Review Paper on Analysis of Heat Transfer in Spiral Plate Heat Exchanger Using Experimental and CFD

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Abstract— Heat transfer is the key to several processes in industrial application. In a present days maximum efficient heat transfer equipment are in demand due to increasing energy cost. For achieving maximum heat transfer, the engineers are continuously upgrading their knowledge and skills by their past experience. Present work is a skip in the direction of demonstrating the use of the computational technique as a tool to substitute experimental techniques. For this purpose an experimental set up has been designed and developed. Analysis of heat transfer in spiral plate heat exchanger is performed and same Analysis of heat transfer in spiral plate heat exchanger can be done by commercially procurable computational fluid dynamic (CFD) using ANSYS CFX and validated based on this forecasting. Analysis has been carried out in parallel and counter flow with inward and outward direction for achieving maximum possible heat transfer.In this problem of heat transfer involved the condition where Reynolds number again and again varies as the fluid traverses inside the section of flow from inlet to exit, mass flow rate of working fluid is been modified with time. By more and more analysis and experimentation and systematic data degradation leads to the conclusion that the maximum heat transfer rates is obtained in case of the inward parallel flow configuration compared to all other counterparts, which observed to vary with small difference in each section. Furthermore, for the increase heat transfer rate in spiral plate heat exchanger is obtain by cascading system.

Keywords: spiral plate heat exchanger, Computational Fluid Dynamics (CFD), ANSYS CFX, heat transfer rate, Reynolds number, Nusselt number.

I. INTRODUCTION

A. Heat exchanger

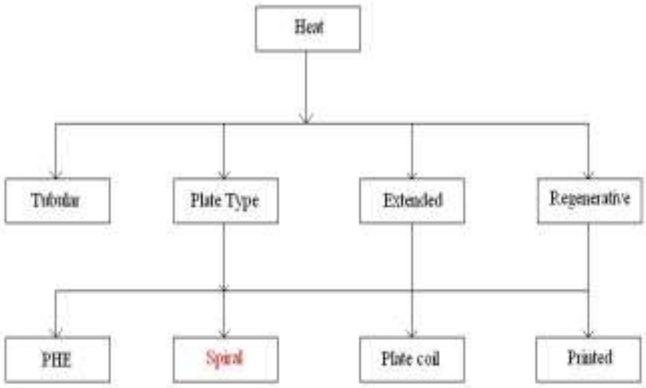
A heat exchanger is a device used to transfer of heat from higher temperature to lower temperature. We can be done transfer of heat between two or more fluids, between two solid surfaces and a fluid, or between solid particulates and a fluid, at various temperatures and in thermal contact.

B. Types Of Heat Exchanger

- According to construction features
- According to heat transfer mechanisms
- According to flow arrangements
- According to transfer processes
- According to surface compactness
- According to number of fluids

Classification According To Construction Features

Generally, the most basic compact heat ex-changers have a 50% less than volume of that of a comparable shell-and-tube heat exchanger, for a given work. Compact heat exchangers are classified into two types of spiral heat exchanger and plate type heat exchangers. Compact heat exchangers are characterized with its large amount of surface area in a given volume compared to other



Traditional heat exchangers, in particular the shell-and-tube type. The development and screening of compact heat exchangers has become an important requirement during the last few years. The interest stems from various reasons viz. less energy re-sources and decreasing raw material, the increasing pollution of environment and in-creasing operation costs and manufacturing costs of heat exchangers. The smooth and curved channels result in a very little fouling tendency with difficult fluids. Each fluid has only one channel and any localized fouling will result in degradation in the channel cross sectional area causing a increase velocity to roam the fouling layer. Spiral heat exchangers can be clean by itself. It is a main advantage of spiral heat exchanger so, the decreasing its operating cost due to self cleaning effect, when the unit is horizontally mounted.The heat exchanger can be optimized for the process concerned by using various channel widths. Width of plate along the heat exchanger axis may be 2 m, as can the exchanger diameter, Heat transfer areas giving up to 600 m^2 in a exchanger. Width of channel is generally in the range 5 to 30 millimeters.

