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Design and Thermal Analysis of Shell and Tube Heat Exchanger

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Abstract: Heat exchangers are used in a number of applications in various industries. The present study focus on calculation of shell and tube heat exchanger design with minimum pressure drop. Calculation of heat exchanger design has been done by considering with two case of different coolant are used 98ºC of water is enter to the exchanger and its outlet at 60ºC.c Water is used in case one and another case R134a is used for coolant. This study also including different coolant temperature use and MATLAB software is used to analyze for distribution of pressure drop. When a heat exchanger is placed into a thermal transfer system a temperature drop is required to transfer heat. The magnitude of this temperature drop can be decrease by utilizing a larger heat exchanger but this will be large pressure drop, increase the cost of the heat exchanger. Economic considerations are important in engineering design, and in a complete engineering equipment, not only the thermal performance characteristics but also the minimum pressure drop are requirement.
Keywords: over all heat transfer coefficient, heat transfer rate, heat transfer area, pressure drop. pressure distribution.

1. INTRODUCTION

A heat exchanger is a device in which heat is transferred between a warmer and a colder substance, usually fluid. There are various types of heat exchanger

(1)The type of heat exchanger (a) recuperator and (b) regenerator.

(2) The type of heat exchanger process between the fluids (a) indirect or transmural and (b) direct contact.[1]

(3)Thermodynamic phase or state of the fluids (a) single phase (b) evaporation or boiling (c) condensation[1].

(4) The type of construction or geometry (a) tubular (b) plate and (c) extended or finned surface.[1]

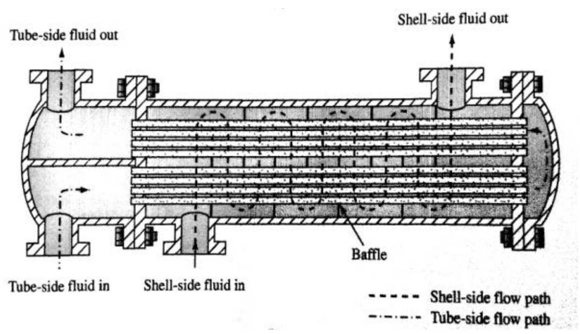
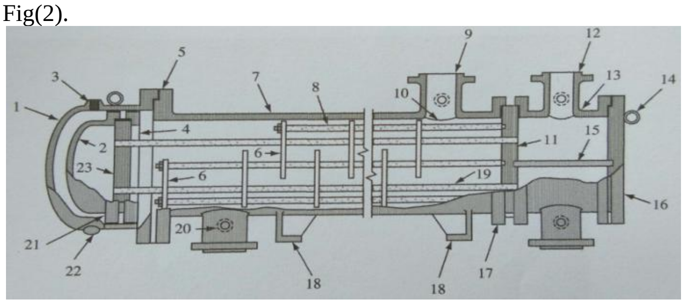


Figure 1.Shell and Tube Heat Exchanger with Segmental baffles: Two Tube Pass, One Shell Tube[1]

In the design of heat exchanger it is important to specify whether the fluids are mixed or unmixed, and which of the fluid is mixed. It is also important to balance the temperature drop by obtaining approximately equal heat transfer coefficient on the exterior and interior of the tubes. If this is not done, one of the thermal resistances may be unduly large and cause an unnecessarily high overall temperature drop for a given rate of heat transfer, which in turn demands larger equipment and results in poor economics. The shell-and- tube heat exchanger illustrated in Fig (1) has fixed tube sheets at each end, and the tubes are welded or expanded into the sheets.[1]

This type of the construction has the lowest initial cost but can be used only for small temperature differences between the hot and cold fluids because no provision is made to prevent thermal stresses due to the differential expansion between the tubes and the shell. Another disadvantage is the tube bundle cannot be removed for cleaning. These drawbacks can be overcome by modification of the basic design in Fig(2).



