A Review on Plate Fin Heat Exchanger

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Abstract

This review paper presents the advances in plate fin heat exchangers. A considerable amount of experimental as well as numerical and computational research has been carried out on the enhancement of heat transfer and pressure drop characteristics and other parameters. In this review study, a brief survey of the relevant literature is presented to indicate the extent of work already reported in open literature pertaining to the enhancement of heat transfer by introducing protrusions mounted on the heat transfer surfaces. This section deals with the overview of the past work involving the use of various plate fin heat exchangers on different surface geometries i.e. rectangular channel, fin-tube heat exchangers etc.

Keywords – *heat exchangers, pressure drop heat transfer*

I. INTRODUCTION

A plate-fin heat exchanger is a type of heat exchanger design where plates and finned chambers are used to transfer heat between fluids. It is often categorized as a compact heat exchanger because of its high heat transfer surface area to volume ratio. The plate-fin heat exchanger are mainly used in many industries, like aerospace industry for its properties like compact size and lightweight, and also in cryogenics where heat transfer takes place with a small temperature differences. In a plate-fin heat exchanger, the fins can easily be rearranged. Flows like cross flow, counter flow, parallel flow are possible in different application if the fins are designed well, the plate-fin heat exchanger works in a perfect condition in a counter cross arrangement. [1-3]

II. EXPERIMENTAL ANALYSIS

A. *Pressure Drop And Heat Transfer Characteristics*

From the early literature on the experimental analysis of thermal–hydraulic performance of Copper–water nanofluid flow in different plate-fin channels presented by M. Khoshvaght-Aliabadi[4] et al., fabricated and tested a seven plate-fin channels, including plain, perforated, offset strip, louvered, wavy, vortex generator, and pin. The fluid used for testing was copper–water nanofluids. The experimental setup is shown in Fig .1.

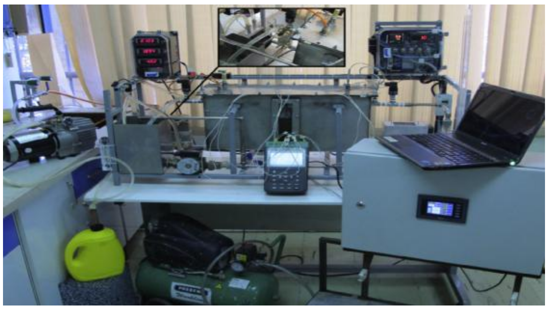


Fig.1 Experimental Setup.

Experimental study on thermal ehydraulic performance of a wavy fin-and-flat tube aluminium heat exchanger presented by Junqi Dong [5] et al., in this experimental investigation a 16 samples with different geometry parameters were tested and the effects of fin height, fin pitch, fin length, wavy amplitude, and wavy length on the heat transfer and pressure drop were studied.

Experimental and numerical investigation of thermal -hydraulic performance in wavy fin-and-flat tube heat exchangers presented by Junqi Dong [6] et al., experimentally investigated the air flow and heat transfer characteristics over the wavy fin heat exchangers and the results of friction factor and heat transfer performance test data are for fully developed turbulent region of air flow in the wavy fin. José Fernández-Seara[7] et al., investigated on the pressure drop and heat transfer characteristics of a titanium brazed plate-fin heat exchanger with offset strip fins by using firstly water on both sides of the heat exchanger and secondly 10-30 wt% ethylene glycol aqueous solutions as working fluids and both the results were compared. The Experimental Setup is shown in the Fig.2.

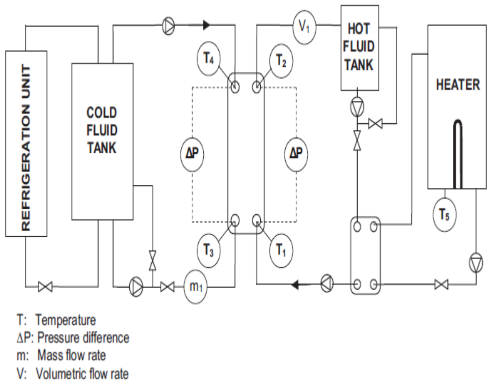
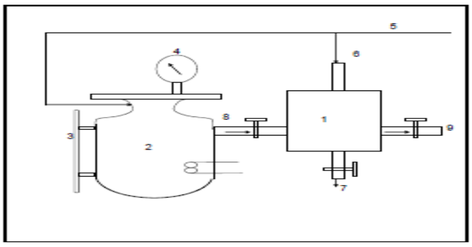


Fig 2. Experimental Setup

Giovanni lozza[8] et al., showed the performance of various fin configurations in air cooled condenser and liquid coolers to enhance the heat transfer capabilities of the devices the results showed louvered fin geometry had the best heat transfer rate but the pressure drop was high. S.M. Pesteei[9] et al., investigated experimentally study of the effect of winglet location on heat transfer enhancement and pressure drop in fin-tube heat exchangers the results showed a reasonable amount of increase in the heat transfer with addition of winglet type vortex generators. Ting Ma[10] et al.,conducted a experimental study on investigation of a novel bayonet tube high temperature heat exchanger with inner and outer fins where the numerical results showed that the inner fins and inner tube both should not be welded together and the mass flow rate and the inlet temperature on the fuel gas side have a reasonable effect on the heat transfer rate and effectiveness, and the pressure drop ratios are mainly affected by the mass flow rate rather than the inlet temperature.

Design and experimental analysis of spiral tube heat exchanger by Jay.J.Bhavsar[11] et al., a spiral tube heat exchanger was fabricated and experimental analyzed and was compared with a shell and tube heat exchanger and the results showed the spiral tube heat exchanger had a better heat transfer rate with a increase in pressure drop compared to shell and tube heat exchanger. Performance analysis of cross flow plate fin heat exchanger for Immiscible system using ANN by M.Thirumarimurugan[12] et al., the results such effectiveness and overall heat transfer were obtained experimentally and simulation results were also obtained by using ANN general regression it showed the predicted results obtained by the ANN approach are close to the experimental results. The experimental setup used for this experiment is shown in Fig.3.



1 Cross flow heat exchanger,
2 Steam generator,
3 Level indicator,
4 Pressure guage,
5 Cold liquid,
6 Cold liquid inlet,
7 Cold liquid outlet,
8 Steam inlet,
9 Steam outlet
.

