Offset-Strip Fin Heat Exchangers A Conceptual Review Study

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Abstract

This paper is a review of research work of last few years on heat transfer growth in offset-strip fin heat exchangers. It features a broad discussion on the application of enhanced heat transfer surfaces to offset strip fin heat exchangers. 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.

Keywords - CFD Analysis, Offset-strip fin, Heat transfer growth, laminar and turbulent flow.

INTRODUCTION

The first sign of movement to relatively “compact” heat exchangers was seen in the automotive industry in the early 1900’s, when an improved manner for removing heat from engines with minimal material (weight) was sought. Whereas heat was previously removed from engines by boiling a collection of water and releasing it into the air in an unsophisticated convection process, heat exchangers were seen as an inexpensive way to improve engine performance (Shah & Sekulic, 2003).[1]

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. 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.

The Offset Strip Fin Geometry

The geometry of the offset strip fin surface is described by the following parameters:

(i) Fin spacing (s), excluding the fin thickness,
(ii) Fin height (h), excluding the fin thickness,
(iii) Fin thickness (t), and
(iv) The strip length (_), in the flow direction.

The lateral fin offset is generally uniform and equal to half the fin spacing (including fin thickness). Figure shows a schematic view of the rectangular offset strip fin surface and defines the geometric parameters. The following are some commonly used secondary parameters derived from the basic fin dimensions

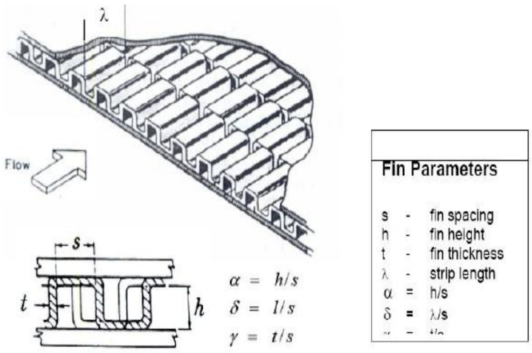

Fig.1Offset-strip fin Geometry

1. Two & Three Dimensional analysis in OSFs Heat Exchangers

Patankar and Prakash [2] presented a two dimensional analysis for the flow and heat transfer in an interrupted plate passage which is an idealization of the 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. Their calculation method was based on the periodically fully developed flow through one periodic module since the flow in OSF channels attains a periodic fully developed behaviour after a short entrance region, which may extend to about 5 (at the most 10) ranks of plates (Sparrow, et al. 1977). Steady and 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. Specially for the higher values of t/H. They used the constant heat flow boundary condition with each row of fins at fixed temperature. They made their analysis for different fin thickness ratios t/H= 0, 0.1, 0.2, 0.3 for the same fin length L/H = 1, and they fixed the Prandtl number of fluid = 0.7. For proper validation they compared there numerical results with the experimental results of [London and Shah][1] for offset strip fin heat exchangers. The result indicated reasonable agreement for the f factors, but the predicted j factor was twice as large as the experimental data. They concluded that the thick plate situation leads to significantly higher pressure drop while the heat transfer does not sufficiently improve despite the increased surface area and increased mean velocity.

Fangjun Hong & Ping Cheng [3] show 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.

2. Experimental & investigating research on OSFs

Manglik and Bergles[4] carried an 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 18 different OSFs. After their analysis they arrived upon two correlations, one for heat transfer and another one for pressure drop. The correlations were developed for all the three regions. They compared there results from the data obtained by other researchers in the deep laminar and fully turbulent regions. There correlations can be acceptable when comparing the results of the expressions to the experimental data obtained by Kays and London [5].

Hu and Herold [6] presented two papers to 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 OSFs 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 range of Reynolds number varying from 10 to 2000 in both the papers. The results of the two studies showed that the Prandtl number has a significant effect on heat transfer in OSF channel.Although there is no effect on the pressure drop.

Zhang et al [7] investigated the mechanisms for heat transfer enhancement in parallel plate fin heat exchangers including the inline and staggered arrays of OSFs. They have also taken into account the effect of fin thickness and the time dependent flow behavior due to the vortex shedding by solving the unsteady momentum and energy equation. The effects of vortices which are generated at the leading edge of the fins and travel downstream along the fin surface was also studied. From there study they 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.

Dejong et al [8] carried out an experimental and numerical study for understanding the flow and heat transfer in OSFs. In the study the pressure drop, local Nusselt number, average heat transfer and skin friction coefficient on fin surface, instantaneous flow structures and local time averaged velocity profiles in OSF channel were investigated. They compared there results with the experimental results obtained by Dejong and Jacobi [1997] and unsteady numerical simulation of Zhang et al [1997]. 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.