1. Shell cover
2. Floating head
3. Vent connection
4. Floating head backing device

5. Shell cover end flange
6. Transverse baffles or support plates
7. Shell
8. Tie rod and spacers
9. Shell nozzle
10. Impingement
11. Stationary tube sheet
12. Channel nozzle
13. Channel
14. Lifting ring
15. Pass partition
16. Channel cover
17. Shell channel end flange
18. Support saddles
19. Heat transfer tube
20. Test connection
21. Floating head flange
22. Drain connection
23. Floating tube sheet

Figure 2.Shell and Tube Heat Exchanger with Floating Head [1]

In this arrangement one tube sheet is fixed but the other is bolts to a floating-head cover that permits the tube bundle to move relative to the shell. The floating tube sheet is clamped between the floating head and flanges so that it is possible to remove the bundle for cleaning. The heat exchanger shown in Fig (2) has one shell pass and two shell passes.

In the design and selection of a shell-and-tube heat exchanger, the power requirement and the initial cost of the unit must be considered. Show that the smallest possible pitch in each direction result in the lowest power requirement for a specified rate of heat transfer, since smaller values of pitch also permit the use of a smaller shell, the cost of the unit is reduced when the tubes are closed packed. There is little difference in performance between inline and staggered arrangement, but the former are easier to clean. [1]

Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. In the analysis of heat exchangers, it is convection to work with an overall heat transfer coefficient U that account for the contribution of all these on heat transfer.

The rate of heat transfer between the two fluids at a location in heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the heat exchanger. In the analysis of heat exchangers, it is usually convection to work with the logarithmic mean temperature difference LMTD, which is an equivalent mean temperature difference between the two fluids for the entire heat exchanger. [5]

2. LOG MEAN TEMPERATURE DIFFERENCE

The temperature of fluids in a heat exchanger are generally not constant but vary from point to point as heat flows from the hotter to the colder fluid.

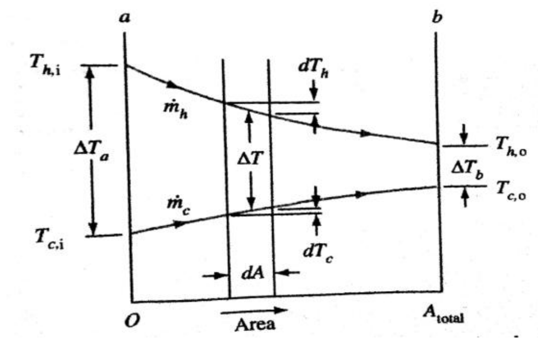


Figure 3(a) Temperature Distribution in Single Pass Parallel Flow Heat Exchanger [1]

Even for a constant thermal resistance, the rate of heat flow will therefore vary along the path of the exchangers because its value depends on the temperature difference the cold fluid and hot fluid in that section. Fig (3) illustrate the changes in temperature that may in either or both fluid in a simple shell and tube exchanger.[1]The distances between the solid lines are proportional to the temperature differences ΔT between the two fluids.

$$\Delta T= (\Delta T_a-\Delta T_b)/\ln(\Delta T_a/\Delta T_b)$$

Where the subscripts a and b refer to the respective ends of the exchanger and ΔTa is the temperature difference between the hot and cold fluids streams at the inlet while ΔTb is the temperature difference at the outlet end as shown in Fig (3)..

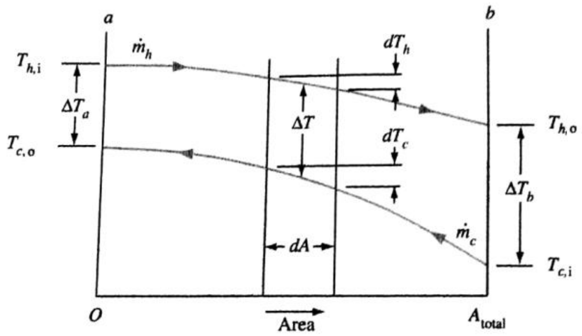


Figure 3 (b) Temperature Distribution in Single Pass Parallel Flow Heat Exchanger [1]

The distances between the solid lines are proportional to the temperature differences ΔT between the two fluids.