Fig 3. Experimental Setup

Experimental determination of correlations for mean heat transfer coefficients in plate fin and tube heat exchangers by Dawin taler[13] experimental determined the heat transfer coefficient for a cross flow plate fin and tube heat exchanger and correlation were developed for the this type of heat exchanger the result show increase in heat transfer and as well as increase in pressure drop.

B. Design And Geometrical Consideration

Vaisi[14] et al., carried out an experimental investigation of geometry effects on the performance of a compact louvered heat exchanger in which the results indicated that the configuration of the louvered fins has the dominant influence on the heat transfer and pressure drop from that louver fin. The test setup is shown in Fig.4.

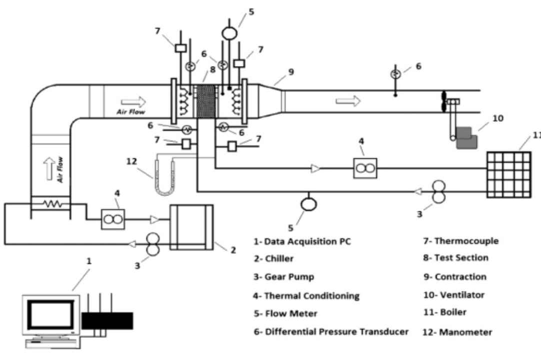


Fig.4. Test Setup

Heat-transfer enhancement in fin-and-tube heat exchanger with improved fin design by Mao-Yu Wena[15] et al., showed the study of use of the compounded fin constructed for heat exchanger. Results of the compounded fin had an increase in heat transfer and pressure drop, f factor and j factor compared to the flat fin heat transfer coefficient. The experimental setup is shown in the Fig.5.

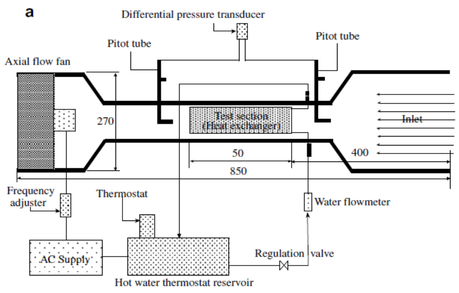


Fig.5.Experimental Setup

Role of channel shape on performance of plate-fin heat exchangers. Experimental assessment by M. Khoshvaght-Aliabadi[16] et al., carried out a comparison study on seven common configurations of channels used in plate-fin heat exchangers .All the channels, including plain, perforated, offset strip, louvered, wavy, vortex-generator, and pin, were fabricated and tested experimentally. The working fluid was water. The results showed that the vortex-generator channel has a significant enhancement in the heat transfer coefficient and a proper reduction in the heat exchanger surface area.

An experimental investigation of heat transfer and friction losses of interrupted and wavy fins for fin and tube for fin and tube heat exchanger by Giovanni lozza[17] et al., conducted an experimental study on a pin fin heat exchanger used in air cooled and liquid cooler condensers with different fin configuration like flat, wavy and louvered fins. All the fins geometries were compared by experimental data and the results showed a better heat transfer and pressure drop enhancement when louvered fins compared to flat and wavy fins. Performance evaluation of wire spring fin for compact plate fin heat exchangers by H.Iwai[18] et al., suggested a usage of thin metal wire structure as a new type of extended heat transfer surface the fin was used in a plate fin heat exchanger at low Reynolds number between 100 to 1000 and heat transfer was evaluated and the result showed a better heat transfer compared a offset fin plate fin heat exchanger. The schematic diagram of the experimental setup is shown below in Fig.6.

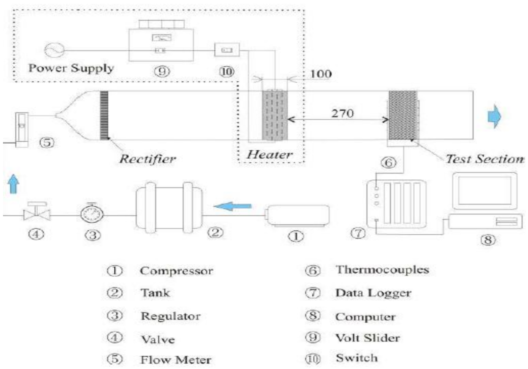


Fig.6. Schematic diagram of Experimental Setup

Yonghan Kim [19] et al., experimental investigated on heat transfer rate of flat plate finned-tube heat exchangers with large fin pitch in this experiment a total of 22 heat exchangers were tested with different fin pitch tube and number of tube rows and tube alignment. The experimental setup is shown in Fig.7. The results showed with the increase in fin pitch and tube row there is a decrease in heat transfer. The decrease in the heat transfer is approximately 10 %.

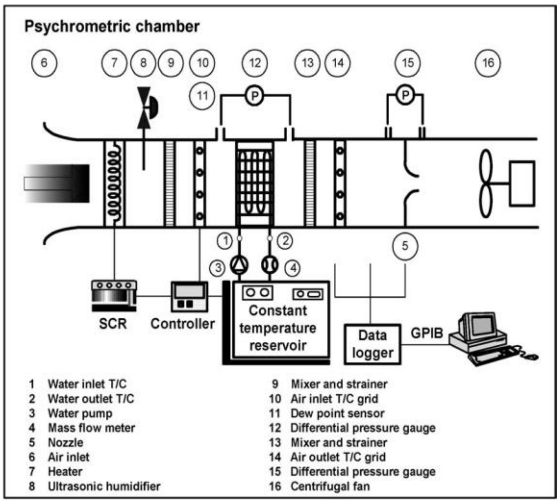


Fig.7. Experimental Setup

Praveen Pandey[20] at el., carried an experimental investigation on the effect of fin pitch on the performance of plate type fins the experiment was conducted for different pitch settings, three types of fins were used for this experiment the experiment was conducted in both free and force convection. And the results show there is increase in heat transfer coefficient with decrease in fin base temperature and there is significant effect on the performance of heat exchanger with change in fin pitch. Effect of fin pitches on the optimum heat transfer performance of crimped spiral fin-and-tube heat exchangers by Parinya Pongsoi[21] et al., carried out various experiments to optimize the fin pitch for a crimpled spiral fin and tube heat exchanger. The test setup is shown in Fig.8. The size of the fin was varied from 2.4-6.5 mm. The flow arrangement used is parallel cross flow is combined with counter cross flow in a two row configuration. The results show a low convective heat coefficient at the size 2.4 and the optimum pitch for this experiment is 4.2mm.

