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Review on Numerical and Experimental Offset-Fin Heat Exchangers

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Abstract--- The present work focus on the various numerical and experimental works carried out by different researchers on the plate fin heat exchangers with offset-strip fin. Different co-relation to find out the heat transfer co-efficient and pressure drop for offset strip plate-fin heat exchanger are studied in the present work and based on this study conclusion is drawn.

Keyword--- Plate-Fin Heat Exchanger, Offset Fin, Heat Transfer Co-Efficient, Pressure Drop

I. Introduction

Heat exchangers are used to transfer thermal energy between two or more media. Various types of heat exchangers are used for different industrial applications and one of the important types is the compact heat exchanger. The compact heat exchanger can be either plate-fin type or tube-fin type. Plate-fin heat exchangers are widely used in gas-gas applications such as cryogenics, micro-turbines, and automobile, chemical process plants, naval and aeronautical applications. Plate-fin heat exchanger has high thermal effectiveness (because fins are employed on both the sides to interrupt boundary layer growth), large heat transfer surface area per unit volume and high thermal conductivity due to small thickness of plate. This leads to reduction of space requirement, weight, energy requirement and cost. However this superior thermal performance of the compact heat exchanger is at the expense of higher frictional losses (i.e. pressure drop). Therefore, the optimum design of compact heat exchanger is always required as the optimal trade-off between the increased heat transfer rate and the power consumption due to higher pressure drop within the given set of constraints [1].

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Plate fin heat exchanger is a type of compact exchanger that consists of a stack of alternate flat plates called parting sheets and corrugated fins, both being brazed together as a block. Streams exchange heat by flowing along the passages made by the fins between the parting sheets. Separating plates act as the primary heat transfer surfaces and the appendages known as fins act as the secondary heat transfer surfaces intimately bonded to the primary surface. The performance of a plate and fin heat exchanger is not uniquely determined by the hydraulic diameter. Other geometrical parameters such as fin spacing, fin height, fin thickness and types of fins play significant roles [2].

Moreover, the fin geometry plays an important role in the performance of plate fin heat exchanger. Different fin geometry is available for plate fin heat exchanger like plain rectangular fin, plain trapezoidal fin, wavy fin, serrated fin, offset strip fin, louvered fin, perforated fin etc. Previously different researchers investigate the effect of different fin geometry on the performance of plate fin heat exchanger and developed the correlation for predicting the efficiency based on experimental analysis [3].

Due to the complex nature of the flow in this type of heat exchanger, empirical correlations have been developed for over last many years, with the first friction factor and Colburn modulus data being presented [4] for 3 offset surfaces. Since this date, these correlations have been constantly updated, and as reported by [5], the most comprehensive correlations available at this date were provided by [6].

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The offset strip fin is one important finned surfaces used in high effectiveness heat exchangers employed in cryogenic and aircraft applications. These fins are created by cutting a set of plain rectangular fins periodically along the flow direction, and shifting each strip thus generated by half the fin spacing alternately left and rightward. The flow is thus periodically interrupted, leading to creation of fresh boundary layers and consequent heat transfer improvement. Interruption of flow also leads to greater viscous pressure drop, manifested by a higher value of effective friction factor. In addition to the effect of wall shear, resistance to flow also increases due to form drag over the leading edges of the fin sections facing the flow, and due to trailing edge vortices. The effective heat transfer coefficient and friction factor are composite effects of the above mechanisms [7].

II. REVIEW ON PLATE-FIN HEAT EXCHANGER AND FIN-GEOMETRY

Miguel Henrique Teruel [1] this paper presents a lumped parameters model of predicting the temperature behavior of heat exchanger core, as the out temperature behavior of both the hot and cold flows. Fin and core's geometry are used in empirical correlations for providing mass flow and thermal resistances to the model. These correlations predict the experimental data of 18 test cores within ± 20% for $120 \leq Re \leq 104$.In this paper provides a simple solution, using only one derivative, for representing the behaviour of a heat exchanger of geometry. Even though developed for an offset strip-fin geometry, the steps described here could be for developing representations of other geometries as well, where only an approximated mean temperature provides enough information.Correlations and the equivalent thermal resistance circuits.

