REVIEW ON PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGERS CONFIGURED WITH DIFFERENT BAFFLE TYPES

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ABSTRACT
This paper provides a brief research background on shell and tube heat exchangers. Shell and tube heat exchangers find a great use in industries for cooling and heating purposes. Many successful efforts have been made from years to increase the performance of STHXs. These efforts mainly include the variations in baffle types. Varying baffle types or baffle angles do provide a vast field to work on. There are many configurations given to baffles which provided better results at different stages of their usage. Many more alterations can still be done in STHXs to give better performance. These alterations can be done to different parts of STHX. This paper gives sum of such alterations which were successful and left enough traces for future to work on.

Keywords: Shell and tube heat exchanger, baffles, pressure drop, heat transfer coefficient, Reynolds Number, Nusselt Number, baffle spacing and baffle angle.

Nomenclature:

Abbreviation	Quantity	Unit
A	Area	$meter^2$
D	Diameter	Meter(m)
L	length	Meter(m)
Cp	Specific heat at constant. pressure	KJ/Kg
f	Friction factor	nil
m	Mass	kg
V	Velocity	Meter/sec. (m/s)
Re	Reynold Number	nil
ρ	Density	Kg/m^3
Pr	Prandtl number	nil
μ	Viscosity	Kg/ms
Nu	Nusselt Number	nil

Word phrases:
STHX: Shell and tube heat exchangers
STHXSB: Shell and tube heat exchanger with segmental baffles
STHXHB: Shell and tube heat exchanger with helical baffles

Introduction:
In every aspect of life, competition has become a key factor to engineers to utilize every bit of energy in proper manner. Stress is mainly on engineers that how to make devices which are compatible to this era. This competition has lead the industries to work smarter and more skillfully. The advancement in living has put a greater demand for more compact and energy saving devices. This criterion of energy saving now-a-days has revolutionized the industrial sector. This is because energy sources are limited and every industry wants the better use of the source it has. Thus energy conservation, conversion and utilization can have a vital developmental role in industry. One bitter truth we faced earlier times was that most of industries lacked the techniques to fully utilize any energy source. Thus energy dissipation was a big drawback. But advancement in engineering fields leads us to develop devices which could properly utilize the energy of a source. Among some devices was one which is used to utilize heat energy of a source.
The devices designed to allow heat to convey from a fluid kept at more temperature to a fluid maintained at

relatively low temperature than first one are termed as heat exchangers. This heat transfer between two fluids can occur through two possible ways direct encounter between fluids or restricting them from mixing and allowing heat to transfer by some other means. In first case only convection is possible as fluid is directly made incident on another fluid e.g. cooling tower. The latter is quite complicated and doesn't allow fluids to mix they are restricted by putting a barrier in between them. This barrier must be a good conductor of heat. The heat transfer occurs in following manner:

Convection: it occurs when flowing hot fluid transfers its energy to the stationary barrier.

Conduction: It occurs inside the barrier and transfers heat from one side of barrier to another side.

Convection: It occurs at the other barrier end where from heat has to be transferred to the other fluid maintained at varying temperature.

Double pipe heat exchanger is a kind of device which doesn't allow mixing of fluids. In this heat exchanger a less crossectional area pipe is installed in shell having large diameter. The fluids at varied temperatures are allowed to pass through these two pipes

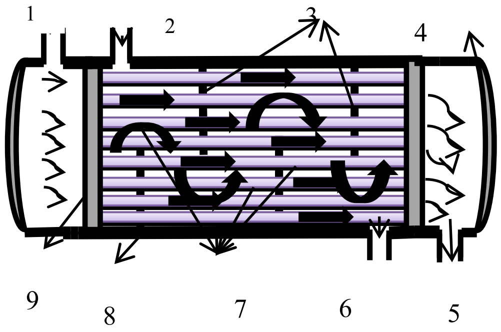


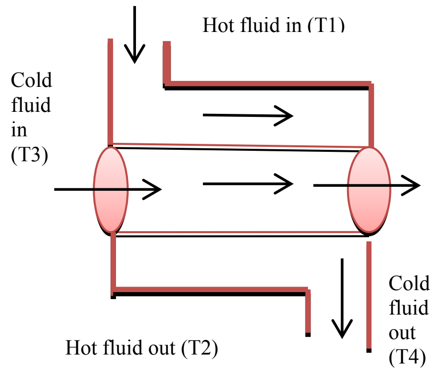
Fig. 1 Design and flow pattern in shell and tube heat exchanger

1. Tube side fluid inlet
2. Shell side fluid inlet
3. Baffles
4. Shell head
5. Tube side fluid out
6. Shell side fluid out
7. Tubes
8. Shell
9. Tube plate

STHX is among the type which doesn't allow the mixing of the two fluids. In this one fluid is allowed to pass through tubes and another fluid passes through the shell (which holds tubes).