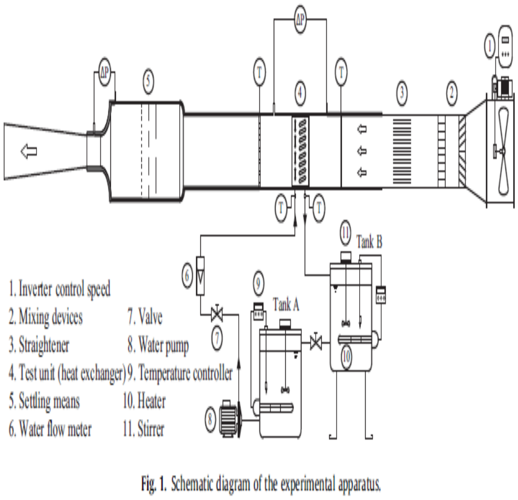


Fig.8. Experimental Setup

Performance investigation of an innovative offset strip fin arrays in compact heat exchangers by Hao Peng[22] et al., carried out experimental investigation with five different set arrays of offset fins with various air velocities with a constant inlet steam pressure. The experimental results indicated that the fin pitch, fin length and fin bending distance have a significant influence on thermal performance of fins. The main conclusion obtained from this work is it will be helpful for future development and design of high-efficiency heat exchangers involving offset strip fin structures.

Effect of fin pitch and number of tube rows on the air side performance of herringbone wavy fin and tube heat exchangers by Somchai Wongwises[23] et al., conducted an experimental study to investigate the effects of a number of tube rows and fin pitch on the air side performance of fin and tube heat exchangers having herringbone wavy fin configuration with various fin thicknesses. The experimental results showed that when the fin pitches changes it affects the heat transfer characteristic. By increasing the fin pitch the friction factor increases when Reynolds number is at 2500. The Colburn factor and the friction factor decreases with increasing number of tube rows when Reynolds number is at 4000 .The results remain the same when the fin thickness is changed.

C. *Flow Patterns*

Sedat Yayla[24] conducted a experimental investigation on flow characteristic of staggered multiple slotted tubes in the passage of a fin tube heat exchanger a particle flow velocimetry (PIV) was used to study the specified flow filed and time averaged flow data was collected and was presented graphical for a fin tube heat exchanger and the result showed a three dimensional and complex flow behaviour in the heat exchanger.

Anjun jiao[25] et al., carried out a experimental analysis on Effects of distributor configuration on flow maldistribution in plate-fin heat exchangers in which the effects of distributor parameters on fluid flow in plate fin heat exchanger was completed experimentally. The results showed that the flow maldistribution plays a significant role in optimizing the structural design and also improve the performance of a plate fin heat exchanger.the experimental setup is shown below Fig.9.

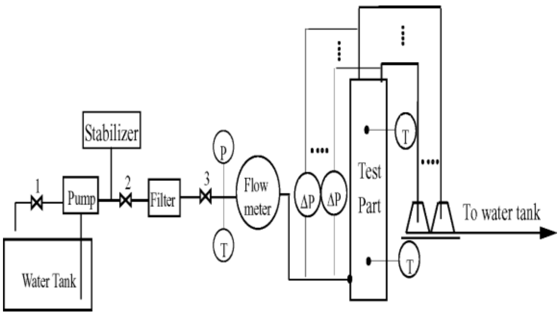


Fig.9. Experimental Setup

Masoud Asadi[26] et al., investigated on the effects of mass flow rate in terms of pressure drop and heat transfer characteristics the results indicated that as the mass flow increases the heat transfer and pressure drop also increases and the optimum mass flow rate depend on the dimensions of the heat exchanger. Experimental investigation of header configuration on flow misdistribution in plate-fin heat exchanger by Anjun Jiao[27] et al., showed that the performance of flow distribution in PFHE is effectively improved by the optimum design of the header configuration.

III. NUMERICAL ANALYSIS

A. *Heat Transfer And Pressure Drop Correlations*

A number of literature surveys have been carried on numerical analysis of plate fin heat exchanger like numerical study by Dong Junqi [28] et al., carried out an investigated on the heat transfer and pressure drop correlations for the wavy fin and flat tube heat exchangers in which the effects of fin pitch, fin height and fin length on the thermal hydraulic performance were examined. K.Thirumalai kannan[29] et al., carried out an investigation on Heat transfer and fluid flow analysis in plate-fin and tube heat exchangers with different shaped vortex generators to study the heat transfer and flow in the plate-fin and tube heat exchangers with different shaped vortex generators mounted behind the tubes with different span angles and varying the Reynolds number. Heat transfer and pressure drop correlations for the multi-louvered fin compact heat exchangers by Junqi Dong[30] et al., investigated an experimental studies on the air side heat transfer and pressure drop characteristics for 20 types of multi-louvered fin and flat tube heat exchangers the result showed that the fin length and fin pitch have significant effects on the heat transfer coefficients and pressure drop as a function of frontal air velocity.

Heat transfer analysis of cylindrical perforated fins in staggered arrangement by Amol B. Dhumne[31] et al., the experiment was carried by varying Reynolds number and other parameters were varied to obtain nusselt number and correlations were developed for heat transfer and friction factor and effectiveness of the heat exchanger and the result showed a increase in heat transfer with increase in pressure drop in the heat exchanger with perforated fins. The experimental setup is shown in Fig.10.

Fig.10. Experimental Setup

Heat transfer and pressure drop characteristics of flat tube and louvered plate fin surfaces by A. Achaichia[32] et al., carried out a numerical analysis where Stanton number and Reynolds number variation were considered the results showed a very low Reynolds number obtained and a non-dimensional correlation was obtained for Stanton number. An equation for friction factor was also obtained, but a dimensional form of the correlation was also found to be necessary for it to retain useful accuracy. Thus the heat transfer rate increases with increase in pressure drop. Performance investigation of plain and finned tube evaporative cooled heat exchangers presented by Ala Hasan [33] et al., in which a model was developed to calculate the performance of plain and finned tubes. As the total area ratio increased, correspondingly the thermal performance increased. The average fin efficiency for this work was calculated to be 43%.