C. Construction

Spiral plate heat exchangers consist of plates forming in a spiral by plate rolled together. The space between the two plates is kept by welded bolts to form the channels for the flow of the working fluids. In single phase applications, it is common for the hot (water) fluid enters to the heat exchanger through the central part of the exchanger and to exit at the extent. The cold (Water) fluid also enters the exchanger through the central part of the exchanger and to exit at the extent.

(1) Typically spiral heat exchangers are available in three configurations:Media in full counter-current flow.
(2) Combination Spiral Flow and Cross-Flow.
(3) One medium in spiral flow whilst the other is in cross flow.

D. Operating Limits

Generally, the maximum design temperature is depending on the gasket material and it is normally 400°C temperature set by the limits of the gasket material. For high temperature operating limit up to 850°C but it can be done by Special designs. Maximum design pressure is usually 15 bars in heat exchanger by without gasket, we can obtain maximum pressures up to 30 bar but we need some special design.

E. Application

- The design is ideal for fluids prone to fouling, or polluted with particles as a result of the relatively large width of channel. Hence, it's widely used in the food industry as like slush, sauces, and slurry as well as wine making.
- Spiral heat exchangers have a many applications in the, Petroleum processing, chemical industry and recovery of heat from many industrial effluents.
- Spiral heat exchangers are already providing the temperature control of sewage sludge digesters plus other public and industrial waste plants.
- They can maximize the heat recovery on largest cogeneration projects although they may be large expensive than plate designs. Spiral heat exchangers permit the best possible overlap of exit temperatures because of it has completely counter-current flow paths.
- It has a some Specific advantages like low pressure drop, ease of installation and large flow cross-section.
- There are lots of condensing applications in several process industries particularly for condensing under vacuum.

II. LITERATUREREVIEW

A. Review papers

Many analyses have studied the heat transfer characteristics of flow through the spiral plate heat exchangers. The studies cover a huge variety of fluids such as water, palm oil, nitrobenzene etc. The industrial application of heat transfer processes in spiral plate heat exchanger is not new J. E Durastanti et.al [1] produced a thermal modeling of the heat exchangers in both time dependant and steady state cases with 2D spiral geometry, allowing computation with various materials, forced convective heat transfer models in geometrical parameters options and turbulent flow. Findings of the results were displayed in steady state conditions with a view to enhance the performance of the exchanger.

M. Pico´n-Nu´n˜ ez [2] in his experimental paper studies and they are obtained a shortcut method for the sizing of the spiral plate heat exchanger. The approach consists of an iterative process where physical dimensions like plate width and external spiral heat exchanger diameter are given initial values; convergence is achieved when the calculated pressure drop and heat duty is not meet the required specifications of the design problem. The results of the application of the approach were compared with the case studies in the literature. A numerical study using computational fluid dynamics was performed to the rate of performance of the spiral heat exchanger geometry. The temperature profiles of the exchanger calculated by analytically and show the same tendency as those obtained by numerically. Thus this method holds a good starting point for estimating the dimensions of spiral plate heat exchangers in single phase dimensions. Experimental geometrical design of spiral plate heat exchanger figure which is given below,

