Analysis of Shell & Tube Type Heat Exchangers

Ajay Kumar Giri, Navesh Kumar Roul, Tarini Prakash Mishra,
Mr. Debabrata panda, Mr. Ajit Prasad Dash
Department of mechanical engineering, GIET GUNUPUR
Email: giet12me079@gmail.com,naveshroul@gmail.com

Abstract- This paper is based on the study of shell & tube type heat exchangers along with its applications and constructional details. The methods of design and the reasons for the wide acceptance of the shell and tube type heat exchangers have also been included in the paper. There has been a broad analysis on its working and effect on performance under various ambient temperatures.

Index Terms- Shell & tube type heat exchangers; constructional details; methods of design; reasons for the wide acceptance; performance under various ambient temperatures.

1. INTRODUCTION

Basically a heat exchanger is a device that allows heat from a fluid (a liquid or a gas) at a higher temperature to pass onto a second fluid (a liquid or a gas) at a lower temperature, without the two fluids having to mix together or come into direct contact. They have a wide range of applications ranging from the refrigerators and air conditioners in houses to the engines in cars, ships and the smokestacks in power plants.

On classification, a shell and tube type heat exchanger is the most popular type of heat exchanger. It is because of the flexibility the designer has to allow for a wide range of pressures and temperatures. It mostly consists of a number of tubes mounted inside a cylindrical shell, where one fluid flows inside the tube and the other in the shell.

Shell and tube type heat exchanger has its application in various fields such as oil refineries, thermal power plants, chemical industries and many more. The simple design and easy to service methods of a shell and tube type heat exchanger makes it an ideal cooling system for a wide array of applications.

2. COMPONENTS OF SHELL AND TUBE HEAT EXCHANGER

A shell and tube type heat exchanger basically consists of the following components:

2.1. Tubes

The tubes are the fundamental components of a shell and tube type heat exchanger, providing the heat transfer surface between one fluid flowing inside the tube and the other flowing across the outside of the tubes. It is recommended that the tubes materials should have high thermal conductivity otherwise heat transfer will not be efficient. The tubes may be seamless or welded and most commonly made of copper, steel alloys, nickel and other thermally conductive materials.

Most recent development of tubes include: a corrugated tube having both inner and outer heat transfer enhancements, a finned tube which has integral inside tabulators as well as extended outside surface, and tubing which has outside surfaces designed to promote nucleate boiling.

1.1. *Tube sheets*

There are holes in the tube sheets where the tubes are held in place by being inserted into them and then either expanded into grooves cut into the holes or welded to the tube sheet where the tube protrudes from the surface. The tube sheet is usually a single round plate of metal that has been properly drilled and ridged to take the tubes, the gaskets, the spacer rods and the bolt circle where it is fastened to the shell. However, where mixing between the two fluids must be avoided, a double tube sheet may be provided.

The tube sheet, in addition to its mechanical requirements, must withstand corrosive attack by both fluids in the heat exchanger and must be electrochemically compatible with the tube and all tube-side material.

2.3. Shell

The shells are the outer containers normally having a circular cross-section. It is generally made by rolling a metal plate of the appropriate dimensions into a cylindrical first and then welding the longitudinal joint. It acts as the container for the shell-side fluid.

The roundness of the shell is important in fixing the maximum diameter of the baffles that can be inserted and thereby prevent leakage. In large heat exchangers, the shell is made out of low carbon steel.

2.4. Impingement plates

There are chances of breakage or deformation in the tubes upon direct impingement of the fluid, when entering the shell under high pressure. To avoid this the impingement plates are installed to lower the kinetic energy of the incoming fluid up to certain extent so that the fluid will impact the tubes with a lower velocity.

2.5. Channel covers

The channel covers are basically round plates which bolt to the channel flanges and can be removed easily for the tube inspection without disturbing the piping on the tube side. In smaller heat exchangers, bonnets having flanged nozzles or threaded connections for the tube side piping are often used instead of channel and channel covers.