B. Pressure Drop And Heat Transfer Characteristics

Hui Han[34] et al., analysed A numerical study on compact enhanced fin-and-tube heat exchangers with oval and circular tube configurations in which The three kinds of tubes were applied with two types of enhanced fins, wavy fin and louvered fin. The results reveal that using the oval fin-tube can not only reduce the flow resistance but also improve the heat transfer capacity of the heat exchangers which effectively improved the fin efficiency. Numerical investigation of heat transfer and pressure drop characteristics of tube–fin heat exchangers in ice slurry HVAC system presented by S. Kalaiselvam[35] et al., analyzed the heat transfer and pressure drop characteristics of a tube–fin heat exchanger in ice slurry HVAC system. The numerical analysis was conducted by simulating the ice slurry tube flow region and air flow region of tube–fin heat exchanger in the air-handling unit of HVAC system. For the simulation six different louver patterns with 10 to 55 louver angle were considered. The design of the tube–fin heat exchanger for optimal heat transfer and pressure drop characteristics was also determined. Hao Peng[36] et al conducted a numerically analysis on Neural networks analysis of thermal characteristics on plate-fin heat exchangers with limited experimental data. an application of artificial neural networks (ANNs) was presented to predict the pressure drop and heat transfer characteristics in the plate-fin heat exchangers (PFHEs). The predicted values were found to be in good agreement with the actual values from the experiments.

Y.Y Hsieh[37] et al.,conducted an experimental analysis the heat transfer and frictional drop of the ozone friendly refrigerant R-140A flowing through a vertical plate heat exchanger was investigated. The measured data showed that both the boiling heat transfer coefficient and frictional pressure drop increases almost linearly with the imposed heat flux. For the raise of pressure of the refrigerant has a slight influence on the saturated flow boiling heat transfer coefficient. Optimal design of plate-fin heat exchangers by a hybrid evolutionary algorithm by M. Yousefi[38] at el., developed a genetic algorithm hybrid with particle swarm optimization for design of a plate fin heat exchanger seven parameters of a plate fin heat exchanger were considered and higher results were obtained compared to results obtained from GA and PSO Algorithm.

F.S. Javadi[39] et al., numerical investigated on the effects of nanofluid on thermophysical properties and heat transfer characteristics of a plate heat exchanger where nanofluid like SiO_2, TiO_2 and Al_2O_3 were used in the plate heat exchanger and the thermophysical properities and pressure drop across the heat exchanger were analysed. The highest heat transfer coefficient was obtained by Al_2O_3 nanofluid and highest thermo physical properities were obtained by TiO_2 and Al_2O_3 compared to SiO_2 and least pressure was obtained by SiO_2.

A distributed parameter model and its application in optimizing the plate-fin heat exchanger based on the minimum entropy generation by Lina Zhang[40] et al., created a three dimensional distributed parameter model (DPM). The proposed model, allows to vary the fluid thermophysical properties inside the flow path, can be used for both dry and wet working conditions by using the uniform enthalpy equations. The results showed that by application of DPM, the hot fluid outlet temperature of the heat exchanger under wet condition is lower than in dry condition. Ting Ma[41] at el., carried out a numerical analysis on stress analysis of internally finned bayonet tube in a high temperature heat exchanger in which the effects of gap between inner tube and inner fin on the thermal stress and heat transfer performances were compared. The result showed that the gap between the internal fins should be less than 1 mm for bayonet tube with 6 mm annulus height according to the consideration of heat transfer and stress performances.

Ya-Ling He[42] at el., conducted a numerical analysis of heat transfer and pressure drop for fin-and-tube heat exchangers with rectangular winglet-type vortex generators under low reynolds number condition the results showed that the rectangular winglet pairs have a significant improve in the heat transfer performance of the fin and- tube heat exchangers with a moderate increase in pressure loss. Chan Hyeok Jeong[43] at el., conducted a numerical investigation of thermal enhancement of plate fin type heat exchanger with creases and holes in construction machinery proposed a new type of plate fin heat exchanger. The calculated result show that the pressure drop and heat transfer capacity for the new proposed plate fin heat exchanger is higher than the louver fin heat exchanger, the plate fin heat exchanger. Masoud Asadi[44] et al., conducted a numerical analysis on minimizing entropy generation for louvered fins in a plate-fin compact heat exchanger and the work showed that the mass flow rate has a direct effect on the functioning of the heat exchanger so, by optimizing the mass flow rate it not only optimize the costs but also increases the efficiency of the heat exchanger and number of heat transfer units. Thus, the study shows the optimum mass flow rate is obtained based on minimum number of entropy generation.

J.M. Reneaume[45] et al., carried out an investigation on MINLP optimization of plate fin heat exchangers to analysis the company's profit by improving the performance of the plate fin heat exchanger by analyzing the functions such as manufacturing cost, physical volume ,operating and manufacturing constraints and also optimizating the variables including the geometrical fin parameters are by MINLP programming. The results obtained are better compared to the results obtained from other programming algorithm methods like Successive Quadratic Programming (SQP) algorithm, simulated annealing and Branch and Bound (BB) algorithms for the same parameters. P. Teertstra[46] et al., carried out a numerical investigation on the analytical forced convection modelling of plate fin heat sink in this work an analytical modal was developed and average heat transfer rate for the plate fin heat sink was calculated under forced convection. The fluid velocity, nusselt number and geometry were calculated by the modal purposed and the resulted modal was applicable for the Reynolds number range from 0.1 to 100.

Ehsan Khorasani Nejad[47] et al., conducted a numerical investigation on modelling and second law based optimization of plate fin and tube heat exchanger using MOPSO in this study a program was developed to estimate the heat exchanger pressure drop and effectiveness and to scientifically study the design parameters such as longitudinal pitch, transversal pitch, fin pitch, number of tube pass, tube diameter, cold stream flow length, no-flow length and hot stream flow length. Finite element analysis of the effect of brazed residual stress on creep for stainless steel plate-fin structure by Wen-Chun Jiang[48] et al., in this investigation were carried under two conditions firstly a creep analysis at the internal operating pressure was carried out and secondly the creep analysis was carried out considering the internal operating pressure in conjunction with as-brazed residual stress. The results showed that due to the mechanical property mismatch between filler metal and base metal, large amount of stress was generated in the brazed joint, which had a great influence on creep for stainless steel plate-fin structure. The overall creep strain and stress distribution of plate-fin structure was obtained.