Types of shell and tube heat exchangers according to flow arrangement:

- **Parallel flow:** In this type the inlets for the hot fluid and cooler fluid are kept at the same end of the heat exchanger and the working Medias are allowed to move in the same direction towards the outlet.



Fig,. 2 Parallel flow heat exchanger

- **Counter flow:** On the same end of the heat exchanger inlet of one pipe and outlet of another pipe is made. Hence by this configuration fluids will be travelling in vice versa direction to each other.

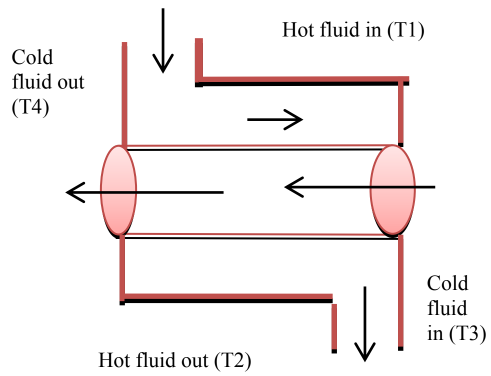


Fig. 3 Counter flow heat exchanger

- **Cross flow:** If fluids are made to move perpendicular to each other this is called cross flow.

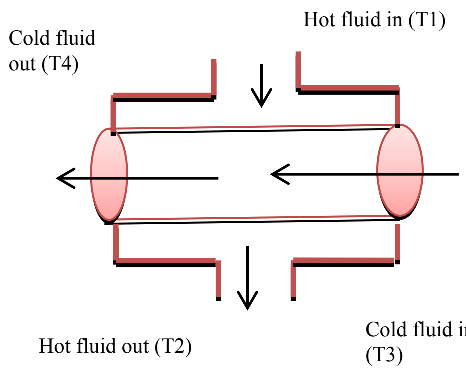


Fig. 4 Cross flow heat exchanger

A STHX can be installed with large number of pipes. These pipes are kept in order that the horizontal axis of pipe is parallel to the shell. Shell is made strong enough to withstand high pressure and high temperature. The fluids to be flown are directed by use of pumps. One of the two fluids is passed through pipe bundles and the other fluid is allowed to pass through shell. The fluid in shell is not allowed to follow a simple path instead some arrangements are done to make the flow complex. The complexity in fluid flow is managed by the use of baffles. These baffles also hold the pipes. Baffles are of different types and no fixed number of baffles is available, so we can use baffles as per we require. The baffles also hold pipes inside shell. We use different kinds of baffles:

- Segmental baffles
- Double segmental baffles
- Helical baffles
- De-resonating baffles
- Orifice baffles

Material selection for tube:
Among the two fluids one is made to pass through the tubes so it becomes necessary to choose a tube which is capable of facing every possible condition. For this the tubes must be having a good thermal conductivity.
As the temperature along width of the tube varies thermal stresses are observed by the tubes. So the tubes must be designed in such a way that it can hold the thermal stresses. And the tube material must be compatible with the pH of the fluid. In addition to all this tube must be corrosion resistant. Commonly used tube materials are, aluminum, copper alloy, stainless steel, Carbon steel and titanium. Fluoropolymers are also used viz, Perfluoroalkoxy alkane (PFA) and Fluorinated ethylene propylene (FEP).

Applications of shell and tube heat exchanger:
These are highly used to make heat transfer possible between two fluids or mediums. These are used in industrial sectors for heating or cooling purpose. The main applications are:

- Space heating
- Refrigeration
- Air conditioning
- Power plants
- Chemical plants
- HVAC
- Air processing

Advantages: The main advantage of STHX is that they are easy to service mainly when installed with floating baffles. Floating baffles are the baffles that are not welded to shell.

