

Design and Performance Analysis of Double Pipe Heat Exchanger

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ABSTRACT: Double pipe heat exchangers are economical choice for closed cycle cooling systems where an adequate supply of suitable water is available at a reasonable cost to meet the water requirements. The double pipe heat exchangers can be connected in different arrangements to meet pressure drop and LMTD (logarithmic mean temperature difference) requirements. The design analysis and comparative study on different flow types is carried out theoretically and experimentally using an experimental setup. The performance analysis is evaluated using CFD (computational fluid dynamics) and the overall effectiveness is determined. Therefore, an appropriate and well-designed heat exchanger can have a very significant and positive impact on plant performance and profitability.

KEYWORDS: LMTD, pressure drop, performance analysis, effectiveness.

I. INTRODUCTION

Heat exchangers are devices used to transfer heat energy from one fluid to another. The temperatures of both fluids may change while flowing through the exchanger. The energy transferred between the streams results in a change in temperature of each fluid stream if neither fluid is undergoing a phase change. As a result of the gradual change in the temperature levels in an exchanger, the temperature difference across the heat transfer barrier vary over the length of the exchanger. The widely varying conditions under which it is essential to affect the exchange of heat dictated the development of many special and general types of heat transfer equipment. The temperature and pressure levels, as well as differences often impose severe problems. The corrosiveness, toxicity and scale forming tendency must be considered in the design of heat exchangers in addition to the thermal properties of the substances. There are also economic considerations which include as initial cost of the exchangers, necessary space, and required life of the unit and ease of maintenance.

The heat transfer in a heat exchanger usually involves convection on each side of fluids and conduction through the wall separating the two fluids. Thus, for analysis of a heat exchanger, it is very convenient to determine an *overall heat transfer coefficient* U , that accounts for the contribution of all these effects on heat transfer. The rate of heat transfer between two fluids at any location in a heat exchanger depends on the magnitude of temperature difference at that location and this temperature difference varies along the length of the heat exchanger. Therefore, it is also convenient to determine the *logarithmic mean temperature difference* LMTD, which is an equivalent temperature difference between two fluids for entire length of heat exchanger. The heat exchangers are commonly used in a wide range of applications. For example, in a car radiator, hot water from the engine is cooled by atmospheric air. In a refrigerator, the hot refrigerant from the compressor is cooled by natural convection into atmosphere by passing it through finned tubes. In a steam condenser, the latent heat of condensation is removed by circulating water through the tubes. The heat exchanger is also used in space heating and air conditioning, waste heat recovery and chemical processing. Therefore, the different types of heat exchangers are needed for different applications.

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Heat exchangers are designed in wide variety of sizes, types, configurations and flow arrangements. Heat exchangers are broadly classified:

- (a) According to heat transfer process [1] Direct contact type [2] Indirect contact type (b) According to constructional features [1] Double pipe heat exchanger [2] Shell and tube heat exchangers [3] Finned tube type [4] Compact type (c) According to flow arrangements [1] Parallel flow [2] Counter flow [3] Cross flow

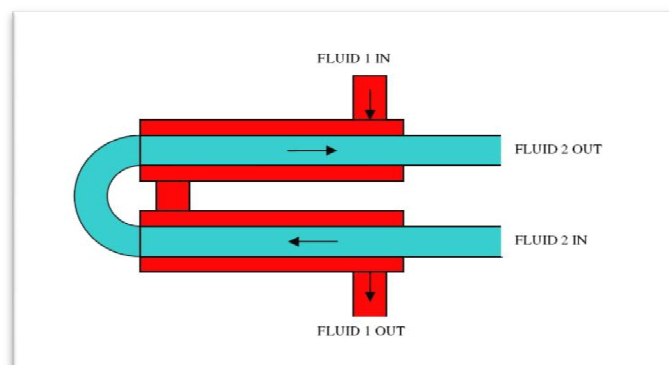


Fig 1 (a) Double pipe heat exchanger

II. RELATED WORK

Extensive work has been completed on the flow and heat transfer characteristics of heat exchangers. There are a number of published papers and handbooks on this subject, for both hydrodynamic and heat transfer aspects. Kays and Perkins (1973), Berger et al., (1983) and Shah and Joshi (1987) are some of the more complete reviews.