C. Design And Material Consideration

Numerical study of the fin efficiency and a modified fin efficiency formula for flat tube bank fin heat exchanger presented by Ke-Wei Song[49] et al., showed that the difference between the fin efficiency obtained by the numerical method using the local heat transfer coefficient and the fin efficiency using the averaged heat transfer coefficient is small, but the fin efficiency obtained by the generally used formula is lower than that obtained by the numerical method using the local heat transfer coefficient; the fin efficiency obtained by the modified formula matches very well with the fin efficiency obtained by the numerical method using the local heat transfer coefficient. Air side heat transfer coefficients of discrete plate finned-tube heat exchangers with large fin pitch presented by Jong Min Choi[50] investigated on the heat transfer characteristics of discrete plate finned-tube heat exchangers with large fin pitches. Thirty-four heat exchangers were tested with variations of fin pitches, the number of tube rows, fin alignment, and vertical fin space.

Numerical investigation of thermal enhancement of plate fin type heat exchanger with creases and holes in construction machinery presented by Chan Hyeok Jeong[51] et al., developed a new shape of plate fin heat exchanger by applying ceases and holes on the plate fin, the louver fin were used. Experimental investigation on the airside performance of fin-and-tube heat exchangers having herringbone wave fins and proposal of a new heat transfer and pressure drop correlation by Nae-Hyun Kim[52] et al., a fin and tube heat exchanger having herringbone wave fin was experimentally investigated 18 samples with different fin pitches were examined with waffle depth and corrugated angle of the fin the existing correlation failed to predict the present data so a new correlation was suggested. The schematic drawing of the experimental setup is shown in Fig.11.

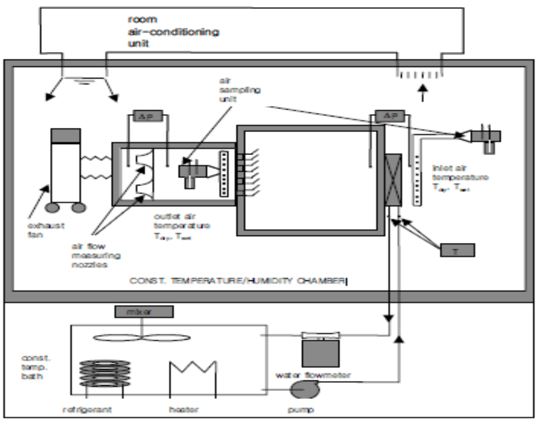


Fig.11. Schematic Drawing of Experimental Setup.

Gandhi Penumuchu[101] et al., made a Numerical and analytical investigation on temperature distributions across different fins of different lengths. And by repeating this process for different materials with different thermal properties and the thermal parameters were varied for these materials and their temperature distribution was analyzed. Here pin fin having 20 mm diameter and 200 mm length was considered for evaluation (l>>d).

Kenan Yakut[53] et al., carried out an experimental investigated on Optimum design-parameters of a heat exchanger having hexagonal fins in which the effects of change in the heights and widths the hexagonal fins and span wise and stream wise distance between the fins pressure drop and heat transfer was determined using Taguchi experimental-design method. The optimum height = 150mm, width = 14mm, span wise and stream wise distance between the fins = 20 mm and flow velocity = 4 m/sec were obtained.

Natural convection heat transfer from horizontal and slightly inclined plate-fin heat sinks by Ilker Tari[54] at el., carried out numerical investigation by both horizontal and slightly inclined from horizontal orientations of the plate fin heat exchange with the inclination angles of 60^0,75^0, 80^0,85^0 and 90^0 from the vertical. A set of correlations were obtained and suggested for both upward and downward facing horizontal cases as result. Hossein Zarea[55] at el., numerically investigated on optimal design of plate-fin heat exchangers by a Bees Algorithm various parameters were considered and a bees algorithm was developed and The results showed that the Bee Algorithm (BA) has a optimum configuration with higher accuracy in comparison with Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Imperialist Competitive Algorithm (ICA) and preliminary design. Numerical simulation of performance augmentation in a plate fin heat exchanger using winglet type vortex generators by Amin Ebrahimi[56] at el., carried out a performance evaluation of the parameters in the laminar flow region with regards to the increase in heat transfer using winglet type vortex generators in a plate fin heat exchanger. Two different type vortex generators were compared in plate heat exchanger one is the rectangular winglet type vortex generator and other is the delta winglet type vortex generator. The result showed a increase in heat transfer and pressure drop in rectangular winglet type vortex generator compared to delta winglet type vortex generator in plate fin heat exchanger.

Mathematical modelling of a multi-stream brazed aluminum plate fin heat exchanger by Ahmed A. Kohil[57] et al., created mathematical model that could evaluate the performance of the heat exchanger by calculating the outlet temperatures of the hot and cold streams when the inlet conditions are known. The model was validated by comparing the results with actual operating values and showed a good validity. Sensitivity analysis was carried out on the model that too showed a good validity. Thermal design algorithm of three stream plate and frame heat with two thermal communications by P.Narataruksa[58] et al., developed a algorithm to propose a new design for the heat exchanger the system consists of one hot stream and two cold stream six port plates are used in this new structure and a thermal mythology has been developed to reduce the number of channels and pinch analysis is carried out to determine the heat recovered in the streams.

A three-dimensional numerical study and comparison between the air side model and the air/water side model of a plain fin-and-tube heat exchanger by R. Borrajo-Peláez[59] et al., numerically investigated on the influence of parameters like Reynolds number, fin pitch, tube diameter, fin length, fin thickness on heat transfer and performance of this type of plate fin heat exchanger. The results from the improved model showed more real temperature contours compared to similar modal and gave more accurate results. R.V. Rao[60] et al., conducted a numerical analysis on the thermodynamic optimization of cross flow plate-fin heat exchanger using a particle swarm optimization algorithm in this work the optimization of parameters like heat exchanger length, fin frequency, numbers of fin layers, lance length of fin, fin height and fin thickness and different flow length of the heat exchanger are carried out and two application examples are also presented to show the effectiveness and accuracy of the proposed algorithm. The results of optimization using PSO are compared with the results obtained by using genetic algorithm (GA) and validated. Parametric analysis is also carried out to demonstrate the effect of heat exchanger dimensions on the optimum solution.