Literature review
As the need of heat exchangers became more for industrial sector, it was necessary to design more efficient heat exchanger. Keeping this in mind in 1975 **B. Peng et al**[1] proposed two STHX with helical continuous baffles installed in them rather than segmental baffles. As the "overall pressure drop" was kept same the heat transfer coefficients from shell side for former baffles was higher than the later ones. The heat transfer coefficient for the continuous helical baffles is 10% more than the segmental baffles. The mean square deviation was less than 3.12% when correlation between Nu, Re and friction factor and Re was developed. For obtaining the values of various working parameters for a heat exchanger in 1976 **B. Gay et al**[**2**] determined heat transfer coefficients on shell side for a cylindrical STHX and described mass transfer electrochemical technique and its applications. Mercury evaporation technique was used to obtain the accuracy of electrochemical method by comparing heat and mass transfer data. This electrochemical method showed good results in determining heat transfer coefficient in STHX. Less error were found by this method. The flow pattern on shell side became a key factor to increase the efficiency of heat exchangers and a research was done in 1996 in which **D. Kral. et al.[3]** experimentally verified the working of heat exchangers having helical baffles. Various baffle geometries were also discussed and results were put forward. Results showed that the optimum baffle angle should be kept from 20^0-40^0 for maximum performance and making heat exchanger a less economic. At helix angle of 40^0 the pumping power required was quite less as compare to other helix angles. The use of segmental baffles was common and in year 1997 **Edward et al.[4]** presented a procedure to find shell sided pressure drop in STHX installed with segmental baffles. By virtue of this procedure gave the measurement of pressure drop in ideal tube bank using correlations and pressure drop through equations on a window section using Delaware method. Tube bank was coupled with correction factor and leakage and bypass stream was taken into account. Results showed the deviation between measured pressure (ΔP_m) and calculated pressure (ΔP_c) with increasing Re. The deviation, experimental and theoretical, was found between ± 35%. When bundle bypass factor and baffle leakage was low, pressure drop was reduced but simultaneously heat transfer decreased drastically. In segmental baffles spacing was main factor and research was done in 1997, where **Huadong li et al.[5]** investigated the pressure drop and heat transfer on shell side of shell-and-tube heat exchanger installed with segmental baffles fitted at different spacing. Measurement of both parameters was doe per row, per tube and each compartment. It was achieved that at Re 5000 the increase in baffle space enhanced heat transfer coefficient. Flow velocity also reached higher values. Short baffle spacing showed less values of pressure drop compared to that of long baffle spacing. **S.Noie[6]** used experimental and theoretical method in determining behavior of shell side flow. Re and effect of different geometrical parameters were taken into consideration. Baffle spacing were taken as 0.20, 0.25, 0.33, 0.50. 0.66 and 1.0 times the inside diameter of the shell and baffle cuts were put as 16%, 20%, 25%, 34%, and 46% of baffle diameter. Results revealed that baffles had great impact on heat transfer