J.S. Jayakumara et al., [1] conducted an experimental study on Computational Fluid Dynamics (CFD) of helically coiled heat exchanger. In this paper, after validating the methodology of CFD analysis of a heat exchanger, the effect of considering the actual fluid properties instead of a constant value is established. Heat transfer characteristics inside a helical coil for various boundary conditions are compared. It is found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger does not yield proper modelling. Hence, the heat exchanger is analysed considering conjugate heat transfer and temperature dependent properties of heat transport media. An experimental setup is fabricated for the estimation of the heat transfer characteristics. The experimental results are compared with the CFD calculation results using the CFD package FLUENT 6.2. Based on the experimental results a correlation is developed to calculate the inner heat transfer coefficient of the helical coil.

M.H. Saber, et al., [2] conducted a study on the simulation and CFD analysis of Heat Pipe Heat Exchanger using fluent, to increase the thermal efficiency. In this paper, a heat pipe heat exchanger is considered and computational fluid dynamics (CFD) is used to analyse its evaporators performance and based on it, it was tried to increase the thermal efficiency and optimize the distribution of fluid flow in this type of heat exchangers. The numerical computations are achieved using Fluent (the CFD solver program).

Warakorn Nerdnoi et al., [3] investigated the heat transfer and pressure drop characteristics in a double pipe heat exchanger fitted with a turbulator. In this paper, the researchers have tried to investigate heat transfer and pressure drop characteristics in a double pipe heat exchanger fitted with a helical-rod insert. Augmented heat transfer was above the plain tube values. Improvement of heat transfer was found from helical-rod inserts where Nusselt numbers ranged from 150% to 160% comparison with the plain tube values at corresponding Reynolds numbers. It is shown that the

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pressure drop for the tube with the helical-rod insert is 6 to 9 times those of the plain tube for the range of Reynolds numbers tested.

Stefano Bracco et al., [4] carried out the numerical discretization for the dynamic simulation of a double pipe heat exchanger. This paper deals with both the steady-state and Dynamic simulation of a double-pipe heat exchanger, in parallel-flow or counter flow arrangement. In particular, the article describes the thermodynamic model that has been implemented in the Mat lab/Simulink environment; the main hypotheses and physical parameters, which characterize the simulation model, are listed. The Paper is focused on the discretization of the heat exchanger which has been divided into N cells, each modelled by means of the energy balance equation. It's important to point out that the model considers the storage of thermal energy in the metal parts and the method of discretization, that has been adopted, gives just acceptable results dividing the heat exchanger in a small number of cells. The paper shows some results of the steady-state simulation of a counter flow heat exchanger, as a function of the number of cells, and the effects of some typical transient operating conditions are described.

William Clark et.al., [5] conducted a study on the computer simulation of laboratory experiments for enhanced learning. This paper consists of testing the hypothesis that computer simulations showing the solutions to the differential equations that govern the fluid flow, heat transfer, mass transfer, and chemical reactions within the equipment will solidify the link between experiment and theory and provide improved learning. In this paper a report on the development and implementation of a simulation of a double pipe heat exchanger has been made using COMSOL Multiphysics, a commercial finite element modelling software package.

M. M. El-Fawal et al., [6] designed a computer program for economical design of shell and tube heat exchanger using specified pressure drop is established to minimize the cost of the equipment including the sum of discounted annual energy expenditures related to pumping. The design procedure depends on using the acceptable pressure drops in order to minimize the thermal surface area for a certain service, involving discrete decision variables. Also the proposed method takes into account several geometric and operational constraints typically recommended by design codes, and may provide global optimum solutions as opposed to local optimum solutions that are typically obtained with many other optimization methods. While fulfilling heat transfer requirements, it has anticipated to estimate the minimum heat transfer area and resultant minimum cost for a heat exchanger for given pressure drops. The capability of the proposed model was verified through two design examples. The obtained results illustrate the capacity of the proposed approach through using of a given pressure drops to direct the optimization towards more effective designs, considering important limitations usually ignored in the literatures.

Timothy J. Rennie [7] conducted experimental and numerical studies on a double pipe helical heat exchanger. A double-pipe helical heat exchanger was studied numerically and experimentally for both heat transfer and hydrodynamic characteristics. Numerical studies were performed with the aid of a commercial computational fluid dynamics package. Two sizes of the heat exchanger were investigated; the difference between the two was the diameter of the inner tube. Simulations were performed using various flow rates (laminar regime) in the inner tube and in the annulus, as well as for parallel flow and counter flow. The results of the Nusselt number in the inner tube were compared to similar experiments reported in the literature. A second study used the same numerical model; however, several Prandtl numbers were used by varying the thermal conductivity of the fluid. Furthermore, the effects of thermally dependent thermal conductivities on the heat transfer characteristics were investigated.

