

Online Mechanical Characterization of a Shell and Tube Heat Exchanger

Raja. H Krishna Chaitanya¹ Subramanyam Ravva² Eadala Sarath Yadav³ I.Thirunavukkarasu⁴✉

Department of Instrumentation and Control Engineering, MANIPAL Institute of Technology, Manipal, Karnataka, India.

✉Corresponding author mail: it.arasu@manipal.edu

Abstract

This paper is concerned with brief study and real time implementation of shell & tube (straight) heat exchanger for analysis of different mechanical parameters involved in it. The efficient analysis of these parameters enables the knowledge of functioning and influence overall thermo hydraulic performance. The impact of losses in the system effects the design. So it is important to consider the system losses while designing real time apparatus. This paper depicts parameters and losses in the shell and tube heat- exchanger. Result analysis via real time shows the efficiency of existing model

Key Words and Phrases: straight line heat exchanger, heat transfer coefficient, heat transfer rate, thermo-hydraulic performance and exergy loss.

1. Introduction

Heat exchanger is an apparatus which is used for the exchange of thermal radiation between two states (or) mediums at various temperatures. There are numerous types of heat exchangers accessible in industry, the shell & tube heat exchanger is the one which is most used type of the heat exchangers. Basically these are used mostly in different places like oil refineries, thermal power plants, chemical industries and many more. This is highly acceptable due to comparative high ratio of heat transfer area to volume and weight, cleaning is easy, replacing of spare parts etc. Shell and tube type heat exchanger consist of a number of tubes through which one fluid flows

which is named as tube side. The same or other fluid flows through the shell which encloses the tubes; pull rods etc. which is named as shell side. Then due to temperature difference there will be heat transfer through the surface of tubes. Meanwhile, good heat transfer performances are obtained due to the venturi effects and eddy streets generated by fluids flowing across rods [5-8]. The heat lost by hot water in tubes is equal to the heat gained by the cold water in the shell side. Besides, viscosity and thermal conductivity of working fluids are greatly related to temperature, while the assumption of constant fluid properties was made in [1].

As the surface area is more the heat transfer rate is also more, so depending on the surface area the heat exchanger is classified as:- Straight tube heat exchanger, coiled tube heat exchanger, spiral heat exchanger. In this paper particularly we discuss on straight tube heat exchanger.

Basic components of Heat exchanger

1.1 Tubes

These are basic parts of shell and tube heat exchanger. The heat transfer takes between the tube side and shell side so these tubes acts as thermal barrier. So the tube material used must be highly thermal conductive such as aluminum alloys, copper etc.

1.2 Shell

The shell is simply the pitcher for the shell side fluid, and it also contain the inlet and exit ports. The shell normally has a circular cross section and is manufactured by continuing a metal plate into a cylinder(of necessary dimensions).The material used must be free from rusting, so mainly stainless steel is used in this type of applications.

1.3 Pull rods

The two main functions of pull rods are: 1) to give support to the baffle assembly part; and 2) to sustain the space between selected baffles.

1.4 Baffles

Baffles serve three functions 1) sustenance of the tube; 2) sustain the spacing between tubes (geometrical parameter); third function is the main function of baffles 3) to straight the flow of fluid in the preferred patterns so that the flow time increases and heat transfer rate also increases.

2. EXPERIMENTAL SETUP

The heat exchanger is a shell and straight tube type with hot water on tube side and cold water on shell side. The function is to maintain the outlet hot water temperature by varying the flow of inlet cold water and maintain constant.



Figure.1 Heat exchanger experimental setup

Fig.1 Shell and Tube Heat Exchanger setup) flow rate of hot water. The outlet pressure of both shell side and tube sides take the boundary conditions of pressure zero [2] and inlet pressure is maintained at 4 bar. Here cold water flow rate is the operated variable. The inlet hot water flow rate is maintained at 120 LPH. Flow rate is controlled by using Rota meter. The hot water inlet temperature is maintained in the range of 75 °C to 85 °C. The cold water inlet temperature is maintained in the range of 27 °C to 32 °C. In this heat exchanger there no baffle plates and no pull rods used. Matlab software has been used for result analysis.