and pressure drop. It was also found that baffle cuts have not much impact while number of baffles had a great effect on shell and tube heat exchangers performance. By varying Re heat transfer increased and Re can be varied using more baffles not by varying velocity as it will be costly. **H. LI et al[7]** visualized and determined heat transfer(local) coefficient using mass transfer measuring technique for two STHXs fitted with disc and doughnut baffles. For Re 500-10000 longitudinal vertices (Taylor Goeter vortices) were seen in center of tube. Disc and doughnut baffles showed better results than single segmental baffles. To study the variations in Nusselt number in 2006 **Ahmet et al.[8]** studied the effects on transient forced convective heat transfer for turbulent flow due to the flow geometry parameters in a round tube with baffles. Variations in spacing of baffles and baffle angles were oriented in experiment. Nine stainless steel baffles were inserted and the Re was varied from 3000 to 200000. Tubes with baffles inserted in them showed better performance than smooth tubes. Nu increased in tubes with baffles. It was necessary for each researcher to reduce heat losses and a research was done in 2008 in which **Simin Wang et al.[9]** configured a STHX in such a way to improve the heat transfer coefficient by installing sealers in shell side. Short circuit flow effectively decreases by blocking vacant space between baffle plates and shell. Experiments found that heat transfer coefficient had an increment of 18.2% – 25.5% and the heat transfer was enhanced by 44.6%-48.8%. Due to sealers pressure losses increased by 44.65%-48.8%. Different types of simulations were given but in 2009 **Jian fei Thang et al.[10]** Presented 3D numerical simulation STHX installed with helical baffles(middle overlapped) by coding of FLUENT 6.3 and GAMBIT 2.3. Simulation was done by adopting parallel computational mode for a heat exchanger with six rounds of middle overlapped helical baffles having helix angle 40^0. Experiments showed that while checking from inlet to outlet Nusselt number and pressure drop both goes on decreasing for helix angle 40^0. This method came-out with less error while doing thermo-hydraulic tests on heat exchanger. To check comparatively the efficient and economic heat exchanger **Jian-fe-zhang et al.[11]** experimentally tested and compared various STHXs among which one installed with segmental baffles while four others were installed with helical baffles provided with a helix angle of 20^0, 30^0, 40^0 and 50^0 respectively. STHXSB showed less performance than STHXHB. Shell side pressure drop was more in STHXHB than STHXSB. STHXHB having helix angle of 40^0 had much value of heat transfer/pressure drop or per unit pumping power and was considered more promising than others. **Wang yongqing et al.[12]** presented a heat exchanger fitted with H shape baffle support structure in shell side. Fluid flow and heat transfer analysis were carried out in different baffles like segmental, rod baffle and H shaped baffle. The flow in H shape heat exchanger reduces kinetic energy losses and reduces dead zones. The fluid flow goes more turbulent in H-shape baffle than the other two. The heat transfer was increased due to the use of H-shape baffles. In year 2012 **B. KP Ary et al.[13]** Numerically and experimentally found the effect on flow pattern with use of number of inclined perforated baffles and with different types of baffles. Variation in Reynold number was made from 23000-57000. The baffles had a width of 19.8cm with an inclination of 50^0 and a square diamond hole having width of 2.55cm. It was observed that Nu ratio increases as we decrease the number of holes in perforated baffles. Each baffle showed transport phenomenon as was depicted by flow patterns and isotherms. Channels with solid-type baffles had high friction factor due to flow blockage. The was not a particular pattern or arrangement in which baffles could b fixed so in year 2012 **Farhad Nemati et al**.[**14**] Observed the impact of non-continuous helical baffle spaces on flow of fluid and "h". Five different heat exchanger having helical baffles at an inclination of 40^0 but varying baffle spacing was designed .Baffle spaces were given as 15mm(end to end type), P/16, P/8, 3P/16 and P/4. 'P' here represents helix pitch. This all setup came up with the following results:

- Pressure gradient decreased as baffle space was increased.
- As mass flow rate and the working conditions were kept constant, reduction in heat transfer was obtained for longer baffle spacing

Governing equations

For representing temperature difference in heat exchangers we use logarithmic mean temperature difference (LMTD). By applying below equation we get the required LMTD

$$\Delta Tlm = \frac{\Delta T_A - \Delta T_B}{\ln(\Delta T_A / \Delta T_B)} \qquad [15]$$

Where the terms used are referred to

ΔTlm is known as Logrithmic mean temperature

ΔT_A represents Change of temperature in hot fluid entering the heat exchanger and cold fluid leaving the heat exchanger ($\Delta T_A = T_{Hin} - T_{Cout}$).

ΔT_B is Variation of hot fluid coming out of heat exchanger and temperature of cold fluid entering the heat exchanger($\Delta T_B = T_{Hout} - T_{Cin}$).

- For measuring rate of heat transfer in heat exchanger below given equation is used

$$Q = UA\Delta Tlm \qquad [16]$$

Where the parameters represent

Q gives Measure of rate of heat transfer between the two fluids (Btu/hr).

U represents Overall heat transfer coefficient (Btu/hr-ft^2-K).

ΔTlm is Logarithmic mean temperature.

- Heat transfer for cold fluid is given by

$$Q = m_c^* Cp_c\ (T_{Cout} - T_{Cin}) \quad [17]$$

Q is Rate of heat transfer between the two fluids (Btu/hr).

m_c^* denotes Mas flow rate of cold fluid.

Cp is Specific heat of cold fluid.

$T_{cout} - T_{cin}$ is Temperature difference of cold fluid at outlet and inlet.