Although a significant amount of research has been performed on the flow patterns and heat transfer in curved pipes, there is still much that needs to be investigated. In particular, the fluid-to-fluid heat transfer needs further study as the past work has mainly focused on the constant heat flux and constant wall temperature conditions. There is little information on a double-pipe heat exchanger existing in the literature. Much importance has been emphasized on the experimental and CFD (Computational Fluid Dynamics) analysis. Hence, fluid flow and the heat transfer need to be studied for a double-pipe heat exchanger. Using such analytical and simulation tools, investigation on double pipe heat

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exchanger needs to be carried out to optimize the distribution of fluid flow and to increase the thermal efficiency of these types of heat exchangers.

III. EXPERIMENTAL SETUP

The experimental setup mainly comprises of a tank, pump, rotameter, control unit, thermocouples and the double pipe heat exchanger.

Water in the tank is heated up by a heating coil element. The required temperature is set via the thermostat. A pump is used to drive this hot water through the annulus of the Double pipe heat exchanger. Cold water is passed through the outer tube directly from an external tank. The flow rates of both- hot and cold water are controlled by rotameters provided as shown in the picture. Thermocouples are located at the inlet and exit points of the annulus and the tube in order to measure the temperature of the fluids at these points. A control unit aids in not only setting the temperature level of the hot water, but also in reading the temperatures at various locations of the thermocouples (J-type thermocouples are used in the present setup). The tank, pump, rotameter and Heat exchanger are connected by appropriate piping and valves.

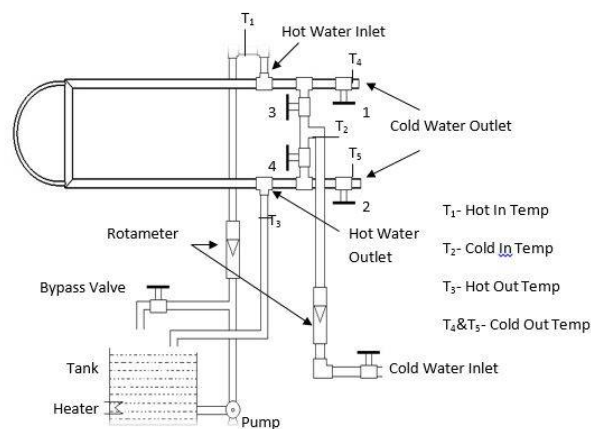


Fig 3 (a) Experimental setup for counter flow and parallel flow heat exchanger

IV. PROBLEM STATEMENT AND METHODOLOGY

Present study deals with the performance analysis of existing double pipe heat exchanger. The actual performance analysis of a double pipe heat exchanger can be accurately determined only by operating the exchanger at different flow rates i.e. at nominal flow and +/- 10% of the nominal flow and different flow configurations (parallel and counter flow). The trials were carried out at different times on different days and the repeatability was checked. From this performance curves were plotted and effectiveness of the heat exchanger is determined.

The required dimensions were taken from the experimental setup and the heat exchanger was physically modelled using 3-D modelling software, after which the model was subjected to tetrahedral meshing, and by suitable boundary conditions the trials were carried out and iterations were progressed, from this appropriate solution for the effectiveness was determined.

The comparison of computational and experimental models was analysed and the effectiveness drop was determined. The effectiveness drop was due to the following factors:

1. The fouling factor is comparatively higher from the actual range.

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2. The Flow inside the Pipe is highly turbulent in nature.
3. Non-standard dimension (Non-Sizing) pipes are used in the present setup therefore the heat transfer rate is considerably reduced.
4. The insulations provided for the present setup is ineffective, hence there is maximum heat loss and pressure drop.

Since the effectiveness of the installed setup is very close to the minimum requirement, the replacement of the heat exchanger has been designed theoretically (by models available in literature) to increase the margin of safety, and examined the effects of various parameters such as *effectiveness of the heat exchanger* (ϵ), *overall heat transfer coefficient* (U), *LMTD* & *pressure drop*.

V. RESULTS

In this parametric study, experiments were conducted by changing the flow rate and flow configurations and effectiveness were determined i.e. 26.5% for parallel flow and 30.5% for counter flow and pressure drop is 7.312 kPa for the pipe. From the simulations, the effectiveness determined was about 34.3 % for parallel flow and 36.7 % for counter flow. Shown in fig 5(a) and fig 5(b) is an ANSYS simulation of a parallel flow and counter flow heat exchanger respectively. The respective temperature vs length graphs are shown in fig 5(c) and fig 5(d). Theoretically designed the heat exchanger, and examined the effects of various performance parameters such as overall heat transfer coefficient as $U= 1050.25\text{W/m}^2\text{K}$, effectiveness $\epsilon = 51.38\%$ for parallel flow and $\epsilon = 55.93\%$ for counter flow, and pressure drop is $P=0.929$ kPa for pipe. From the simulations, the effectiveness determined was about 52.475 % for parallel flow and 57.18 % for counter flow. The theoretically designed length and diameter according to the standards is 3.636 m and 25.273 mm (ID pipe), 28.575mm (OD pipe) and 32.46 mm (annulus) respectively.

