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Performance Optimization of Plate Fins Type Heat Exchanger by Numerical Analysis

Md Asad Mahfuz[1], Dr. Rahul Kumar Singh[2]
[1]M.Tech scholar Rabindranath Tagore University, Bhopal
[2]Associate Professor Rabindranath Tagore University, Bhopal

* Corresponding Author: Md Asad Mahfuz

Abstract: *As we know that in the area of temperature minimize zone, high performance heat exchangers are often used to maintain the cooling effect produced. Therefore, there is no liquid return if the efficiency falls below the design value. Due to their high efficiency, low weight and compactness, compact heat exchangers find many applications in HVAC, oil industry, food industry and processing industry. Plate and fin heat exchanger (PFHE) is a type of compact heat exchanger manufactured by welding a stack of alternating plates (separators) and corrugated fins. Heat exchange occurs through flows that pass through the fins. Generally, aluminum is used to produce PFHE due to its high thermal conductivity and low cost. In the finned heat exchanger, not only the efficiency but also the pressure drop is measured. The increased pressure gradient can be compensated for by reducing the channel length to achieve an acceptable pressure drop. Many research works are carried out to recognize the heat transfer phenomena and also to determine the dimensionless heat transfer coefficients, namely Colburn factor (j) and friction factor (f). This thesis on offset fin plate heat exchangers compares the efficiency, overall thermal conductivity and pressure drop obtained from experimental data with some correlations in plate heat exchangers.*

Keywords: *HVAC, Heat exchanger, plate and pin fins, CFD, thermal conductivity, Heat transfer rate.*

I. INTRODUCTION

A heat exchanger is a device by which thermal energy or enthalpy is transferred between two or more fluids having different temperatures and which are also in thermal contact with each other. The enthalpy can transfer between two or more fluids, between fluid and solid particulates and between fluid and a solid surface which are in thermal contact with each other. Usually in heat exchangers there is no work interaction. The heat exchangers are also adiabatically insulated, so no heat transfer takes place. The cooling and heating of a fluid, condensation of a single or multi- compound fluid, evaporation of a single or multi-compound fluid are the main applications of the heat exchanger. Generally, high effectiveness heat exchangers are used in cryogenic applications. The effectiveness of heat exchangers used in liquefiers is of the order of .96 and above. There will be no liquid yield if the effectiveness of the heat exchangers falls below the design value. But in case of the use of heat exchangers in aircrafts, high effectiveness and performance is not so required rather the aim is to keep the weight and volume of the heat exchanger minimum. These requirements of low volume and weight of the heat exchanger lead to the generation of compact heat exchangers. In general Compact heat exchangers have large surface area density i.e. large surface area to volume ratio which is of the order 700 m2/m3or greater than this value for gas and it should be 300 m2/m3for two-phase streams and liquids.

A. Plate fin heat exchangers

Plate fin heat exchangers are the type of heat exchangers having triangular or rectangular corrugated fins, with the parting sheets or plates (spacers) sandwiched between the parallel plates. The plates and fins separate the two fluid streams from each flow passages. Two or more fluid sides can be formed in the heat exchangers by the connection of the alternative fluid passage using suitable headers. That means it is a stack of parting sheets placed alternatively and the corrugated plate fins brazed collectively in a single block. Since the flow of the passage is through the parting sheets which is controlled by the fins causes the heat transfer between the fluid streams.

These fins are formed by the process of rolling or by using a die. The metal joining processes such as welding, brazing, soldering, extrusion etc. are used to attach the fins to the plates. The fins may be used on both sides in case of the gas-to-gas heat exchangers, but fins are usually used on the gas side only in case of the gas-to- liquid heat exchangers. The fins those are employed on the liquid side are used for flow mixing process and also give structural strength. The plate fin heat exchangers are also known as Matrix heat exchangers in Europe. The plate fin heat exchangers have the advantage of high effectiveness, low weight, compactness and moderate cost.