- Heat transfer for hot fluid can be find out using below equation

$$Q = m_h^* Cp_h\ (T_{hin} - T_{hout}) \quad [18]$$

Q denotes Rate of heat transfer between the two fluids (Btu/hr).

m_h^* is Mass flow rate of hot fluid.

Cp_h represents Specific heat of hot fluid.

$T_{hin} - T_{hout}$ gives Temperature difference between hot fluid at inlet and outlet.

- Formula for finding optimum baffle spacing

$$B = \frac{L_t}{N_b + 1} \quad [19]$$

B is Baffle spacing.

L_t is Tube length.

N_b is Number of baffles.

- Tube side Reynold's number and Nusselt number are given by equations
- Reynold's number: It is calculated so as to find the tube side fluid flow conditions. These conditions could be laminar, transient or turbulent flows

$$R_e = \frac{m^* d_i}{Ac\ \mu} \quad [20]$$

Where the terms used resemble

R_e resembles Reynold's number.

m^* is mass flow rate of fluid.

d_i denotes internal diameter of tube

A_c.is Cross flow area.

μ stands for viscosity of fluid on tube side.

- Nusselt number (Re < 2300) : It is used to find convective heat transfer coefficient on tube side

$$Nu_D = 1.86 \left\{\frac{d_i\ Re\ Pr}{L}\right\}^{\frac{1}{3}} \left\{\frac{\mu}{\mu_s}\right\}^{0.14} \quad [21]$$

Di denotes internal tube diameter.

Re is Reynold's number.

Pr is Prandtl number (0.48< Pr< 16700)

μ/μs is ratio of viscosity on tube side and shell side. (0.0044< (μ/μs)< 9.75).

- Shell side Reynold's number and Nusselt number.
- Reynold's number: It is calculated so as to find the shell side fluid flow conditions. These conditions could be laminar, transient or turbulent flows.

$$R_e = \frac{m^* D_E}{Ac\ \mu} \quad [22]$$

De is Equivalent diameter.

A_c. is Cross flow area.

μ gives viscosity of fluid on shell side.

m^* denotes mass flow rate of fluid shell fluid.

- Nusselt number: It is used to find convective heat transfer coefficient

$$Nu = 0.36\ Re^{0.55} Pr^{1/3} \left\{\frac{\mu}{\mu_s}\right\}^{0.14} \quad [23]$$

- Pressure drop of heat exchanger has separate equations for shell side and for tube side
- Tube side pressure drop

$$\Delta P = 4\left\{\frac{f.l_t}{d_t} + 1\right\} N_p\ \frac{1}{2}\rho . v^2 \quad [24]$$

The parameters used are

ΔP is Pressure drop.

F is Friction factor.for laminar flow (f=16/Re) and for turbulent flow (f={1.58 ln(Re_D)-3.28}^{2}.

l_t gives Tube length.

dt is Tube diameter.

Np is Number of passes.

P means Fluid density.

V denotes velocity of fluid.

- Shell side pressure drop

$$\Delta P = f \frac{Ds}{De} (Nb + 1) \frac{1}{2} \rho . v^2 \qquad [25]$$

F gives Friction factor (f=exp{0.576-0.19ln(Re_s)}.
Ds denotes Shell side diameter.
De is Equivalent diameter.
Nb resembles Number of baffles.
P is Shell side density of fluid.
V is Shell side velocity of fluid
These equations are used to find the various parameters that are involved in fluid flow and heat transfer in shell and tube heat exchangers.

Conclusion

After finding wide applications in industrial sector shell and tube heat exchangers were taken as key topic by many researchers to work on. In order to increase performance of these heat exchangers the numerical and experimental simulations were carried out by changing different parameters. These parameters mainly included baffles, baffle spacing, baffle angles, tube diameter, working fluid etc. The results came out to be promising and surely increased the efficiency of shell and tube heat exchangers.

As according to its use there is still some work needed to make shell and tube heat exchangers less economic and more efficient. Shell and tube heat exchangers do have many parameters on which some more work can be done. The focus could be mainly done on baffles due to their high impact on performance of shell and tube heat exchangers.

Future scope

- STHXs are widely used and if designed properly with better efficiencies it can give a promising feedback.
- STHXs are used for many works i.e. they are multi-purpose and will definitely give a vast field to research on.
- STHXs have various parameters which can be configured in different ways and better experimental results could be found out. These results could prove fruitful to many industries.

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