S. G. Kandlikar[61] carried out a proposed a model for Correlating flow boiling heat transfer in augmented tubes and compact Evaporators the correlation results suggest there are augmentation factors which are found to be the tube geometry but independent of the refrigerant or operating conditions over the range of parameters investigated. Ertan Buyruk[62] et al., conducted a numerical investigation into heat transfer for three-dimensional plate fin heat exchangers with fins placed perpendicular to flow in this study rectangular fins with an angle of 30o and 60^{o} with a offset of 10mm from the horizontal direction perpendicular to flow for heat transfer enhancement in a plate fin heat exchanger was calculated theoretically with the use of a conjugated heat transfer approach. The rectangular fins are mounted on a flat plate channel. The results show that heat transfer is increased in the channel with a fin angle of 60^{o} when compared to the channel without fins and fin angle of 30^{0}. Nilesh K. Patil[63] et al., conducted a numerical investigation on effect of operating parameters on plate fin heat exchanger in this study a MATLAB program was developed under steady state condition for the core dimensions of a plate fin cross flow heat exchanger. Parameters of design such as surface areas, free flow areas, exchanger core size were calculated for the given operating condition parameters of cross flow plate fin heat exchanger. The effectiveness varied from 0.8 to 0.9 for different operating condition parameters.

Jiin-Yuh Jang[64] et al., carried out a study on optimization of the span angle and location of vortex generators in a plate-fin and tube heat exchanger in this study the characteristics of a 3-D laminar inclined and staggered plate-fin and tube heat exchangers with block type vortex generators mounted behind the tubes were investigated and the optimization of the span angle and the transverse location were done numerically and the results show that the area reduction ratio is maximized. Numerical model on frost height of round plate fin used for outdoor heat exchanger of mobile electric heat pumps by Moo-Yeon Lee [65] purposed a numerical model to predict the frost growth on the round plate fin of the round plate fin- tube heat exchanger under frosting conditions. The frost growth is calculated by considering the frost density change with time and the result had a good agreement with the compared experimental data. Praful Date [66] et al., carried out a review on heat transfer enhancement in fin and tube heat exchanger and proposed a novel approach towards the heat transfer enhancement of plate and fin heat exchanger by improving fin design facilitating the vortex generation. The vortex generator can be placed on the plane fin at a low cost without effecting the original design and setup of the heat exchangers. Due to this modification the result show a increase in heat transfer and performance of the plate fin heat exchanger. Development of structural design procedure of plate-fin heat exchanger for HTGR by Yorikata Mizokami[67] et al., proposed a new structural design as this heat exchanger required is fabricated by brazing a lot of fins and plates together it requires a region with temperature around $950^{o.}$ The structural design is developed by homogenization FEM modelling and the new structural design is proposed as per the HTGR required criteria.

IV. SIMULATION ANALYSIS

A. Pressure Drop And Heat Transfer Characteristics

A number of research have carried out number simulation for different fin geometry for a plate fin heat exchanger and varying the parameters such as Reynolds number and overall heat transfer coefficient in the similar way Evaluation of elliptical finned-tube heat exchanger performance using CFD and response surface methodology by Lei Sun[68] et al., proposed a numerical model to simultaneously predict the fluid flow and heat transfer on both airside and water-side of elliptical FTHE. Surface analysis was used to evaluate the axis ratio effect on the overall thermal hydraulic performance which was quantified by the heat transfer rate per unit power consumption. The results indicate that the axis ratio strongly interacts with air velocity and water volumetric flow rate. The increase of axis ratio improves the overall thermal hydraulic performance
analysis of heat transfer and pressure drop characteristics in an offset strip fin heat exchanger by H. Bhowmik [69] et al., conducted a steady-state three-dimensional numerical model was used to study the heat transfer and pressure drop characteristics of an offset strip fin heat exchanger. Water was the heat transfer medium, and the Reynolds number Redh ranged from 10 to 3500. Variations in the Fanning

friction factor f and the Colburn heat transfer factor j relative to Redh were observed. Effect of geometrical parameters on heat transfer and pressure drop characteristics of plate fin and tube heat exchangers by Aytunc¸ Erek [70] et al., investigated the influences of the changes in fin geometry on heat transfer and pressure drop of a plate fin and tube heat exchanger are investigated, numerically. A computational fluid dynamics (CFD) program called Fluent is used in the analysis. The segment of one tenth of fin is used in the modelling, due to symmetrical condition. The results of heat transfer, static, and total pressure drop values of ten different fins are tabulated and the normalized values of them are, also, given for the comparison of the models. The distance between fins is found to have a considerable effect on pressure drop.

3-D Numerical study on the correlation between variable inclined fin angles and thermal behaviour in plate fin-tube heat exchanger presented by Hacı Mehmet Sahin[71] et al., investigated the heat transfer enhancement and pressure drop values of seven different fin angles with plain fin-tube heat exchangers by using a three dimensional (3-D) numerical computation technique. The heat transfer and pressure drop values of the vertical fin angle (h = 0) were provided to compare with variable inclined fin angles (h = 5, 10, 15, 20, 25, 30). The heat transfer values were normalized to compare all cases. For inclined fin angle h = 30 which is the optimum angle, the maximum heat transfer enhancement per segment was obtained. Ahmed F. Khudheyer[72] et al., conducted a numerical analysis of fin-tube plate heat exchanger by using CFD technique a three dimensional model was created and the heat transfer and pressure drop characteristics were investigated by varying the Reynolds number from 330 to 7000. The result showed a reasonable agreement between the obtained experimental and simulation data.