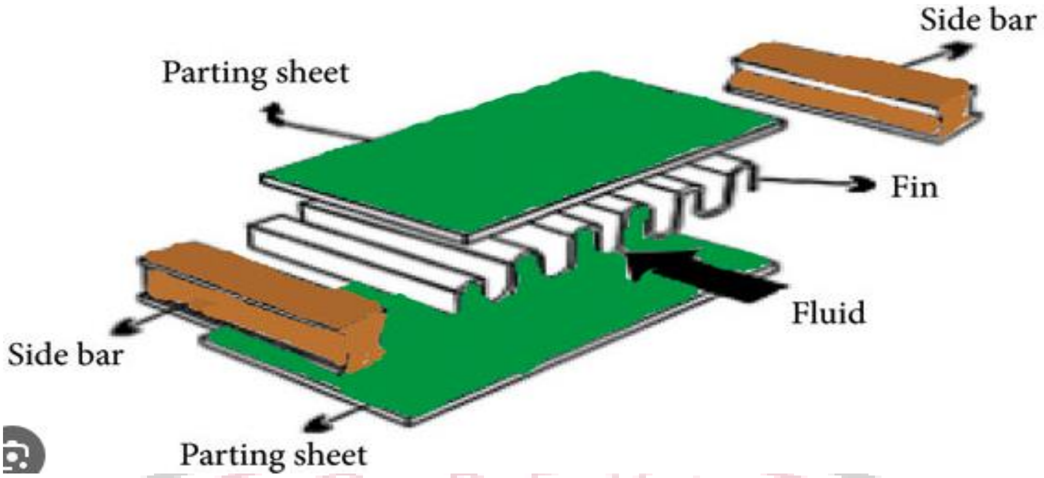

Figure 1. A stack of fins placed between the parting sheets

The separating plate and the fins in the plate fin heat exchangers act as the primary and secondary heat transfer surfaces respectively. The spilling over of the fluid to the outside is prevented by the side bar of the plate fin heat exchangers. The side bars and fins are brazed to the parting sheets for providing mechanical stability and also to provide a good thermal link. A clear view of a compact plate fin heat exchanger with two layers is shown in figure 2.

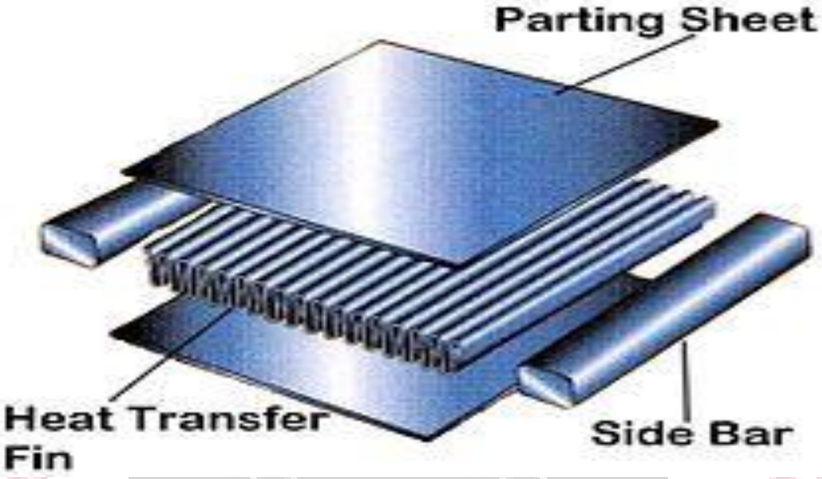

Figure 2. The assembly details of a plate fin heat exchanger

The compact plate fin heat exchangers can be divided into various types depending on their fin structures. Some fin types are:

1. Triangular or rectangular cross-section plate fins (straight and uncut fins)
2. Wavy fins.

Various types of interrupted fins like offset strip fin, perforated fin, louver and pin fin. The strip fins are also known as serrated or segmented fin lance offset fin and offset fin

II. LITERATURE REVIEW

Fehle et al. [1] found the heat transfer behavior of the compact plate fin heat exchanger by applying holographic interferometry. For this, he enabled a non-invasive and inertialess visualization of the temperature field. Then from the constant temperature line at the wall of the temperature field, he determined the local Nusselt number. For determining the effect of corner radii of the heat metal sheets, they first investigated the transfer of heat in plane fin arrangements.

Ranganayakulau et al. [2] analyzed the cross flow plate fin, cross flow tube fin, parallel plate fin and the counter-flow plate fin heat exchangers by taking the effect of heat conduction in the longitudinal direction across the heat exchanger wall by using finite element method. They observed that the performance declination of cross flow type heat exchangers is higher compared to the counter-flow and parallel flow heat exchangers for all the cases. This occurrence of the distribution of temperature is two dimensional.