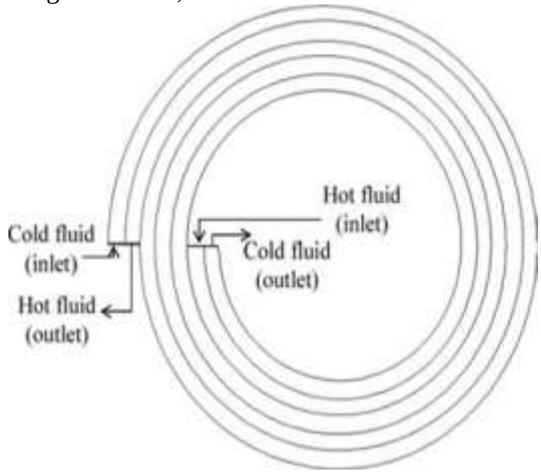


Fig. 1: Flow pattern for counter-flow arrangement in spiral heat exchangers

An experimental studies of convective heat transfer co-efficient for electrolytes using spiral plate heat exchanger was carried out by R.Rajavel and K.Saravanan[3].The test section consisted of a plate thickness 0.001mm, width 0.315m, and mean hydraulic diameter of 0.01m. The mass flow rate of electrolytes for a cold fluid Experimental study is compared with the theoretical data. Besides a new correlation was varying from 0.483 kgs-1 to 0.704 kgs-1. Experiments were conducted by varying the temperature and pressure of cold fluid and mass flow rate and for hot fluid keeping the mass flow rate is constant. The effects of relevant parameters on spiral plate heat exchanger were found out. The data obtained from the Nusselt number was developed which can be used for practical applications.

$N_u=0.0465R_e^{0.834}\,P_r^{-0.153}$ (1)

$3750>Re<8750,\ 4<Pr<6$

In this paper they have selected modified spiral plate heat exchanger for experimental investigation. The schematic diagram and experimental set up parameters given below,

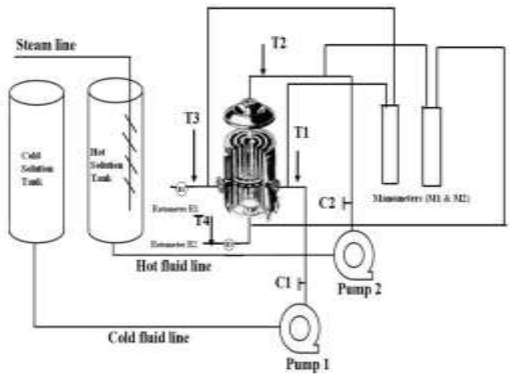


Fig.2. Schematic diagram of experimental apparatus

Parameters	Dimensions (P5-VRB Plate)
Plate width, m	0.3150
Plate thickness, m	0.0010
Mean channel spacing, m	0.0050
Mean hydraulic diameter, m	0.0100

Heat transfer area, m^2	2.2400

Table 1: Dimension of Spiral Plate Heat Exchanger

P.Naphon[4] was investigated of Numerical and experimental results for the heat transfer and flow characteristic. The spiral coil tube was fabricated by bending 8.00mm diameter straight copper tube into a spiral coil of five turns. Water are used for Hot fluid and cold fluid as a working fluid.The k-ε standard two equation turbulence model is used to simulate the turbulent flow and heat transfer characteristics. A finite volume method is used for the solution of the main governing equations with an unrestricted non- uniform grid system. Experiments were performed to obtain flow characteristics and heat transfer for verifying by the numerical results. Judicious agreement was obtained from the comparison between the results from the model and those obtained from the experiment. In addition, the Nusselt number and pressure drop per unit length obtained from the spiral coil tube are 1.50 times higher than those for the straight tube.

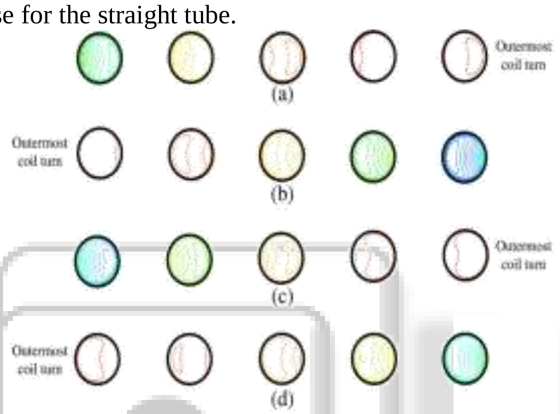


Fig. 3: Development of the temperature field (a) θ=0°, (b) θ=90°, (c) θ=180°, (d) θ=270°

The effect of centrifugal force on the temperature distribution as shown in Figure 3, the Nusselt numbers obtained from the spiral-coil tube are 1.49 times higher than those from the straight tube. As the distance increases from the inlet section, the centrifugal force instantly increases. Due to this force, the maximum point of the temperature is shifted toward the outer side of curve as shown in Figure 3. This result has significant effect on the heat transfer increase between the working fluid near the core and working fluid near the tube wall.

