…………………………………………………. (2)**

We will determine friction factor () from the Colebrook equation,

Relative roughness

Using an equation solver or an iterative scheme, the friction factor is determined to be

From Eq.2

**=**

**Pump work done is calculated as-**

**Headis calculated by,**

= 24m

**Data for Motor Selection:**

Model No # X$D Ultra NEMA premium (M480) ¾ - 300 Hp

Company = General electric

Specification of Motor:

RPM = 3600

Full Load amp = 8.5

Efficiency = 90%

Power factor = 87 % (at full load)

Volt = 460

= 4.76hp

It is almost close to the power required to pump.

**Operating cost:**

O.C. = (Pumping Power, KW) x (Hours of operation) x (Price of electricity, $ / kwh)

Operating Hours = (8 hr/day) x 5 day

= 40 hr / week

Total kWh = 40 x 3.64

= 145.6 / week.

Consider rate = 15 Cents / kWh

Operating Cost = 145.6 x 0.15

= $ 21.84 / week.

**CONCLUSION**

From this project we studied design of heat exchanger especially for shell-and-tube heat exchanger which is the majority type of liquid-to-liquid heat exchanger, different flow arrangement, and basic design consideration for heat exchanger, design steps etc

Counter-Flow Tube-in-Tube type heat exchangers are the most efficient means of safely transferring heat to sludge without the risk of overheating and baking sludge to the inside of the tubes.

**REFERANCES**

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