Sanaye and Hajabdollahi [3] applied ε-NTU method for the thermal modeling of the compact heat exchanger. By applying ε-NTU method, they calculated the effectiveness and the pressure drop of the heat exchanger. The fin pinch, height of the pin, offset length of the fin, flow length of the cold stream, no-flow length and flow length of the hot stream are considered as the six design parameters. They used non-dominated sorting genetic algorithm (NSGA-II) for getting the maximum effectiveness and minimum total yearly cost as two objective functions.

Rao and Patel [4] thermodynamically optimized the cross flow PFHE by using particle swarm optimization (PSO). The reduction of entropy generation for a given space restriction for specific heat duty, reduction of total volume and reduction of total unwanted cost are the basic objective functions, which are treated individually.

Hajabdollahi at el. [5] presented a thermal model and optimally designed a compact heat exchanger. Fin pitch, the height of the fin, flow length of the cold stream, no-flow length and flow length of the hot stream are the five deign parameters. By using CFD analysis along with ANN (Artificial Neural Network), they developed a relation between the Colburn factor (J) and Fanning friction factor (f).

Zhang et al. [6] examined evaporative mist pre-cooling, deluge cooling and combined cooling schemes for enhancing the performance of the heat exchanger.

Pingaud et al. [7] performed both the steady state simulation and the dynamic simulation of the plate fin exchanger. By using the modeling based on mass balance, momentum balance and energy balance, they developed an algorithm for multi-fluid and multi passage PFHEs for both the transient and steady-state simulations. For treating the counter current flow and for solving the model equations involving the partial differentiation, they adopted an integration scheme which is implicit in nature.

Menzel and Hecht [8] found that the heat exchanger performance decreases by the slog flow reversal, two-phase up-flow in PFHEs and they liquid logging involved in the heat exchanger surfaces. So, they adopted a special care by selecting wide boiling range fluid mixtures which evaporates at high NTU values at relatively low gas fluxes. Flow condition of non- refluxes needs a large gas mass flux, thus a higher pressure drop.

Dubrovsky [9] investigated a new convective heat transfer augmentation law for PFHE surfaces. This is characterized by (ζ/ζsm)≤(Nu/Nusm) with the comparison to the vortex promoted heat transfer surfaces having an equal small channel at the same Reynolds numbers.

Ranganayakulau et al. [10] analyzed the effect of non-uniform flow distribution of two- dimensional inlet fluids of both the cold and hot sides of the fluid in a cross-flow PFHE using finite element method. They developed mathematical equations for different mal-distribution models for various types of fluid flow, for the effectiveness of the exchanger and its declination due to the flow non-uniformity for all ranges of design and operating conditions.

III. EXPERIMENTAL SET-UP AND OPERATIONS

The experimental setup includes the heat exchanger core, the air supply system, the heating unit, and the measurement/instrumentation system, as shown in Figure 13. In the experiment, the liquids flow in the countercurrent direction. The working environment for this experiment is air. A screw compressor is used to continuously supply dry air to the fin heat exchanger. A control valve is used to regulate the flow. Cold air is blown to the bottom of the heat exchanger. As cold air circulates through the heat exchanger, it is heated by transferring heat from hot air to cold air. The air then leaves the heat exchanger and is heated as it passes through the heating unit. Here, the hot air coming out of the radiator is directed from above to the heat exchanger. At the hot air inlet, e.g. H. At the hot air inlet, a valve is used to control the mass flow of hot air. If the two liquids have the same mass flow rate, the bypass valve closes.

The inlet and outlet pressure of hot and cold liquids is measured using manometers. To measure the pressure drop in the heat exchanger, pressure measurement points before and after the heat exchanger are used. The U-shaped pressure gauge connected to the pressure tap indicates the pressure drop. RTDs (resistance temperature detectors) are used to measure the inlet and outlet temperatures of fluids.

A rotameter is installed at the outlet of the heat exchanger to measure the flow and achieve balanced flow. Orifice meters are used to measure the flow of hot and cold liquids when the flow is unbalanced. The rotameter is also used to calibrate the aperture if necessary.

To prevent heat loss from the system to the environment, the test section is completely insulated with expanded polystyrene panels or a thermocouple and glass wool. A resistance temperature detector is installed on the outer surface of the insulation to display the temperature difference. Heat loss to the environment can be calculated from this temperature difference.