Dr. K. Saravanan[5] have a produce Heat transfer coefficients of benzene in a spiral plate heat exchanger. The test section consisted of a plate thickness 0.001m, width 0.3150 m, and mean hydraulic diameter 0.01m. The mass flow rate of water (hot fluid) was kept varying from 0.5kgs-1 to 0.8kgs-1 and the mass flow rate of benzene was kept varying from 0.4kgs-1 to 0.7kgs-1. Experiments were conducted by varying the temperature, mass flow rate, and pressure of cold fluid keeping the mass flow rate of the hot fluid constant. Find out the effects of relevant parameters on spiral plate heat exchanger. The data obtained from the theoretical data were compared with the theoretical study. Besides, a new correlation for the Nusselt Number was developed which can be used for practical purposes.

$N_u=0.0476R_e^{0.832} P_r^{-0.149}$ (2)

$6000 < Re < 11000, 4.7 < Pr < 5.9$

They concluded that different length of heat exchanger which greatly affect the co efficient of heat transfer, Reynolds number and Nusselt number which is given below,

- Length from spiral centerVs Heat transfer coefficient

The variation of the length from spiral centre and heat transfer coefficient of benzenefor different mass flow rates. It is clear that the heat transfer coefficient is varying with mass flow rates. When the massflow rate is increased the heat transfer coefficient is also increased. On the other hand, the heat transfer coefficient isdecreased when the length of spiral plate is increased.

- Length from spiral centerVs Liquid Reynolds number

The variation of the length from spiral centre and Reynolds number of water and benzene fordifferent mass flow rates. It should be noted that the Reynolds number is varying with mass flow rates. When the massflow rate is increased the Reynolds number is also increased. On the other hand the Reynolds number is decreased whenthe length of spiral plate is increased.

- Comparison of Nusselt number (Experimental) Vs (predicted)

The comparisons of the Nusselt numbers obtained from the experiment conducted with those calculatedfrom theoretically. It can be noted that the experimental and Predicted Nusselt numbers fall within ±3%.The majordiscrepancy between the measured data and calculated results may be due to the difference in the configuration of testsections and uncertainty of the correlation.

The proposed Nusselt number correlation (1) for spiral plate heat exchanger is expressed as follows.

The correlation is obtained by fitting a total of 129 experimental data. (R2 =0.98)

$N_u=0.1868R_e^{0.708} P_r^{-0.371}$ (3)

$6000<Re<11\,000, 4.7<Pr<5.9$

P. Kalaichelvi [6] Heat transfer studies in two-phase flow streams (particularly liquid-liquid) are becoming very important since this is frequently encountered in petrochemical and other process industries. The objective of the present analysis is to evolve a correlation to predict two phase heat transfer co efficient with high accuracy which will help to optimally design the heat exchanger. Experimental studies were done in a spiral plate heat exchanger in laminar range using the two phase system of water –n-dodecane in different in different mass fractions and flow rates as the cold fluid. The two phase heat transfer co-efficient were related with Reynolds numbers and fitted into a relation in the form $h = aRe^m$. The mass fractions of n-dodecane for identical Reynolds numbers are related to the heat transfer coefficient. Correlation were developed between the two phase multiplier (ratio of the heat transfer co efficient of the two phase fluid and that of the single phase fluid) this enables prediction of the two phase heat transfer coefficients using single phase data with an accuracy of ± 8%.

Rangasamyrajavel, KalinnanSaravanan[7] Spiral plate heat exchangers play a vital role for high density and high viscous fluids in cooling process. This paper presents an experimental investigation of convective heat transfer co-efficient for electrolytes using spiral plate heat exchanger. The test section consists of a Plate thickness 0.001 m, width 0.3150 m, and mean hydraulic diameter of 0.01 m. The mass flow rate of cold fluid varies from 0.3 kg sec-1 to 0.8 kg sec-1 and the mass flow rate of hot fluid is varying from 0.4 kg sec-1 to 0.8 kg sec-1. Experiments have been conducted by varying the temperature, mass flow rate, and pressure of cold fluid, the mass flow rate of hot fluid is keeping constant. The effects of relevant parameters on spiral plate heat exchanger are found out. The theoretical data are compared with the experimental data which is obtaining from the experimental study. Besides, a new correlation for the Nusselt number was developed which can be used for practical applications. They concluded that different length of heat exchanger which greatly affect which is given below,The correlation is obtained by fitting a total of 153 experimental data. (R^2=0.97)