Table.1. Specifications of heat exchanger used in laboratory

Shell material	SS316
Tube material	Copper(Cu)
Tube length	750mm
Shell Diameter	150mm
No of Tubes	37
Tube diameter	6mm
Over all heat transfer	1000 W/m ² .°c
Heat transfer area	1.136m ²

(SHELL AND TUBE)

Parameter	Unit	Comment	
Uncertainty in the temperature measurement			T
Cold fluid inlet temperature	°C	±0.5	a
Cold fluid outlet temperature	°C	±0.5	bl
Hot fluid inlet temperature	°C	±0.5	e.
Hot fluid outlet temperature	°C	±0.5	2.
Ambient temperature	°C	±0.5	M
Uncertainty in the measurement of volume flow rate			a
Water (tube side)	LPH	±5	xi
Water (shell side)	LPH	±5	m
Uncertainty in reading values of table (v...)	%	±01-0.2	u

m uncertainty of parameters

3. CHARACTERIZATIONS OF DIFFERENT PARAMETERS

3.1. Shell side Reynolds number

It is a dimensionless number used in fluid mechanics to indicate the type of flow where the flow is turbulent or laminar. If the $Re < 2300$ then it is said to be laminar, if $Re > 4000$ then it is said to be turbulent, in between the range refers to transition flow.

$$Re = \frac{4\rho_s q_{v,s}}{\mu_s \pi (D + n_t d_0 + n_p d_p)} \quad (1)$$

In Eq.1. Reynolds number (Re) is directly proportional to cold water inlet flow rate ($q_{v,s}$) and inversely proportional to viscosity.

3.2 Heat transfer rate

Heat transfer is the thermal energy transfer between two physical arrangements. The rate of heat transfer depends on the temperature and properties of medium. The heat transfer rate will be zero only when the system achieve thermal equilibrium. This can be calculated by the fluid enthalpy difference between flowing in and out of the device on either shell or tube side. it is also directly proportional to cold water flow rate.

$$Q = \rho_s q_{v,s} C_{p,s} (T_s^{in} - T_s^{out}) \quad (2)$$

3.3 Logarithmic mean temp difference

This is used to determine the temperature driving force for heat transfer in flow system and particularly in heat exchangers. . The larger the LMTD, the more heat is transferred. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties. This can be expressed as

$$\Delta T_m = \frac{(T_s^{in} - T_t^{out}) - (T_s^{out} - T_t^{in})}{\ln \left(\frac{T_s^{in} - T_t^{out}}{T_s^{out} - T_t^{in}} \right)} \quad (3)$$

The overall heat transfer coefficient is a measure of the overall ability of a series of conductive and convective barriers to transfer heat. It is commonly applied to the calculation of heat transfer. For the case of a heat exchanger, can be used to determine the total heat transfer between the two streams in the heat exchanger by the following relationship.

$$q = kA\Delta T_{LM}$$

Where:

q= heat transfer rate

u = overall heat transfer coefficient.

A = heat transfer surface area.

ΔT_{LM} = logarithmic mean temperature difference.

3.4 Overall heat transfer coefficient

The heat transfer coefficient in thermodynamics is a proportionality const. between volumetric flow rate and temperature difference. This characteristic appears as a proportionality factor a in the *Newton-Reichmann relation*. The heat transfer coefficient (k) of the heat exchanger is calculated by the heat transfer equation, i.e.

$$k = \frac{Q}{n_t d_0 \pi L_t \Delta T_m} \quad (4)$$

3.5 Shell side convection heat transfer coefficient

This can be expressed as

$$h_s = \frac{1}{\frac{1}{k} - \frac{1}{h_t} \cdot \frac{d_o}{d_i} - \frac{d_0}{\bar{\alpha}_{s,t}} \ln \frac{d_o}{d_i}}$$

(5)