A. *Frontal and Flow Areas*

When calculating the friction factor, mean flow velocity and hence Reynolds numbers, and fully developed flow friction factors, the following definitions are used for frontal area of a cell, actual flow area, porosity or frontal area reduction, and sub-channel aspect ratio:

$$A_{front} = (s + t)H \quad (2)$$

$$A_{flow} = (H - t)s$$

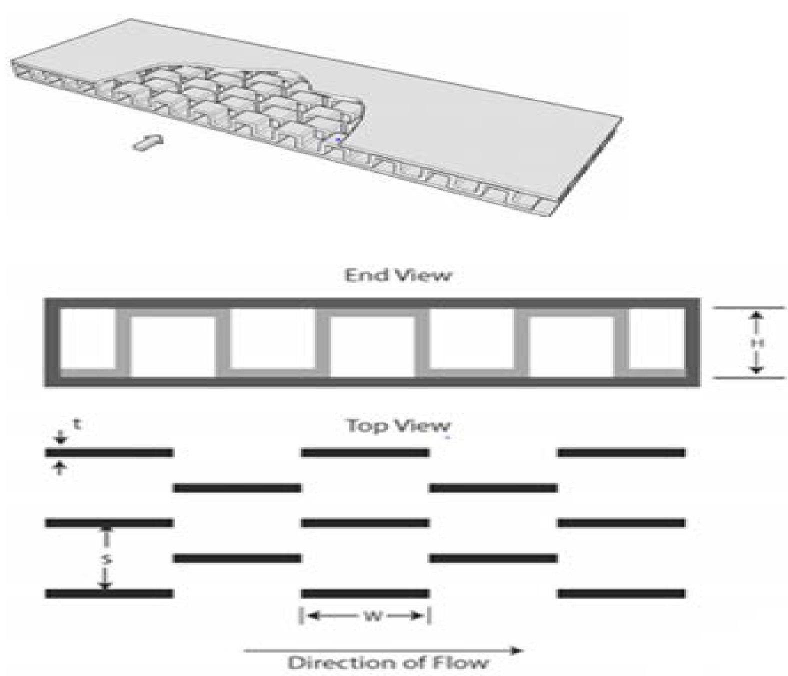

Figure 1: Geometry of Offset Strip Fin

B. Frontal and Flow Areas

When calculating the friction factor, mean flow velocity and hence Reynolds numbers, and fully developed flow friction factors, the following definitions are used for frontal area of a cell, actual flow area, porosity or frontal area reduction, and sub-channel aspect ratio:

Afront = (s + t)H

Aflow = (H – t)s

C. Surface Area

When calculating the j factor, the total heat transfer surface area, the fin surface area, and their respective reference ratios are required. These are defined as:

Atotal = 2sW + 2(H – t)W + 2Ht + st

$$F_A = \frac{2sW + 2(H-t)W + 2Ht + st}{2W(s+t)}$$

D. Fin Area

The ratio of the finned surface area to the total area is used in surface efficiency calculations. This is defined using:

Af = 2(H – t)W + 2Ht + st

$$F_f = \frac{A_f}{A_{total}} = \frac{2(H-t)W + 2Ht + st}{2sW + 2(H-t)W + 2Ht + st}$$

E. Fin Length

In the definition of fin efficiency, the fin length is approximated as one half the channel separations (assuming good thermal contact exists between the fin and wall):

$$S_0 \approx \frac{H}{2}$$

F. Friction Factor

The Fanning friction factor was determined from the following expression:

$$f = \frac{d_h}{4L}\left[\frac{\Delta p_{core}}{\frac{1}{2}\rho_m \bar{w}^2}\right]$$

Moslem Yousefi [27] This study explores the application of Imperialist Competitive Algorithm (ICA) in thermodynamic optimization of a cross-flow plate fin heat exchanger. Design parameters namely, hot side length, cold side length, fin height, fin frequency, fin thickness, number of fin layers for hot side and offset-strip length are chosen as optimization variables. In this paper a relatively new evolutionary algorithm based on social-political evolution of societies is used for the first time to optimize the geometry configuration of plate fin heat exchangers. This also is considered the first application of the ICA in entire thermal engineering problems. The primary objective of the optimization algorithm is the minimization of the total number of entropy generation units.

III. METHODS OF EXPERIMENTAL& PERFORMANCE ANALYSIS ON OFFSET-FIN HEAT EXCHANGERS

Hu and Herold [9] show the effect of Prandtl no. on heat transfer and pressure drop in OSF array. Experimental study was carried out in the first paper to study the effect for which they used the seven offset strip-fin having different geometries and three working fluids with different Prandtl number. At the same time the effect of changing the Prandtl number of fluid with temperature was also investigated. The study was carried out in the different Reynolds number.