$$\Delta T= (\Delta T_a-\Delta T_b)/\ln(\Delta T_a/\Delta T_b)$$

Where the subscripts a and b refer to the respective ends of the exchanger and ΔTa is the temperature difference between the hot and cold fluids streams at the inlet while ΔTb is the temperature difference at the outlet end as shown in Fig (3)..In practice, it is convenient to use an average effective temperature difference ΔT for the entire heat exchanger, defined by

$Q=UA\ \Delta T$

The ordinate of each is the correction factor F. to obtain the true mean temperature for any of these arrangements, the LMTD calculate for correction factor, that is

$\Delta Tm=LMTD\times F$

The values shown on the abscissa are for the dimensionless temperature-difference ratio temperature-difference ratio

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

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

Where the subscripts h and c refer to the hot and cold fluid respectively

$T_{h,o}$=outlet temperature of hot fluid

$T_{h,i}$=inlet temperature of hot fluid

$T_{c,o}$=outlet temperature of cold fluid

$T_{c,i}$=inlet temperature of cold fluid[1]

The ratio P is an indication of the heating and effectiveness and can vary from zero for a constant temperature of one of the fluid to unity for the case when the inlet temperature of the hotter fluid equal to the outlet temperature of the cooler fluid. The parameter for each of the curves, Z, is equal to the ratio of the temperature changes of the shell fluid divided by the temperature change of the fluid in the tube. Fig (4) show the correction factor F chart for common shell and tube and cross flow heat exchanger.[1]

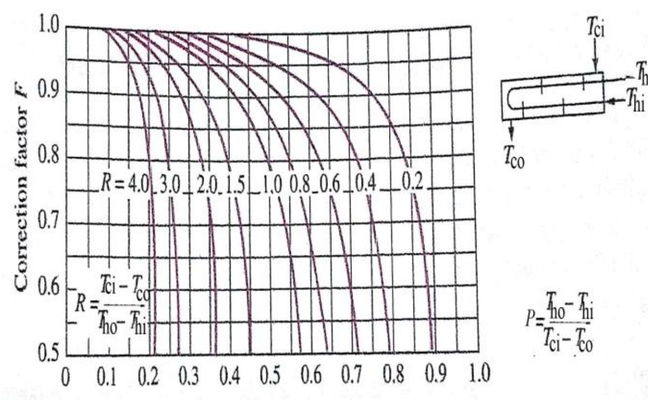


Figure 4. Correction Factor F Chart. [5]

3. OVERALL HEAT TRANSFER COFFICIENT

A heat exchanger typically involve two flowing fluids separated by a solid wall. Heat is first transferred from the hot fluid to the wall by convection, through the wall by conduction, and from the wall to the cold fluid again by convection. Any radiation effects are usually included in the convection heat transfer coefficients. The thermal resistance network associated with this heat transfer process involves two convection and one conduction resistances, as shown in Fig(5). The subscripts i and o represent the inner and outer surfaces of the inner tube. [5]

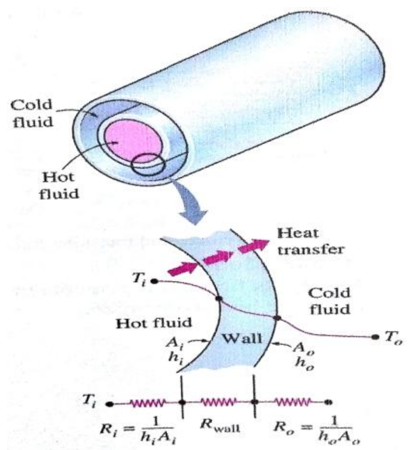


Figure 5. Thermal Resistance Network Associated with Heat Transfer [5]