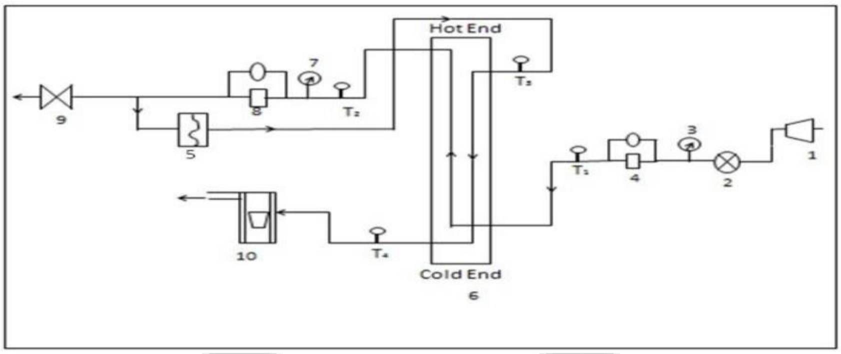

Figure 3. Schematic diagram showing Piping &Instrumentation of the experimental test rig

Table 1. Components shown in the Piping &Instrumentation of the experimental test rig

1-Compressor	2-Control Valve	3, 7- Pressure Taps
4, 8- U-tube manometer	5- Heater	6- Test Section
T_1, T_2, T_3, T_4 are RTDs	9- Bypass Valve	10- Flowmeter

The volumetric flow rate of the liquid passing through the test section is set to the desired value and this flow rate can be measured with a rotameter connected to the outlet of the heat exchanger in balanced state. Initially, the Variac value is set to a low value and then gradually increased depending on the hot inlet temperature. By regulating the power of the Variac, the temperature of the hot air entering the heat exchanger is maintained at the desired temperature. This system can operate until the study status is reached. RTDs are then used to measure the inlet and outlet temperatures of the two fluids. The U-tube mercury manometer is used to measure the pressure drops of two liquids.

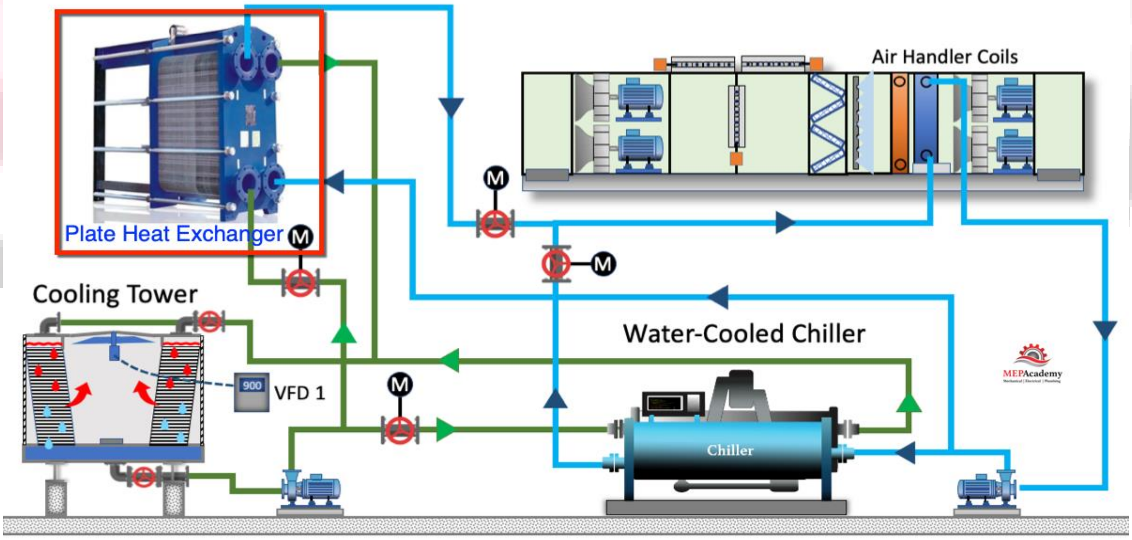

Figure 4. Picture of the experimental set-up.

- Web Information Integration and Schema Matching: The Web is filled with data, yet each website (or even page) displays the same data differently. Finding or matching data that is semantically similar is a significant issue with several practical applications.
- Extracting opinions from internet sources: There are various places to find opinions online, including forums, blogs, chat rooms, and consumer reviews of goods. For marketing intelligence and product benchmarking, mining opinions is crucial.
- Synthesis of knowledge: Concept hierarchies or ontologies are helpful in a variety of applications. However, manually producing them takes a lot of time. To provide the user with a comprehensive understanding of the issue area, the key application is to organize and synthesize the bits of information found on the web. We'll outline a few current techniques for investigating information redundancy on the web.