2.6. Baffles

Baffles mostly serve two functions; First, they support the tubes in proper position during assembly and operation and thereby prevent vibration of the tubes caused by the eddies due to flow. Secondly, they direct the shell side flow back and forth across the tube field, increasing the velocity and heat transfer coefficient.

WORKS REVIEWED

Reviewing the works of prominent scholars it is quite clear that considerable amount of works have been carried out in the field of shell and tube type heat exchangers (STHE). Among which, some important works have been specified in detail as under:

Ahmad Fakheri [1] in his article highlights upon the efficiency of heat exchangers among the different networks and kinds of heat exchangers. The paper provides a simple equation which can be used to calculate the efficiency of heat exchangers in networks. It even assists in calculating the efficiency or effectiveness of individual heat exchangers and also of the number of heat exchangers required for any particular purpose. //Rajeev Mukherjee

Ahmad Fakheri [2] in his paper has also shown the way to calculate the efficiency of the heat exchangers based on the second law of thermodynamics. He has stated that corresponding to every heat exchanger there is an ideal balanced counter flow heat exchanger which has the properties of the same UA, the same LMTD and the minimum entropy generation analogous to minimum losses and irreversibility. The efficiency of the heat exchanger can be calculated by comparing the heat transfer capability of ideal heat exchanger with that of the actual heat exchanger.

E.G. Phillips, P.E, R.E. Chan [3]·A computer program was urbanized to simulate the performance of residential air-to-air heat recovery ventilators of various effectiveness operating under freezing conditions. Algorithms were developed to predict the energy performance of the heat recovery ventilators for several frost control and defrost strategies for any given climatic conditions. This paper describes the weather model, the heat exchanger performance/frosting model, and the defrost and frost control algorithms developed for the ASH RAE-funded project.

J. Kragh, J. Rose [4],In this paper, the construction and test measurements of a new counter flow heat exchanger is designed for cold climates. The developed heat exchanger is capable of continuously defrosting itself without using extra heating. Other advantages being simple construction and low pressure loss. The disadvantage is that the exchanger is bigger compared to other heat exchangers. In this paper, the experiment shows that the heat exchanger is capable of continuously defrosting itself at outer air temperatures well below the freezing point while still maintaining a very high efficiency

A. Pignotti [5] in his paper threw light upon the relationship between the effectiveness of two heat exchanger configurations which differ from each other in the inversion of either one of two fluids used. This paper provides the means by which if the effectiveness of one of the combination is known in measures of heat capacity rate ratio and NTUs then the effectiveness of the other combination can be known easily.

M. S. Bohn [6] in his article accessed a method for calculating the electric power generated by a thermoelectric heat exchanger. The method he presented in his paper is an extension of the NTU method used to calculate the heat-transfer effectiveness of the heat exchanger. The effectiveness of thermoelectric power generation is expressed as the ratio of the actual power generated to the power that would be generated if the entire heat-exchanger area were operated at the inlet fluid temperatures.

Hetal Kotwal and D.S Patel [7] focused on the various researches in Computational Fluid Dynamics (CFD) analysis in the field of heat exchangers. Different turbulence models available in CFD tools like Standard k-ε model, k-ε RNG model, Realizable k-ε, k-ω and RSM model in conjunction with velocity pressure coupling scheme, have been adopted to carry out the simulation. The sturdy increase in computing power has enabled the model to react for multi-phase flows in realistic geometry with good quality resolution. The quality of the solution has proved that CFD is effectual to predict the behavior and performance of heat exchangers.