3.6 Overall thermo-hydraulic performance

By this result we can discuss the overall performance of the heat exchanger and can do structural modifications if necessary in the exchanger for the improvement of performance. This is expressed by the ratio between shell side heat transfer coefficient to the flow resistance or pressure difference. This is given by [1], [3] and [4].

$$\frac{h_s}{\Delta p_s} \quad (6)$$

3.7 Tube side Reynolds number

Tube side Reynolds number can be expressed as

$$Re = \frac{V d_i}{\nu} \quad (7)$$

Where:

V = max velocity

d_i = internal diameter of tube

ν = kinematic viscosity of water

3.8 Exergy loss calculation

Assuming heat losses $\dot{Q}_{loss}$ to be negligible in a heat exchanger, exergy loss E_{loss} can be calculated as [9, 10].

$$E_{loss} = T_e [\dot{m}_t C_{pt} \ln(T_t^{out}/T_t^{in}) + \dot{m}_s C_{ps} \ln(T_s^{out}/T_s^{in})] \quad (8)$$

Dimensionless exergy loss (e) can be calculated as follows [11].

$$e = \frac{E_{loss}}{T_e C_{min}} \quad (9)$$

$$C_{min} = \text{Min} \{C_t = \dot{m}_t C_{pt} \text{ and } C_s = \dot{m}_s C_{ps}\}$$

4. RESULTS ANALYSIS

4.1 Heat transfer rate

The figure (2) represents the heat transfer rate versus shell side Reynolds number graph. We can observe from graph that heat transfer rate is directly proportional to cold water flow rate. As the cold water

flow rate increases heat transfer from hot water to cold water also increases which in turn increases heat transfer rate

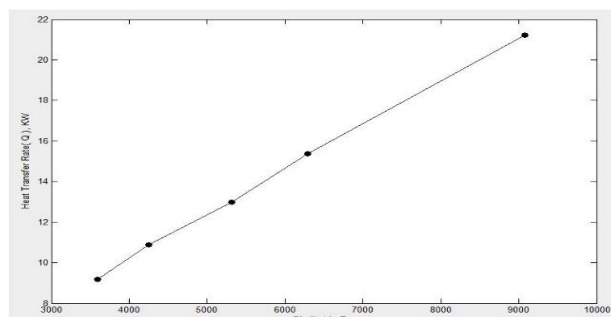


Figure.2 Heat transfer rate

4.2 Overall heat transfer coefficient

The figure (3) represents the heat transfer coefficient versus Reynolds number and this is also related flow rate as the cold water flow rate increases the heat transfer coefficient also increases.

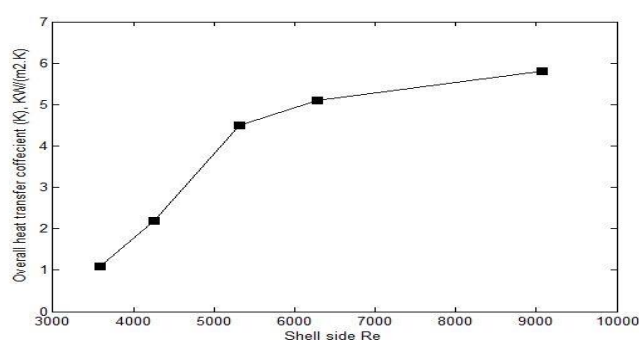


Figure.3 Heat transfer coefficient

4.3 Over all thermo-hydraulic performance

This is expressed by the ratio between shell side heat transfer coefficients to the flow resistance. The flow resistance(R) is constant and it is calculated by using poiseuille's equation:

$$R = \frac{8\eta l}{\pi r_s^4}$$

The overall performance of heat exchanger can be deduced by this graph. Heat exchangers are universal in every thermal system receiving or rejecting heat with its surroundings. Thermal performance of a system is highly dependent on the heat exchangers ability to transfer heat which is governed by distinct fluid flow

characteristics in the tube passages. The Figure (4) represents the overall thermo-hydraulic performance versus shell side Reynolds number.