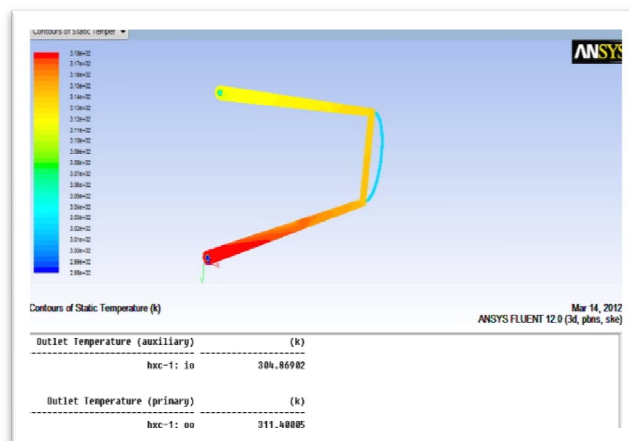


Fig 5 (a) Parallel flow contour

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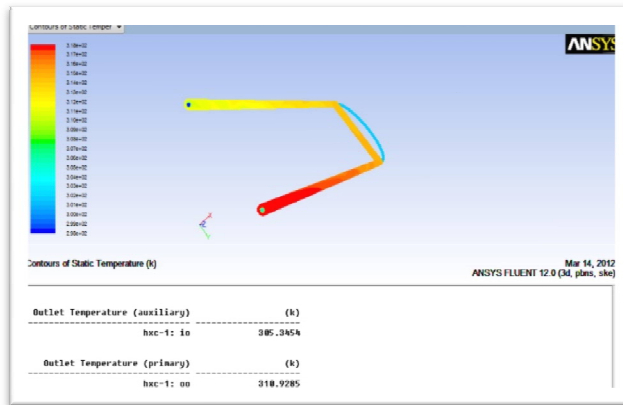


Fig 5 (b) counter flow contour

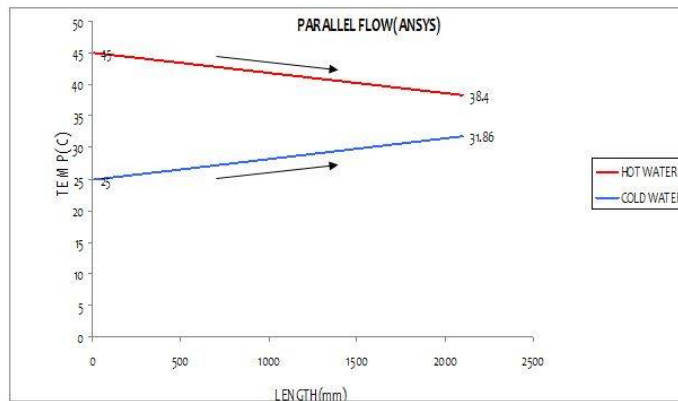


Fig 5 (c) Parallel flow graph

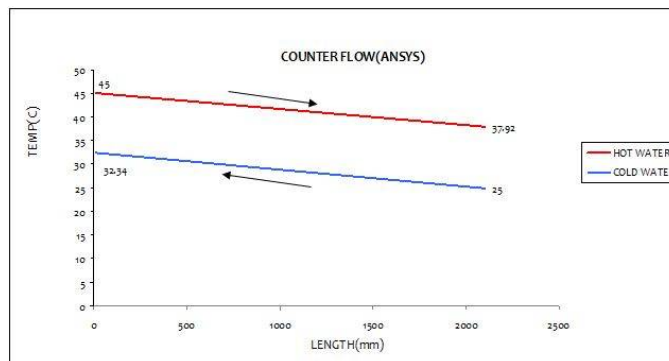


Fig 5 (d) counter flow graph

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VI. CONCLUSION

A detailed theoretical and practical analysis with simulations of the design and performance of the double pipe heat exchanger was done. From comparison with simulated model and experimental setup the drop-in effectiveness exceeded the limit. The reasons for the drop were listed and suitable suggestions were made. And further it was concluded that as the surface area increases the overall heat transfer co-efficient increases and hence the heat exchanger effectiveness increases.

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