FIGURE OF SHELL AND TUBE HEAT EXCHANGER

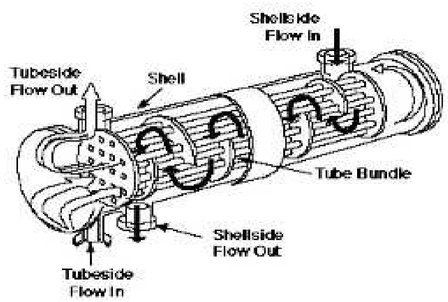

Figure- Shell and Tube Heat Exchanger

3. DESIGN CONSIDERATION

3.1. Convective heat transfer

Resistance to the convective heat transfer is proportional to the convective heat transfer coefficient, h = 1/ R_{conv} . The convective heat transfer Unit Operations Lab Heat Exchanger 1-3 coefficients depend on fluid properties, flow geometry and the flow rate. It is convenient to describe this dependence using several dimensionless numbers, namely the Reynolds's number,

$$R_e = \frac{\rho V D}{\mu}$$

the Prandtl number,

$$P_r = \frac{\mu C_p}{k}$$

and the Nusselt number,

$$N_u = \frac{hL}{k}$$

Here ρ, μ, K, q are the density, viscosity, thermal conductivity and the heat capacity of the fluid, is the flow velocity and L is the characteristic length. The choice of L depends on the system geometry. For example, for a flow in a circular pipe, L is the pipe diameter.

Relationship between *Re*, *Pr*, and *Nu* depends on the system geometry and whether the flow is laminar or turbulent.

3.2. Conductive heat transfer

The resistance to heat transfer through the partition depends on the system geometry. In experiments, we need to consider heat conduction in the radial direction of a cylindrical tube and hat conduction across a thin plate. Resistances in both of these cases can be obtained analytically by solving the heat diffusion equation.

3.3. Logarithmic Mean Temperature Difference (LMTD) Method

The temperature difference between the hot and cold fluids varies with the position in the heat exchanger, therefore it is convenient to determine log mean temperature difference ΔT_m.

The total heat transfer rate between the hot and cold fluids can be calculated by using overall heat transfer coefficient and surface area as :

$$Q = UA\Delta T_m$$

Where **U** = Overall heat transfer coefficient,

A = surface area for heat exchanger,

$\mathbf{\Delta T_m}$ =log mean value of temperature difference.

3.4. Number of Transfer Unit (NTU) Method

Effectiveness of heat exchanger in Parallel flow and counter flow

$$NTU = \frac{UA}{C_{min}}$$

$$R = \frac{C_{min}}{C_{max}}$$

Effectiveness can be defined as,

$$effectiveness = \frac{Q_{act}}{Q_{max}}$$

Q_{act} = actual heat transfer
Q_{max} = maximum heat transfer

5. RESULT

Experimental result of mass & velocity for parallel & counter flow of fluids

For Velocity:

(T-1) Parallel hot fluid

u_1 = 0.02m/sec
u_2 = 0.019 m/sec
u_3 = 0.017 m/sec
u_4 = 0.02 m/sec
u_5 = 0.014 m/sec

(T – 4) Parallel cold fluid

u_1 = 0.021m/sec
u_2 = 0.021 m/sec
u_3 = 0.028 m/sec
u_4 = 0.02112 m/sec
u_5 = 0.01005 m/sec

(T-3) Counter hot fluid

u_1 = 0.0461m/sec
u_2 = 0.0225 m/sec
u_3 = 0.01818 m/sec
u_4 = 0.0189 m/sec
u_5 = 0.01241 m/sec

(T – 2) Counter cold fluid

$u_1 = 8.484 \times 10^{-3}$m/sec
u_2 = 0.035 m/sec
u_3 = 0.0137 m/sec
u_4 = 0.0430 m/sec
u_5 = 0.03 m/sec

For mass :

(T-1) Parallel hot fluid

$m_1 = 7.84 \times 10^{-3}$ kg/sec
m_2 = 0.020 kg/sec
m_3 = 0.056 kg/sec
m_4 = 0.0182 kg/sec
m_5 = 0.026 kg/sec

(T – 4) Parallel cold fluid

m_1 = 0.0379 kg/sec
m_2 = 0.0433kg/sec
m_3 = 0.0275kg/sec
m_4 = 0.0455 kg/sec
m_5 = 0.0478 kg/sec