S.YoucefAli_,J.Y.Desmons[9] Presented

A mathematical model that allows the determination of the thermal performances of the single pass solar air collector with offset rectangular plate fin absorber plate is developed (fig.2). The model can predict 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, mounted in a staggered pattern, 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. The experimental results of the air stream temperature will be compared with the results obtained by the theoretical model suggested

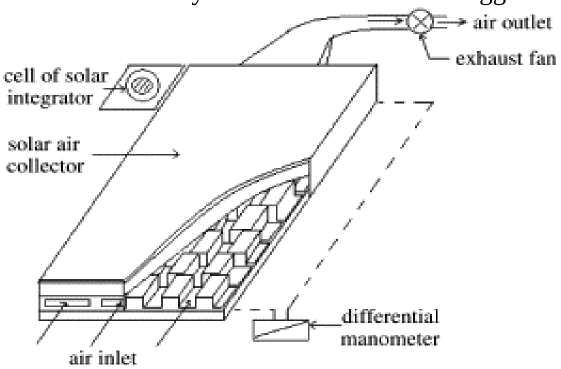

Fig. 2 Experimental setup

The model, which determines the thermal performances of this collector and temperatures of all its components and air stream, uses an equation of global irradiance incident along the collector, ambient and inlet collector temperature. Predicted and experimental results of the air stream temperature are in good agreement particularly in the transition flow regime. On the other hand, in the laminar flow system, the greatest recorded variation, which is of 71°C obtained for the lowest value of the Reynolds number Re ¼ 479. In this same case, the difference between the theoretical and the experimental air stream temperature at the collector exit is only of 41 °C which is acceptable.

3. Analytical model to predict the heat transfer coefficient and the friction factor of the OSFs geometry

Joshi and Webb [10] developed an analytical model to predict the heat transfer coefficient and the friction factor of the offset strip fin surface geometry. To study the transition from laminar to turbulent flow they conducted the flow visualization experiments and an equation based on the conditions in wake was developed. They also modified the correlations of Weiting [11]. There was some difference between there correlation. Four different flow regimes were identified by Joshi and Webb [12] from there experiment. The flow was found to be laminar and steady in the first regime. In the second regime the oscillating flow structures were found in the transverse direction. The flow oscillated in the wake region between two successive fins in the third regime. And in the fourth regime the effect of vortex shedding came into picture. The laminar flow correlation of Joshi and Webb started to under predict the j and f factors at the second regime. So they assumed the Reynolds number at that point as the critical Reynolds number to identify the transition from laminar to turbulent.

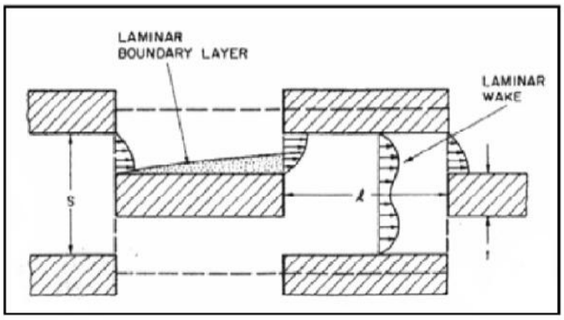

Fig.3(a) Laminar flow on the fins and in the wakes (Source Joshi and Webb 1987)

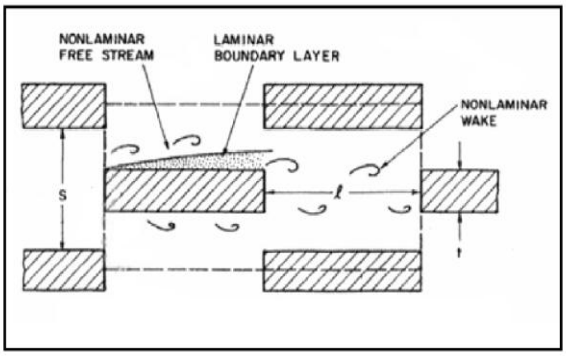

Fig.3(b) Laminar flow on the fins and oscillating flow on the wakes
(Source Joshi and Webb 1987)

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4. Heat transfer and pressure drop Characteristics of an OSFs

H. Bhowmik and Kwan-Soo Lee [13] studied the heat transfer and pressure drop characteristics of an offset strip fin heat exchanger. For their study they used a steady state three dimensional numerical model. They have took water as the heat transfer medium, and the Reynolds number (Re)in the range of 10 to 3500. Variations in the Fanning friction factor f and the Colburn heat transfer j relative to Reynolds number were observed. General correlations for the f and j 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.