$Q = U\ A\ F\ \Delta T_m$

$UA = 1/[(1/h_iA_i)+(x/kA_k)+(1/h_oA_o)$

Where,

h_i =convection heat transfer hot coefficient = 7500 W/m²K

h_o =convection heat transfer cold coefficient for water = 8000 W/m²K

A_i=area of hot fluid

A_o=area of cold fluid

A_k =area of copper tube

x =thickness of copper tube $= 5\times10^{-3}$m

k= thermal conductivity of copper tube = 399.375W/mK

U = 3692.04 W/m²K

4. FOULING FACTOR

The overall heat transfer coefficient of a heat exchanger under some operating conditions, especially in the process industry, often cannot be predicted from thermal analysis alone. During operation with most liquids and some gases, a deposit gradually builds up on the heat transfer surface. The deposit may be rust, boiler scale, silt, coke, or any number of things. Its effects, which is referred to as fouling, is to increase the thermal resistance. The manufacturer cannot usually predict the nature of the deposit or the rate of fouling. Therefore, only the performance of clean exchanger can be guaranteed. The thermal resistance of the deposit can generally be obtained only from actual tests or from experience. If performance tests are made on a clean exchanger and repeated later after the unit has been in service for some time, the thermal resistance of the deposit (or fouling factor) R_d can be determined from the relation. [1]

$R_d = 1/U_d – 1/U$

Where,

U=overall heat transfer coefficient of clean exchanger =3692.04W/m²K

U_d=overall heat transfer coefficient after fouling has Occurred

R_d=fouling factor (or unit thermal resistance) of Deposit = 0.0002

Table 1 is shown typical fouling factor .A convection working from is

$U_d = 1/[R_d+(1/U)]$

Table 1.Tpical Fouling Factors [2]

Type of Fluid	Fouling Factor, (m^2 °C/W)
Seawater	
below 125ºF	0.00009
above 125ºF	0.002
Treated boiler feedwater above 125ºF	0.0002
Fuel oil	0.0009
Quenching oil	0.0007
Alcohol vapors	0.00009
Steam, non-oil-bearing	0.00009
Industrial air	0.0004
Refrigerating liquid	0.0002

5. CALCULATION OF HEAT TRENSFER RATE

Heat exchanger usually operate for long periods of time with no change in their operating conditions. Therefore they can be modeled as steady-flow devices. As such, the mass flow rate of each fluid remains constant, and the fluid properties such as temperature and velocity at any inlet or outlet remain the same. Also, the fluid streams experience little or no change in their velocities and elevations, and thus the kinetic and potential energy changes are negligible. The specific heat of a fluid, in general, changes with temperature. But, in a specified temperature range, it can be treated as a constant at some average value with little loss in accuracy. Axial heat conduction along the tube is usually insignificant and can be considered negligible. Finally, the outer surface of the heat exchanger is assumed to be perfectly insulated, so that there is no heat loss to the surrounding medium, and any heat transfer occurs between the two fluids only. [5]

The idealization state above are closely approximated in practice, and they greatly simplify of a heat exchanger with little sacrifice of accuracy. Therefore, they are commonly used. Under these assumptions, the first law of the thermodynamics requires that the rate of heat transfer from the hot fluid be equal to the rate of heat transfer to the cold one. That is,

$Q^{\cdot} = m_c C_{p\,c}(T_{c,o} - T_{c,i})$

Where,

m_c = mass flow rate of cold fluid

C_{pc} =specific heat of cold fluid

$T_{c,o}$=outlet temperature of cold fluid

$T_{c,i}$=inlet temperature of cold fluid

$Q^{\cdot} = m_h C_{ph} (T_{h,i} - T_{h,o})$

$Q^{\cdot}$ =326.87kW

m_h= mass flow rate of hot fluid

=2.05kg/s

C_{ph} =specific heat of hot fluid

=4.196kJ/kgK

$T_{h,o}$=outlet temperature of hot fluid

=60ºC

$T_{h,i}$=inlet temperature of hot fluid

=98ºC

Where the subscripts c and h stand for cold and hot fluids, respectively. Note that the heat transfer rate Q• is taken to be a positive quantity, and its direction is understood to be from the hot fluid to the cold one in accordance with the second law of thermodynamics. In heat exchanger analysis, it is often convection to combine the product of the mass flow rate and the specific heat of a fluid into a single quantity.