$N_u=0.0476\ R_e^{0.832}\ P_r^{-0.149}$ (4)

3800>Re<8500

M.picon Nunez, L.CanizalezDavalos and A. Morales Fuentes [8] their work represents approach for an alternative design for the sizing of spiral heat exchangers in single phase counter-current applications. In this approach, pressure due to fluid friction can be directly related to the heat transfer coefficient through the exchanger geometry, thus resulting maximizes pressure drop in a sizing methodology and results in the design of the possible smallest dimensions. In the counter-current flow arrangement both fluids have the same flow length. A degree of freedom may be changed in design is the plate spacing that in order for both fluid streams to maximize its allowable pressure drop. The approach is compared with design results presented in the open literature and their results show that the method is reliable and easily applicable.

S. Ramachandran, P. Kalaichelvi, and S. Sundaram [9] Experimental analysis were conducted in a spiral plate heat exchanger with hot water as the service fluid and the two-phase system of water – palm oil in different mass flow rates and mass fractions as the cold process fluid. The heat transfer coefficients in two phase system were correlated with Reynolds numbers (Re) in the form $h = a\ Re^m$, adopting an approach available in literature for two phase fluid flow. The heat transfer coefficients were also related to the mass fraction of palm oil for identical Reynolds numbers. The two-phase multiplier (ratio of the heat transfer coefficient of the two phase fluid and that of the single phase fluid) was correlated with the Lockhart Martinelli parameter in a polynomial form. This enables prediction of the two phase co efficient using single-phase data.

J.S.Jayakumara, S.M.Mahajania and J.C.Mandala [10] increasing in heat transfer rate due to helical coils has been reported by many researchers. While the characteristics of heat transfer in double pipe helical heat exchangers are already available in the literature, there exists no one published any experimental or theoretical analysis of a helically coiled heat exchanger considering fluid-to-fluid heat transfer, which is the main subject for this work. After validating the methodology of CFD analysis of a heat exchanger, the effect of considering, Established the actual fluid property instead of a constant value. Heat transfer characteristics inside a helical coil for different boundary conditions are compared. It is found that the specification of a constant heat flux or constant temperature boundary condition for an actual heat exchanger does not yield proper modeling. Hence, the heat exchanger is analysed considering conjugate heat transfer and temperature dependent properties of heat transfer media. An experimental setup is produced for the estimation of the heat transfer characteristics. The experimental results are compared with the CFD analysis using the CFD package FLUENT 6.2. Based on the experimental results a correlation is developed which can be used for the calculation of the inner heat transfer coefficient of the helical coil.

ZeidY.Munir[11] Energy balances over finite control volumes were performed to run an iterative numerical computation scheme for solving for the temperature profile of equal capacitance fluids in counter current flow inside spiral-plate heat exchangers. The thermal effectiveness was calculated as a function of the computed fluid temperatures. Several domain discretization and convective interpolation schemes were investigated. Numerical results show a maximum of effectiveness versus number of transfer units (NTU), the maximum effectiveness and its corresponding NTU being proportional to length of the spiral. Results also show that the loss of effectiveness at high NTU is due to the exchange of heat between the two channels in the outermost turns. The quadratic convective interpolation scheme provided more accurate numerical results than did the linear upwind scheme.

B. Literature summary

Many researchers worked on spiral plate heat exchanger particular based on design, geometrical shape, changed different parameters like various temperature, mass flow rate, pressure for obtaining better heat transfer rate. They have concluded that all above things by experimental and theoretical point of view but few researchers worked on CFD analysis and compared with experimental data. Present days CFD analysis is too much well known for the optimum heat transfer rate in heat exchanger but nobody aware about that analysis and this is reduced the cost of research.

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