(T-3) Counter hot fluid

m_1 = 0.0606 kg/sec
m_2 = 0.0267kg/sec
m_3 = 0.0478kg/sec
m_4 = 0.065 kg/sec
m_5 = 0.0455 kg/sec

(T – 2) Counter cold fluid

m_1 = 0.0261 kg/sec
m_2 = 0.0267kg/sec
m_3 = 0.0193kg/sec
m_4 = 0.0267 kg/sec
m_5 = 0.0157 kg/sec

Experimental results of(Reynolds Number)R_e for Parallel & counter flow of fluids

(T-1) Parallel hot fluid

$R_{e\,1}$ = 4958.67
$R_{e\,2}$ = 23436.69
$R_{e\,3}$ = 83416.62
$R_{e\,4}$ = 32893.83
$R_{e\,5}$ = 70458.71

(T – 2) Counter cold fluid

$R_{e\,1}$ = 84014.85
$R_{e\,2}$ = 176047.90
$R_{e\,3}$ = 225205.47
$R_{e\,4}$ = 384766.97
$R_{e\,5}$ = 305454.54

(T-3) Counter hot fluid

$R_{e\,1}$ = 32225.24
$R_{e\,2}$ = 31316.45
$R_{e\,3}$ = 65122.38
$R_{e\,4}$ = 118073.75
$R_{e\,5}$ = 108022.63

(T – 4) Parallel cold fluid

$R_{e\,1}$ = 124929.17
$R_{e\,2}$ = 260995.00
$R_{e\,3}$ = 32341.01
$R_{e\,4}$ = 655609.75
$R_{e\,5}$ = 720307.16

Experimental results of the heat transfer co-efficient for Parallel & counter flow of fluids

(T-1) Parallel hot fluid (h_o)

h_{o1} = 1022.21
h_{o2} = 2822.76
h_{o3} = 1340.70
h_{o4} = 2468.69
h_{o5} = 1318.88

(T – 2) Counter cold fluid (h_i)

h_{i1} = 7123.08
h_{i2} = 12872.31
h_{i3} = 15643.44
h_{i4} = 24011.88
h_{i5} = 19962.96

(T-3) Counter hot fluid (h_o)

h_{o1} = 1289.04
h_{o2} = 1289.04
h_{o3} = 2315.68
h_{o4} = 3727.39
h_{o5} = 3471.38

(T – 4) Parallel cold fluid (h_i)

h_{i1} = 9763.24
h_{i2} = 17602.422
h_{i3} = 3311.48
h_{i4} = 36777.85
h_{i5} = 39653.69

Experimental results of heat flow Q for parallel & counter flow of fluids For (A = 0.079m^2)

(T-1) Parallel hot fluid

Q_1 = 2013.98 watt
Q_2 = 1798.41 watt
Q_3 = 594.68 watt
Q_4 = 1821.92 watt
Q_5 = 881.20 watt

(T – 2) Counter cold fluid

Q_1 = 1508.98 watt
Q_2 = 1064.45 watt
Q_3 = 2788.62 watt
Q_4 = 3313.64 watt
Q_5 = 3387.42 watt

(T-3) Counter hot fluid

Q_1 = 1077.84 watt
Q_2 = 1480.97 watt
Q_3 = 1673.17 watt
Q_4 = 2548.95 watt
Q_5 = 2569.77 watt

(T – 4) Parallel cold fluid

Q_1 = 633.63 watt
Q_2 = 1608.73 watt
Q_3 = 833.67watt
Q_4 = 1946.37 watt
Q_5 = 938.90 watt

Expermental result of ΔT_{lm} for parallel & counter flow of fluids

(T-1) Parallel hot fluid

ΔT_1	ΔT_2	$\Delta T_{lm} = \frac{\Delta T1 - \Delta T2}{\ln\left[\frac{\Delta T1}{\Delta T2}\right]}$
40	18	27.551
34	1	9.358
27	1	7.888
37	1	9.969
31	1	8.736