The heat capacity rate of a fluid stream represents the rate of heat transfer needed to change the temperature of the fluid stream by 1ºC as it flows through a heat exchanger. Note that in a heat exchanger, the fluid with a large heat capacity rate will experience a small temperature change, and the fluid with a small heat capacity rate will experience a large temperature change. [5]

That is, the heat transfer rate in a heat exchanger is equal to the heat capacity rate of either fluid multiplied by the temperature change of that fluid. Note that the only time of temperature rise of a cold fluid is equal to the temperature drop of the hot fluid is when the heat capacity rates of the two fluids are equal to each other. [5]

5.1. Calculation of Heat Transfer Area

Heat transfer of hot water is determined by the following equation,

$Q^{\cdot} = m_h C_{ph}(T_{h,i} - T_{h,o})$

$= U\ A\ F\ \Delta T_m$

Where,

U =overall heat transfer coefficient

=3692.04W/m²K

F =correction factor

=0.98

ΔT_m=log mean temperature difference

=30.04

$Q^{\cdot}$ =heat transfer rate

=326.87kW

A = heat transfer area

=3m²

Table 2. Comparison Result Table of H_2O and R 134a

Name	**Symbol**	**H_2O**	**R.134a**	**Unit**
Coolant inlet temperature	T_{ci}	40	-41	ºC
Coolant outlet temperature	T_{co}	55	-26	ºC
Heat Loss	Q	326.87	326.87	kW
Convection heat transfer for cold Fluid	h_{cold}	8000	2261.307	W/m²K
Thermal conductivity	k	399.375	403.425	W/mK
Over all heat transfer coefficient	U	3692.04	1700.8	W/m²K
Heat transfer area	A	2.82	1.71	m²

Length of tube	L_{tube}	38	22	m
Volume of tube	V_{tube}	0.192	0.011	m³
Volume of cold fluid	V_{cold}	0.012	0.022	m³
Pressure drop for hot fluid	ΔP	2.69	1.56	m

5.2 Pressure Drop for Heat Exchanger

Pressure drop is a major constraint in thermal design of shell and tube heat exchanger is meaningful only when it is optimum and the extent of the optimality is constrained by the pressure drop. Optimization of thermal design requires maximization of overall heat transfer coefficient and effective mean temperature difference. So as to minimize the heat transfer area subject to constraints, pressure drop being the major one [4]. Tube side pressure drop can be lowered in following ways;

(a) Increasing the shell diameter. Increasing the shell diameter increases tube flow area due to increased number of tubes and, thereby reduces tube flow velocity and, hence, reduces tube side pressure drop. Further—, it also means reduced tube length which, too, leads to reduced pressure drop.

(b) Increasing the tube diameter. Increasing the tube diameter reduces velocity and, thereby, reduce pressure drop. However, tube diameters are standardized and standard outside diameters are limited. Further tube outside diameters more than 1.0inch is generally not desirable as higher tube diameter means higher shell diameter to accommodate required number of tubes due to increased tube pitch which, in turn, means higher cost.

(c) Increasing the nozzle size. If the nozzles are too small in diameter, their diameter can be increased reasonably to lower the pressure drop.

(d) Using the shells in parallel. Multiple shells can be used in parallel so that total tube side flow is split and flow velocity is reduced. Consequently, pressure drop is reduce. However, it increases the cost due to the reasons as mentioned for shell side pressure drop.