A numerical investigation of heat transfer enhancement in offset strip fin heat exchangers in self-sustained oscillatory flows by Arash Saidi[73] et al., in this study an analysis based on the two dimensional governing equations of the fluid flow and heat transfer with the use of computational fluid dynamics methods in a Unsteady calculations was carried out. The obtained results were compared with previous numerical and experimental results. Weiping Wang[74] et al., conducted a simulation analysis on hydrodynamic characteristics of plate-fin heat exchanger using porous media approach numerical plate-fin heat exchanger a model was proposed to investigate .The effects of the fluid dynamic viscosity and perforated fins on flow distribution and pressure drop of the plate fin heat exchanger were studied. The results showed that flow distribution of the plate fin heat exchanger was improved by increasing the fluid dynamic viscosity and adding perforated fins in each fin channel, but at the cost of an increased pressure drop. Design of six step dual tube heat exchanger to implement cold testing of PFHX by Ajay Kumar Gupta[75] et al.,in this work the LMDT method was used to estimate the length and number of tubes for the heat exchanger and simulation was carried out using CFD and the results were validated. The results showed that there was a low pressure across the inlet and outlet of the heat exchanger and a high performance coefficient was obtained.

Numerical Analysis of Tube-Fin Heat Exchanger using Fluent by M. V. Ghori[76] et al., carried out a simulation work using software fluent a three dimensional modal was developed and the Reynolds number was varied from 330-1000 and the heat transfer and pressure drop were obtained. The results showed a reasonable agreement with the experimental results. Jin Gi Paeng[77] et al., carried out a simulation work on experimental measurement and numerical computation of the air side convective heat transfer coefficients in a plate fin-tube heat exchanger in this work the forced convective heat transfer were obtained by varying the Reynolds number based on the diameter of the pipe and maximum velocity. The nusselt numbers were obtained by varying the Reynolds number for same range by using CFD software. There were some errors obtained between the experimental and simulation results. Offset-Strip Fin Heat Exchangers A Conceptual Review Study by Alok Vyas[78] et al. conducted,a review on the 2D and 3D simulation analysis on offset-strip fin heat exchanger in the last few years and predicted the heat transfer and pressure drop characteristics of the offset-strip plate fin heat exchanger.

Heat transfer augmentation in plate finned tube heat exchangers with vortex generators: a comparison of round and flat tubes by M. Mirzaei[79] et al., conducted a numerical analysis on a finned tube heat exchanger with vortex generators to determine the heat transfer and pressure drop due to the addition of the vortex generators and a three dimensional simulation were carried out by varying the Reynolds number from 600- 4050. The various parameters were also calculated such as nusselt number and effectiveness of the heat exchanger. The results showed that the performance of the heat exchanger increased by addition of the vortex generators.

The thermal resistance of pin fin heat sinks in transverse flow by Sukhvinder Kang[80] et al., carried out a three dimensional simulation using CFD. A modal of two building blocks are created in CFD and the effects of thermal wake function and the adiabatic heat transfer coefficient were analysed. The simulation results were validated with experimental results. A numerical and experimental analysis of heat transfer in a wavy fin-and-tube heat exchanger by Igor Wolf[81] et al., in this work a heat exchanger was studied with three rows of circular tubes in a staggered arrangement. Using CFD software based on control volume numerical method a three dimensional steady-state fluid flow and heat transfer mathematical model was solved. The simulation results were compared with numerical and experimental results and found a good compatibility between them.

B. Flow Patterns

Jian Wen[82] et al., conducted a simulation analysis on an experimental and numerical investigation of flow patterns in the entrance of plate-fin heat exchanger in which the turbulent flow structure inside the entrance of plate-fin heat exchanger was characterized by CFD simulation and PIV experiment under the similar conditions. CFD results and PIV data are in good agreement with each other. Anupam Sinha[83] et al., conducted simulation on effects of different orientations of winglet arrays on the performance of plate-fin heat exchangers in this simulation five different strategic placements of the VG, namely, common-flow up in series (CFU–CFU), common-flow down in series (CFD–CFD), combined (CFD–CFU), inline rows of winglet (IRW) and staggered rows of winglet (SRW) were analysed . Results show that amongst the different types of arrangements of the VG, performance of CFU–CFU configuration is best in terms of heat transfer as well as quality factor. Experimental distribution of phases and pressure drop in a two-phase offset strip fin type compact heat exchanger presented by Selma Ben Saad[84] et al., carried out a simulation first, on a single-phase flow .A correlation for friction factor was derived from experiments covering laminar, transition and turbulent regimes. CFD simulations of the single-phase flow were performed. The numerical results were compared with the determined correlation and with correlations available in the literature. In single-phase flow, a uniform distribution was experimentally observed. .

L. Sheik Ismail[85] et al., carried out an simulation study on Studies on pumping power in terms of pressure drop and heat transfer characteristics of compact plate-fin heat exchangers review focuses on the research and developments of compact offset and wavy plate-fin heat exchangers. The review is summarized under three major sections. They are offset fin characteristics, wavy fin characteristics and non-uniformity of the inlet fluid flow. The various research aspects relating to internal single phase flow studied in offset and wavy fins by the researchers are compared and summarized.CFD simulation on inlet configuration of plate-fin heat exchangers presented by Zhe Zhang[86] et al., developed a computational fluid dynamics (CFD) program FLUENT has been used to predict the fluid flow distribution in plate-fin heat exchangers. It is found that the flow maldistribution is very serious in the y direction of header for the conventional header used in industry. The results of flow maldistribution are presented for a plate-fin heat exchanger, which is simulated according to the configuration of the plate-fin heat exchanger currently used in industry. The numerical prediction shows a good agreement with experimental measurement.

Numerical study of 3D thermal and hydraulic characteristics of wavy fin and tube heat exchanger by Arafat A. Bhuiyana[87] et al., in this work a air-side performance of a wavy fin-and-tube heat exchanger having 4 row configurations was analyzed using CFD considering the condition s of steady state, incompressible 3D flow results are presented in the form of friction factor Colburn factor and efficiency. The numerical results were validated by comparing with published experimental results and were found to be good.

C. Design And Geometrical Consideration

An innovative ceramic high temperature plate-fin heat exchanger for EFCC processes by Jan Schulte-Fischedick [88] et al., proposed, a heat exchanger applications based on the ‘‘Offset Strip Fin’’ design for the Need in extreme operation temperatures such as in the field of power generation or heat recovery a ceramic plate-fin heat exchanger. W.K. Ding[89] presented on the topic A general simulation model for performance prediction of plate fin-and-tube heat exchanger with complex circuit configuration in which a circuit data structure (circuit connection network) for a general description of different circuit configurations in computer programs .On basis of this data structure, a general tube-by-tube simulation model and the corresponding code for prediction of plate fin-and-tube heat exchanger performance were developed. The code can be applied to any complex circuit configuration, and also has great flexibility in simulation of heat exchanger with different fin structures, tube types, and various refrigerants under both dry and wet conditions.