(T – 4) Parallel cold fluid

ΔT_1	ΔT_2	$\Delta T_{lm} = \frac{\Delta T1 - \Delta T2}{\ln\left[\frac{\Delta T1}{\Delta T2}\right]}$
19	3	8.668
18	3	8.371
33	2	11.058
26	3	10.650
18	4	9.308

(T – 2) Counter cold fluid

ΔT_1	ΔT_2	$\Delta T_{lm} = \frac{\Delta T1 + \Delta T2}{2}$
20	15	17.5
9	14	11.5
21	14	17.5
12	14	13.0
15	14	14.5

(T-3) Counter hot fluid

ΔT_1	ΔT_2	$\Delta T_{lm} = \frac{\Delta T1 + \Delta T2}{2}$
9	16	12.5
16	16	16.0
5	16	10.5
5	15	10.0
7	15	11.0

Experimental results of the heat transfer co-efficient & effectiveness for Parallel & counter flow of fluids (**A = 0.079m^2**)

For Overall heat transfer co-efficient:

For Parallel Flow

U_1 = 925.32 W/ m^2 ℃

U_2 = 2432.65 W/ m^2 ℃

U_3 = 954.32 W/ m^2 ℃

For effectiveness :

For Parallel Flow

1 = 0.86

2 = 0.86

3 = 0.86

$U_4 = 2313.40$ W/ m^2 °C	4 = 0.86
$U_5 = 1276.84$ W/ m^2 °C	5 = 0.86

For Counter Flow	**For Counter Flow**
$U_1 = 1091.49$ W/ m^2 °C	1 = 1.17
$U_2 = 1171.66$ W/ m^2 °C	2 = 1.17
$U_3 = 2017.66$ W/ m^2 °C	3 = 1.19
$U_4 = 3226.53$ W/ m^2 °C	4 = 1.18
$U_5 = 2957.16$ W/ m^2 °C	5 = 1.18

6. CONCLUSION

On the basis of above study, it is easy to say that the shell and tube type heat exchangers are the most widely accepted group of heat exchangers among all the classes due to their flexibility and weight ratios. Lot many methods and design are available for its construction as well as detailed analysis. A lot many factors affect the performance of the heat exchanger . By changing the value of one variable and by keeping the rest variables constant, we can obtain different results. Then based on that result we can optimize the design of the shell and tube type heat exchanger.

REFERENCE

[1] Ahmad Fakheri, "Efficiency and Effectiveness of Heat Exchanger Series", J. Heat Transfer 130(8), 084502 (May 29,2008), asme.org.
[2] Ahmad Fakheri, "Heat Exchanger Efficiency", J. Heat Transfer 129(9), 1268-1276 (Nov 16, 2006), asme.org.
[3] E.G. Phillips, R.E. Chant, D.R. Fisher, B.C. Bradley, Comparison of freezing control strategies for residential air-to-air heat recovery ventilators, ASHRAE Transactions 95 (2) (1989).
[4] Kragh, J. Rose, S. Svendsen, Mechanical ventilation system with heat recovery in cold climates, in: Proceeding of the Seventh Nordic Symposium on Building Physics in Nordic Countries, vol. 2, Technical University of Denmark, 2005.
[5] Pignotti, "Relation Between the Thermal Effectiveness of Overall Parallel and Counter flow Heat Exchanger Geometries", J. Heat Transfer 111(2), 294-299 (May 01, 1989), asme.org
[6] S. Bohn, "Heat-Exchanger Effectiveness In Thermoelectric Power Generation", J. Heat Transfer 103(4), 693-698 (NOV 01, 1981), ASME.ORG.
[7] etal Kotwal and D.S Patel, "CFD Analysis of Shell and Tube Heat Exchanger- A Review", International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 2, March 2013.