The pressure drop can be relatively straightforward in a single-pass pipe-in tube heat exchanger or extremely difficulty in, say a shell and tube exchanger. Table (3) and (4) are shown pressure drop for water and R134a coolant with varies tube length and diameter. The pressure drop in a straight run of pipe, given by

$$\Delta P = fLv^2/2gD$$

Where,

f=friction loss
= 0.023
L=length of tube
v=velocity of hot fluid
=1.24m²
g=gravity
=9.81m/s²
D=diameter of tube
ΔP=pressure drop

Table 3. Pressure Drop for Water with Various Length and Diameter

No	Length(m)	Diameter(m)	Pressure drop(m)
1	38	0.0254	2.6631
2	34	0.0279	2.2009
3	31	0.0305	1.8493
4	29	0.0330	1.5758
5	27	0.0356	1.3587
6	25	0.0381	1.1836
7	24	0.0406	1.0403
8	22	0.0432	0.9215
9	21	0.0457	0.8219
10	20	0.0483	0.7377

Table 4. Pressure Drop for R134a with Various Length and Diameter

No	Length(m)	Diameter(m)	Pressure drop(m)
1	19.5497	0.0254	1.3848
2	17.7725	0.0279	1.1445
3	16.2915	0.0305	0.9617
4	15.0383	0.0330	0.8194
5	13.9641	0.0356	0.7065
6	13.0332	0.0381	0.6155
7	12.2186	0.0406	0.5409
8	11.4998	0.0432	0.4792
9	10.8610	0.0457	0.4274
10	10.2893	0.0483	0.3836

Figure 6 shown the pressure drop with varies tube diameters and figure 7 shown the tube length with varies tube diameters.

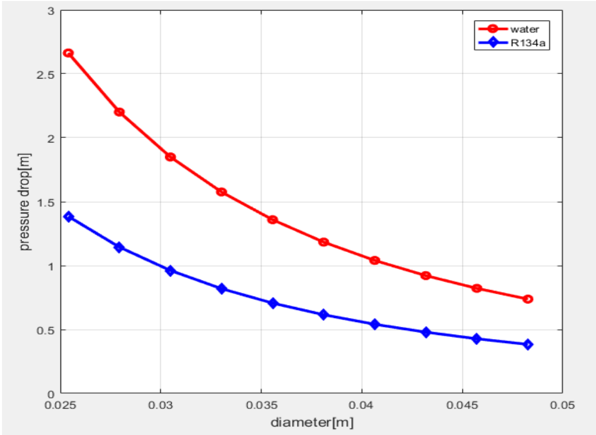


Figure 6. Pressure Drop with Varies Tube Diameters

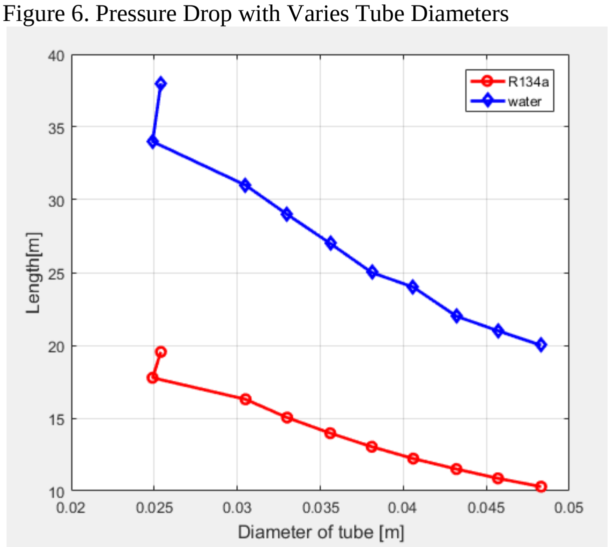


Figure 7. Tube length with Varies Tube Diameters

6. CONCLUTION

In this paper, counter flow shell and tube heat exchanger design are calculated. Hot water enter at 98ºC and at exist 60ºC.Density of the working fluid is used average temperature. Tube material is copper .Tube diameter and length are varies with the calculation of pressure drop .Firstly, cold water is used for coolant inlet temperature 40ºC and outlet temperature 55ºC.The velocity of the hot water is1.24m/s and flow is turbulent. The roughness of the copper pipe is 0.0015mm.finally, the coolant is R134a. Inlet temperature of the coolant is -41ºC and outlet temperature is -26ºC.In this condition the heat transfer area of R134a is less than using the water coolant. Pressure drop is also less than coolant is water for the same diameter. Now a day in shell and tube heat exchanger, tube side pressure drop is 7m used.

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