Manglik&Bergles[10] experimental research on OSFs. They investigated the effects of fin geometries as non-dimensional forms on heat transfer and pressure drop, for their study they used different OSFs. After their analysis they arrived upon two correlations, one for heat transfer and another one for pressure drop. They compared there results from the data obtained by other researchers in the deep laminar and fully turbulent regions.

Zhang et al [11] investigated the mechanisms for heat transfer enhancement in parallel plate fin heat exchangers including the inline and staggered arrays of OSFs. their study found that only the surface interruptions increase the heat transfer because they cause the boundary layers to start periodically on fin surfaces and reduce the thermal resistance to transfer heat between the fin surfaces and fluid. However after a critical Reynolds number the flow becomes unsteady and in this regime the vortices play a major role to increase the heat transfer by bringing the fresh fluids continuously from the main stream towards the fin surface.

S.YoucefAli [12] the determination of the thermal performances of the single pass solar air collector with offset rectangular plate fin absorber plate is developed. The model can fix the temperature profile of all the components of the collector and of the air stream in the channel duct. The offset rectangular plate fins were introduced, which increase the thermal heat transfer between the absorber plate and the fluid. The offset rectangular plate fins are oriented parallel to the fluid flow and are soldered to the underside of the absorber plate. They are characterized by high heat transfer area per unit volume and generate the low pressure losses.

Dejong et al [13] carried out an experimental and numerical study for understanding the flow and heat transfer in offset fin heat exchanger. In the study the pressure drop, average heat transfer and skin friction coefficient on fin surface, and instantaneous flow structures in OSF channel were investigated. There results indicate that the boundary layer development, flow separation and reattachment, wake formation and vortex shedding play an important role in the OSF geometry.

AlokVyas [14] In this paper we are discussing 2D & 3D Analysis in OSF, Experimental & investigating research on OSFs, Analytical model to predict the heat transfer coefficient and the friction factor of the OSFs geometry, Heat transfer and pressure drop Characteristics of an OSFs Thermal performance, CFD Analysis on OSFs. The offset strip fin is one of the most widely used finned surfaces, particularly in high effectiveness heat exchangers employed in cryogenic and aircraft applications.

Akhilesh V. Bapat [15] the consist of multi-pass arrangements with offset strip fins of short lengths. An analytical treatment employing thermal boundary layer development in the entrance region of each offset fin geometry passage is performed. The analytical results are compared with the experiments and the reasons for the differences are discussed. Thus heat transfer is enhanced in micro channels.

$$h = \frac{Nuk}{D_h}$$

Offset strip fin micro channels offer enhancements in heat transfer at the expense of increased pressure drop. Some of the literature on offset strip fin heat exchanger is reviewed before analyzing them with the developing flow theory.

Gregory J. Michna [16] Offset-strip fin heat exchangers take advantage of boundary layer restarting to enhance heat transfer over that of plain-fin heat exchangers. Typically, these heat exchangers are operated at low Reynolds numbers (Re < 1,000). The friction factor decreases monotonically as Reynolds number increases in this range. However, the friction factor stops decreasing at this point and exhibits a kind of oscillatory pattern as it increases to f ~ 0.06 as the Reynolds number increases to 100,000. The heat transfer coefficient is greater than that predicted by the correlation over the entire range of the experiments. It should be noted, however, that the correlation was developed using data in the range 120 < Re < 10,000, Some of the deviation may also be caused the fin thickness to fin length ratio in these experiments is outside of the range of the strip-fin geometries used to develop the correlation.

Operation of an offset-strip fin heat exchanger at high Reynolds numbers may be useful in systems where minimizing heat exchanger size is more important than minimizing fan power.

Patankar and Prakash [17] study on a two dimensional analysis for the flow and heat transfer in an interrupted plate passage which is an OSFs heat exchanger. The main aim of the study is investigating the effect of plate thickness in a non-dimensional form t/H on heat transfer and pressure drop in OSF channels because the impingement region resulting from thick plate on the leading edge and recalculating region behind the trailing edge are absent if the plate thickness is neglected.

Sparrow [18] Steady about laminar flow was assumed by them between Reynolds numbers 100 to 2000. They found the flow to be mainly laminar in this range, although in some cases just before the Reynolds no. 2000 there was a transition from laminar to turbulence. They made their analysis for different fin thickness ratios t/H for the same fin length L/H and they fixed the Prandtl number of fluid For proper validation they compared there numerical results with the experimental results for offset strip fin heat exchangers.