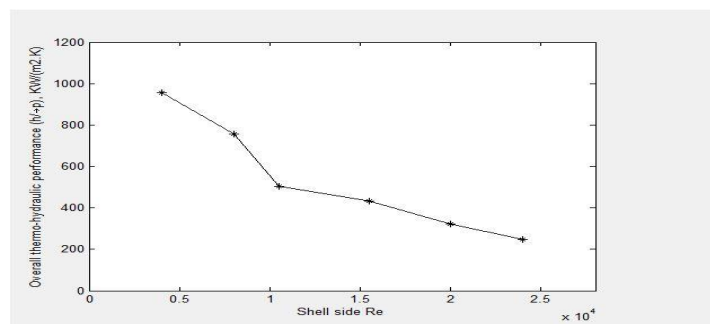


Figure.4 Overall thermo-hydraulic performance

4.4 Exergy loss

The figure (4) represents exergy loss (E_{loss}) versus the tube side Reynolds number. Cold and hot water temperatures are kept constant at around 30 °C and 70 °C respectively. Shell side flow rate is kept constant at around (100, 150, 200, 250 LPH) for different tube side flow rates which are kept constant at around (50, 75, 100, 125 LPH). Maximum exergy loss occurs at shell side flow rate of 250 LPH and minimum occurs at 100 LPH. Also, it can be noticed that as the tube side flow rate increases (from 50 to 125 LPH) for constant shell side flow rate (say 150 LPH) exergy loss also increases.

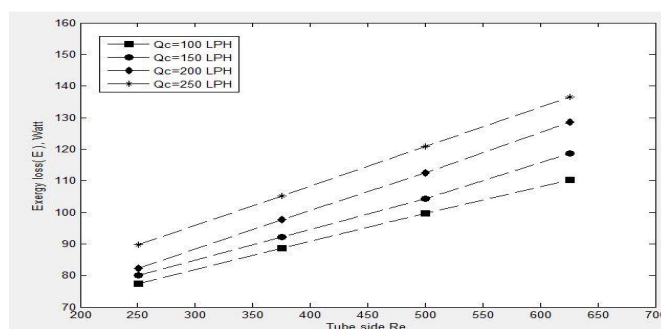


Figure.4 Exergy loss

4.5 Dimensionless exergy loss

The figure (5) represents dimensionless exergy loss (e) versus tube side Reynolds number. Curves behavior depends both on E_{loss} and C_{min} . For shell side flow rate of 100 LPH last two points are evaluated using C_{min} of shell side and rest all points are evaluated using C_{min} of coil side flow rate. These curves does not follow any particular trend

because dimensionless exergy loss depends on $C_{\min}$. But, we can observe from graph that when shell side flow rate is less than coil side flow rate dimensionless exergy loss increases and vice versa.

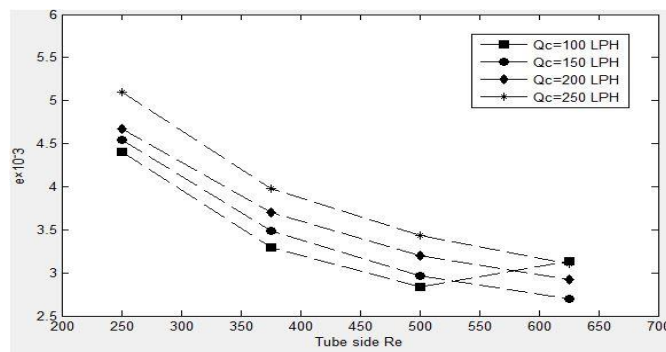


Figure.5 Dimensionless exergy loss

5. Conclusion

The production throughput and efficiency of the system depends on the precise functioning of the physical parameters of that system. The work concludes brief study and analysis of different physical parameters of shell and tube heat exchanger. The overall thermo-hydraulic performance depends on the physical losses and quality of material. Therefore as a part of system performance analysis, different parameters like heat transfer rate, overall heat transfer coefficient, overall thermo-hydraulic performance, exergy loss and dimensionless exergy loss with respect to Reynolds number calculation etc. The performance of system has been analyzed and portrayed.

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