- Segmenting Web sites and identifying noise: In many Web applications, one just needs the primary content of the Web page without adverts, navigation links, and copyright notices. It's an intriguing challenge to automatically partition Web pages and extract the key material.

IV. METHODOLOGY

The basic design considerations of a plate fin heat exchanger include:

1. Process & design specifications
2. Hydraulic & thermal design
3. Mechanical designManufa
4. cturing considerations
5. Trade-off factors and system based optimization

In heat exchanger design, the process & problem specification is one of the most important steps. Any specification for process and design procedure counts all the required information for designing and optimizing the exchanger for a particular application. It includes:

- Specification of the problem for operating conditions
- Type of heat exchanger
- Type of flow arrangement
- Materials
- Considerations for design/manufacturing/operation
- Information on the minimum input specifications

The selection of design conditions is the first and important consideration. Then, the next is the off- design and design point condition. The specification for operating conditions and the operating environment should be mentioned which includes:

- Mass flow rates
- Fluid types and their thermos-physical properties
- Inlet temperature & pressure of both fluid streams
- Maximum allowable pressure drop on both fluid sides
- Inlet temperature & pressure fluctuation due to variation in the processor environmental parameters
- Corrosiveness
- Fouling characteristic of fluids and
- Operating environment

V. PERFORMANCE ANALYSIS

The performance parameters of a plate fin heat exchanger mainly include effectiveness, overall thermal conductance & pressure drop. A number of experiments have been performed at different mass flow rates & at different hot fluid inlet temperatures under balance conditions by S. Alur. We have compared these experimentally obtained results with Joshi-Webb correlation, Maiti-Sarangi, Manglik-Bergles correlation and by using CFD analysis.

A. Numerical analysis by CFD

The computational fluid dynamics is used for the prediction of fluid flows & heat transfer using the computation method.

B. Description to the problem & geometry:

In the present thesis, an offset strip fin plate fin heat exchanger is investigated numerically & is compared with the experimentally obtained results.

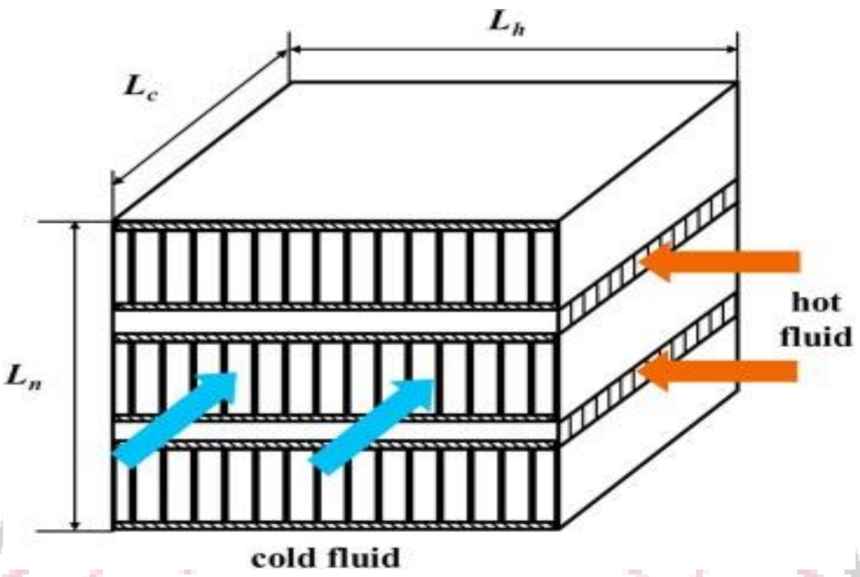

Figure 5. The geometry of the offset fin with the dimensions

V. CONCLUSION

The experimentally obtained results are compared with various correlation results and also with the results obtained from the simulation software of the CFD-fluent. The effectiveness v/s mass flow rate, overall thermal conductance v/s mass flow rate & pressure drop v/s mass flow rate for different hot inlet temperature are evaluated by using the correlations and by using CFD, fluent simulation software. The correlations used for the comparison of the performance parameters with the experimental results are Joshi-Webb correlation, Maiti- Sarangi correlation and Manglik-Bergles correlation. The comparison of the experimental results with the results obtained from the correlations & from the simulation software of Ansys fluent gives.

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