Fangjun Hong & Ping Cheng [19] the 3-D numerical simulation, taking into consideration the conjugate heat transfer of heat sink base material and coolant, was conducted for laminar forced convection of water to study offset strip fin micro channel heat sink for microelectronic cooling. It is found that due to the periodical change of the flow direction, the convective heat transfer is enhanced by mixing the cold and hot coolant, and the periodical breakup of boundary layer is another factor to enhance heat transfer. The effects of the ratio of fin interval to fin length K, and fin numbers M on the performance of strip-fin micro channel were also investigated. It is found that for the same K, with the increase of M, the required mass flow rate to keep the maximum wall temperature decreases.

IV. RESULTS OF HEAT-TRANSFER, PRESSURE DROP AND FRICTION CHARACTERISTICS OF THE OFFSET-STRIP FIN EXCHANGERS BASED ON REVIEW

Sparrow and Liu [13] studied basic heat transfer and pressure-drop results for laminar airflow through arrays of inline or staggered plate segments from numerical solutions of the fluid flow and energy equations. The heat transfer and pressure drop results incorporating the entrance region was studied for both in-line and staggered configuration and was presented in the form of table.

Joshi and Webb [20] To study on presented analytical models to predict the heat transfer coefficient and the friction factor of the offset strip fin heat exchanger surface geometry in the laminar and turbulent flow regimes. They also studied the transport of energy and momentum in the boundary layers of the fins because of the oscillating velocities developed from the wakes. Thus the wake distribution was also studied by them to take into considerations the effect of fin length, fin thickness and the fin spacing on the wake flow pattern.

K. Thirumalaikannan, [21]in this paper to work on reanalyzed the empirical f and j data for the rectangular offset strip fin compact heat exchangers. They presented rational design equations for f and j in the form of continuous expressions covering the laminar, transition and the turbulent flow regimes.

MasoudAsadi [22] designing a heat exchanger is optimization process. The enhancement in thermal performance results in a rise in pressure drop and total annual costs. So, finding optimal dimensions of heat exchanger is a key stage in designing process. In this paper, optimization has been done based on entropy generation minimization, where Cuckoo Algorithm aided to reach better results.

H. Bhowmik [23] studies the heat transfer and pressure drop of an offset strip fin heat exchanger. They have taken water as the heat transfer medium, and the Reynolds number (Re) in the range of 10 to 3500. Variations in the Fanning friction factor and the Colburn heat transfer relative to Reynolds number were observed. General correlations for the Fanning friction factor and the Colburn heat transfer factors were derived by them which could be used to analyze fluid flow and heat transfer Characteristics of offset strip fins in the laminar, transition, and turbulent regions of the flow.

Kays and London [24] The studies on the effects of OSFs on heat transfer and pressure drop. But most of the researchers have not taken into account the effect of manufacturing irregularities such as burred edges, bonding imperfections, separating plate roughness which also affect the heat transfer and flow friction characteristics of the heat exchanger.

Saidi and Sudden [25] to study carried out a numerical analysis of the instantaneous flow and heat transfer for OSF geometries in self-sustained time-dependent oscillatory flow. The effect of vortices over the fin surfaces on heat transfer was studied at intermediate Reynolds numbers where the flow remains laminar, but unsteadiness and vortex shedding tends to dominate.

Michna et al [26] to investigate the effect of increasing Reynolds number on the performance of OSFs. He conducted the experiment at varying Reynolds and found that both heat transfer and pressure drop increased with increasing Reynolds number, because the effect of vortex shedding and eddy formation at turbulent regime. Operation of offset strip fin heat exchangers under this Reynolds number may be useful in systems where minimizing the heat exchanger size or maximizing the heat transfer coefficient is more important than minimizing the pressure drop.

V. CONCLUSION

This paper gives a detailed description of offset strip fin types of geometries dimension study that can be used to Heat transfer. Offset-strip-fin enhancement geometries have been developed in order to make heat exchangers more efficient and compact. Currently plate-fin heat exchangers are very common in cryogenic systems and gas-liquefaction plants. Increased demand for smaller and better heat devices will certainly lead to more wide spread use of plate-fin heat exchangers in other applications as well and compare with offset strip fin .

This review paper discuss the numerical and experimental work carried out on offset-strip fin. Still. there is a need of analyzing dynamics similarities amongst the geometrical similarities on large scale model covering industrial application, Further research is required to be conducted at a pressure drop analysis and friction characteristic etc.

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