

Problem: Shell-and-tube Heat Exchanger Design

Background: Heat exchangers are all around us (car radiator, central air, refrigerator, etc.). They are especially important to chemical engineers in reactor design, operating a refinery or chemical process plant, and in many other situations where you need to transfer heat from one stream to another. One of the most commonly used heat exchangers is the Shell-and-tube heat exchanger as shown in Figure 1.

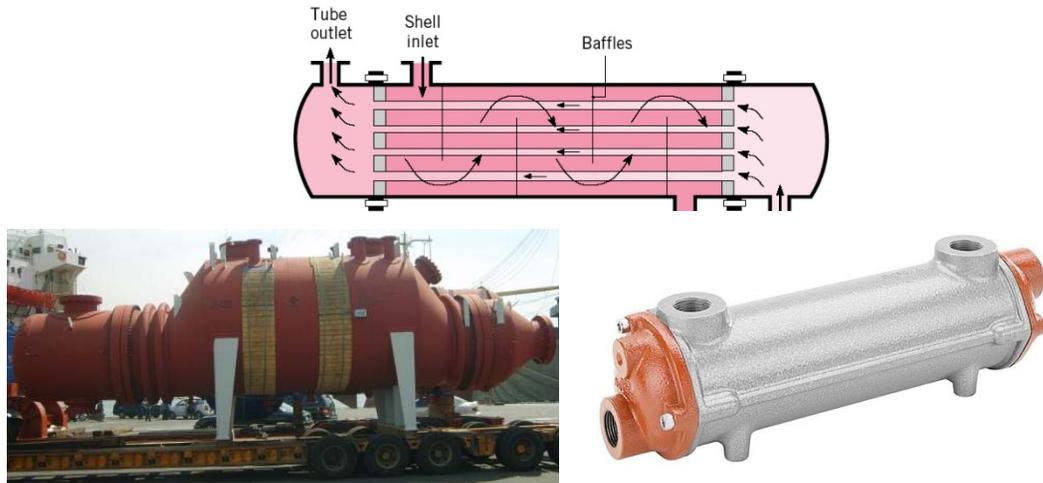


Figure 1: Shell-and-tube Heat Exchanger Illustration (Top). Examples of Heat Exchangers you can buy off the internet (Bottom)

Heat Exchangers exchange heat from a hot fluid to a cooler fluid to either heat up or cool down a stream. In designing our chemical plant, bioreactor, oil refinery, etc. we can determine the fluid temperature conditions that are necessary for optimal performance of our process. The next step is to determine what type of heat exchanger we could buy or if we should make a custom heat exchanger to do the job. Your project assignment is to create a program in which you supply the temperature conditions, the flow rates and the fluid types and it will tell you how large of a heat exchanger to build and how much it will cost.

We will be using the log mean temperature difference method (LMTD) to determine the size (surface area of pipe between fluids) of heat exchanger needed. This is an L3 competency that is commonly missed on the L3 exam (need to pass to graduate). The necessary equations are given below which we will discuss in more detail in your ChE 376 class.

$$q = \dot{m}_h c_{p,h} (T_{h,i} - T_{h,o})$$

$$q = \dot{m}_c c_{p,c} (T_{c,o} - T_{c,i})$$

$$q = FUA\Delta T_{lm}$$

where

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

and

$$\Delta T_1 = T_{h,i} - T_{c,o}$$

$$\Delta T_2 = T_{h,o} - T_{c,i}$$

Also,

$$F = \left(\frac{\sqrt{R^2 + 1}}{R - 1} \right) \frac{\ln[(1 - P)/(1 - P * R)]}{\ln \left[\frac{2 - P(R + 1 - \sqrt{R^2 + 1})}{2 - P(R + 1 + \sqrt{R^2 + 1})} \right]}$$

where

$$R = (T_{h,i} - T_{h,o}) / (T_{c,o} - T_{c,i})$$

$$P = (T_{c,o} - T_{c,i}) / (T_{h,i} - T_{c,i})$$

Variable Definitions:

q is the total heat transfer rate in the heat exchanger (units = J/sec)

T is the temperature of the fluid (subscripts: h = hotter fluid, c = colder fluid, i = input or entrance of heat exchanger, o = output or exit of heat exchanger)

\dot{m} is the flow rate of the fluid (subscripts: h = hotter fluid, c = colder fluid)

c_p is the heat capacity of the fluid (subscripts: h = hotter fluid, c = colder fluid) and **is a function of temperature**. For simplicity sake **we use the average of the inlet and outlet temperatures** of a stream to determine the effective heat capacity for that fluid in the stream.

U is the Overall Heat Transfer Coefficient (a measure of how well heat transfers between the streams and accounts for fouling due to buildup in the exchanger which inhibits heat transfer) (units = J/(s*m²K))

A is the surface area available between the streams. The greater the surface area the greater the heat transfer rate.

ΔT_{lm} is log mean temperature difference (hence the LMTD method)

ΔT_1 and ΔT_2 are the differences in temperature between the streams at one end or the other end of the heat exchanger. Because the shell and tube heat exchanger is a counterflow heat exchanger (see Figure 1), the outlet of the hot stream is by the inlet of the cold stream and outlet of the cold stream. Thus ΔT_1 and ΔT_2 are defined as specified above.

F is a correction factor. The LMTD method was designed for a simple counter flow heat exchanger instead of a shell and tube counter flow heat exchanger. This correct factor is empirically determined (fit the equation to the data like we did in Excel). Note that it is a function of R and P which are functions of the inlet and outlet temperatures of the hot and cold streams.

Assignment: Write a program that can be used to determine the most economical shell and tube heat exchanger. Your program should do the following:

- Determine the surface area (A) needed and the cost associated with constructing our custom heat exchanger if the fluid inlet temperatures ($T_{c,i}$ and $T_{h,i}$), one fluid outlet temp ($T_{c,o}$ or $T_{h,o}$), mass flow rates (\dot{m}), Overall Heat Transfer Coefficient (U), and fluid substances are specified. Deliverables of the program to be presented to the user are **Surface Area (A), Cost, and the unspecified outlet temp ($T_{c,o}$ or $T_{h,o}$)**. Note it costs \$1,000 USD per m² of surface area to have a heat exchanger custom built.
- Ask the user to input values as AES or SI units and report SI units for the output values
- Allows the user to specify: liquid type in the hot and cold streams, U (overall heat transfer coefficient of the heat exchanger to be custom produced), $T_{c,i}$, $T_{h,i}$, \dot{m}_c , \dot{m}_h , and an outlet temp of one fluid ($T_{c,o}$ or $T_{h,o}$). If negative numbers are entered for the mass flow rate or overall heat transfer coefficient warn the user that the variables have an error and end the program.
- Allow the user to select either: water; 1,1,1,2-Tetrafluoroethane (Refrigerant in your car known as R134a); ethanol; or 2,2,4-trimethylpentane (gasoline component) as the hot fluid stream or cold fluid stream in the heat exchanger.
- Notify the user in some way if the inlet or outlet temperatures are invalid (i.e. solid or gas). You can assume it operates at 1 atm.

Also, the DIPPR database will be of use. You can access the database from any BYU computer by going to the library (HBL) homepage, under "Databases & Journals" type "DIPPR", and then select the DIPPR database link. Remember, you have to be at a BYU computer to gain access. If it asks for a username and password please ask either the TA or instructor for the login information.

Assessment: Remember that you will be graded on the readability of your code. The project will be graded based on a set of test conditions that will be used to assess the accuracy and presentation of your results.

Hint: You will need to determine the unspecified temperature from the first two listed equations.