Hydraulic and thermal performances of a novel configuration of high temperature ceramic plate-fin heat exchanger by Vijaisri Nagarajan[90] et al., developed a novel fin configuration for high temperature ceramic plate-fin heat exchanger using the three-dimensional computational fluid dynamics FLUENT code.. The working fluids used in the model were sulfur trioxide, sulfur dioxide, oxygen and water vapour. The parameters like Fluid flow, heat transfer, pressure drop and properties like Nusselt number, friction factor and j-factor were analyzed and studied. The simulation result was compared with the analytical result for all the fins and they were found to be in reasonable agreement. Effects of plate finned heat exchanger parameters on the adsorption chiller performance by Mehdi Mahdavikhah[91] et al., in this work the performance of an adsorption chiller working with water and the composite sorbent SWS-1L was evaluated. A three-dimensional non-equilibrium numerical model describing the combined heat and mass transfer with plate fins was presented. Flow patterns and pressure distributions though out the bed were analyzed for all cycle phases. It was found that the geometric specifications of the adsorption heat exchanger were of great practical importance in designing. A numerical investigation of the geometric effects on the performance of plate finned-tube heat exchanger by Chi-Wen Lu[92] et al., in this study the effects geometrical parameters like fin pitch, tube pitch, fin thickness, and tube diameter were analyzed and the simulation indicates that the performance increases with longitudinal tube pitch and decreases with larger fin thickness or tube diameter.

Simulation of heat transfer enhancement by longitudinal vortex generators in dimple heat exchangers by H.H. Xia[93] et al., a three dimensional modal was created to analyse the flow and heat transfer between longitudinal vortex generators and dimple type plate fin heat exchanger. The nusselt number and friction coefficient were obtained for various Reynolds number. The results show that the performance of the longitudinal vortex generators is greater than the dimple structure in similar flow characteristics. S.K.Rout[94] et al., carried out a simulation work on CFD supported performance estimation of an internally finned tube heat exchanger under mixed convection flow in this work the numerical analysis has been carried by finite element analysis method. The parametric study is carried out using CFD to estimate the performance of the heat exchanger with different shape and size. The results obtained from the study for a steady and laminar flow of fluid under mixed flow convection heat transfer condition shows that there was a minimum wall temperature maintained due to the presence of the fins and the wall temperature is minimum for triangular shaped fins compared to rectangular and T-shaped fins. Hiromu Kobori[95] et al., conducted a simulation analysis on thermal stress simulation of ultrafine plate-fin structures using a homogenization theory in this work the thermal stress in ultrafine plate-fin structures was subjected to a macroscopic temperature increment is simulated macroscopically and microscopically, using a homogenization theory for thermo-elasto-viscoplasticity. The material used for making this heat exchanger Ni-based alloy. The results showed that the higher the macroscopic temperature rate, the higher will be the thermal stress. Moreover, it was seen that the stress concentration occurs at joint regions between plates and brazing parts.

Investigation of fin corrugation effect at plate-fin heat exchanger by Frantisek Lemfeld[96] et al., in this simulation work two different shapes of fins like sinusoidal and angular were compared the fins were analysed by varying the Reynolds number. The cooling effects of both the fins were compared and sinusoidal fins were found to be effective. CFD-based Analysis of Heat Transfer and Flow Pattern in Plate-Fin Micro Heat Exchangers by Osamu Tonomura[97] et al., proposed a new design for plate fin heat exchanger which were micro in size and were named as micro heat exchangers. Different materials were used such as copper, glass and stainless steel. A simulation was carried out and the results suggested that glass and stainless steel have a higher heat transfer efficiency compared to copper. Naveen Kumar [98] et al., conducted a simulation analysis on heat enhance by plate fin heat exchanger with triangular fins using fluent as the CFD tool and gambit as the pre-processor in this work a model of the triangular winglet in the plate fin heat exchanger was developed in gambit and a simulation analysis was carried by using CFD fluent and the results were obtained for a constant Reynolds number of 200. The triangular winglet angel is maintained at an angle of 45^0. The results showed that the heat transfer decreases with placing the triangular winglet away from the inlet and a moderate pressure drop and heat transfer enhancement takes place when the triangular winglet is place at the inlet of the plate fin heat exchanger.

Development of oblique wavy fin heat exchanger by Naoki Shikazono[99] et al., experimental calculated the heat transfer and pressure drop across an oblique wavy fin heat exchanger the results showed that the heat transfer coefficient of the oblique wavy fin was twice larger than conventional louvered fin and the increase in pressure drop was three times smaller than louvered fin. Numerical study of flow patterns of compact plate-fin heat exchangers and generation of design data for offset and wavy fins by L. Sheik Ismail[100] et al., in this work the factors such as Colburn factor j and Fanning friction factor f vs. Reynolds number Re of heat transfer surfaces were analysed to determine the thermo-hydraulic design of compact heat exchangers.Using computation fluid dynamics software called Fluent three types of compact plate-fin heat exchangers were analyzed by flow maldistribution effects with ideal and real cases. Suitable baffle plates were provided at the headers for the improvement in flow distribution. 16 wavy fin geometries with three offset strip fin were used in the compact plate-fin heat exchangers have also been analyzed numerically. The j and f vs. Re design data are generated using CFD analysis only for turbulent flow region.

V. CONCLUSION

A review on the methods and analysis of different parameters of plate fin heat exchanger were carried by different method of analysis like experimental, numerical and simulation. The parameter considered here in this review paper are thermal–hydraulic performance, flow pattern, material and structure, pressure drop and heat transfer characteristics, fin geometry and heat transfer and pressure drop correlations. Still there is a strong need for proposing further techniques to improve the parameters in plate fin heat exchanger which will have a direct impact on operational cost, and last and not least the use of nanofluids and their role in the design aspects of the exchanger, which is considered a new growing research area. As plate fin heat exchangers are going more and more into sever process conditions, corrosion of plates is crucial problem facing the industry due to high operational cost paid.

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