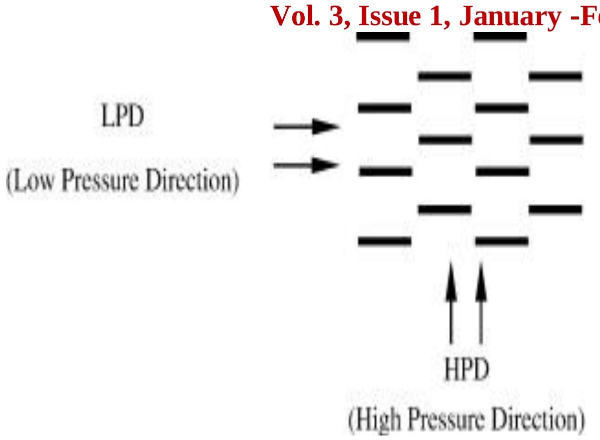

Fig.4 Direction of fluid at LPD & HPD

Saidi and Sudden [14] 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. They compared their numerical results with previous numerical and experimental data done by Dejong, et al. (1998).

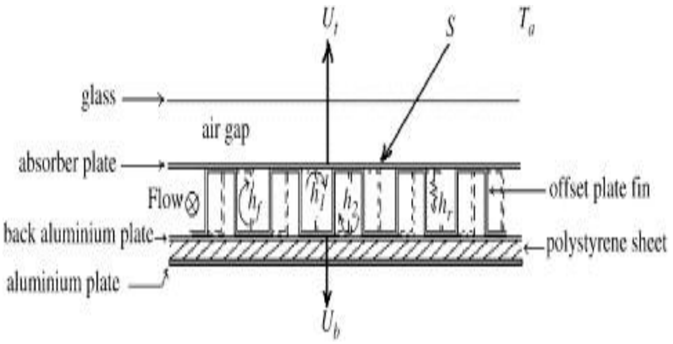

Fig. 5. Heat transfer in offset plate fins

The studies of few researchers like Patankar and Prakash [1], Kays and London [5] it is easy to get information regarding 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. Dong et al [15] made experiments and analysis considering the above factors to get better thermal and hydraulic performance from the OSFs. Sixteen types of OSFs and flat tube heat exchangers were used to make the experimental studies on heat transfer and pressure drop characteristics. A number of tests were made by changing the various fin parameters and all the tests were carried out in specific region of air side Reynolds number (500-7500), at a constant water flow crate. The thermal performance data was analyzed using the effectiveness-NTU method in order to obtain the heat transfer coefficient. They also derived the j factor and f factor by using regression analysis. Results showed that the heat transfer coefficient and pressure drop reduce with enlarging the fin space, fin height and fin length.

Michna et al [16] investigated the effect of increasing Reynolds number on the performance of OSFs. He conducted the experiment at Reynolds number between 5000 to 120000 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 OSF 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.

Various experiments are carried out in order to find out the **j** and **f** factors of the various heat exchangers and are called as the thermal performance testing. These testing are needed for heat exchangers, which do not have reported **j** and **f** data. Therefore, this test is conducted for any new development or modification of the finned surfaces. T. Lestina & K. Bell, Advances in Heat Transfer, told for heat exchangers already existing in the plants this test is done for the following reasons:

a) Comparison of the measured performance with specification or manufacturing design rating data.

b) Evaluation of the cause of degradation or malfunctioning.

c) Assessment of process improvements such as those due to enhancement or heat exchanger replacement.

Another reason for developing these correlations is that, generally in most heat exchanger problems the working fluid, the heat flow rate and mass flow rate are usually known, so if certain correlations between geometry and fin performance is also known, then the problem can be deeply simplified. For that purpose developing the correlations for fanning friction factor *f* and Colbourn factor j are important for heat exchanger.These are the ratio of free flow area (α = *s/h*), the ratio of heat transfer area (β= *t/l*), and the ratio of fin density (y= *t/s*).
Show in Fig.1

5. Thermal performance of OSF Heat Exchangers

S. Youcef-Ali_, J.Y. Desmons [17] A mathematical model that allows the determination of the thermal performances of the single pass solar air collector with offset rectangular plate fin absorber plate is developed. The model, which determines the thermal performances of this collector and temperatures of all its components and air stream, uses an equation of global irradiance incident along the collector, ambient and inlet collector temperature. Predicted and experimental results of the air stream temperature are in good agreement particularly in the transition flow regime.

Suzuki et al [18] in order to study the thermal performance of a staggered array of vertical flat plates at low Reynolds number has taken a different numerical approach by solving the elliptic differential equations governing the flow of momentum and energy. The validation of their numerical model has been done by carrying out experiments on a two dimensional system, followed by those on a practical offset strip fin heat exchanger. The experimental result was in good agreement with the performance study for the practical offset-strip-fin type heat exchanger in the range of Reynolds number of Re<800.

Tinaut et al [19] developed two correlations for heat transfer and flow friction coefficients for OSFs and plane parallel plates. The working fluid for OSF was engine oil and water was taken for analyzing the parallel plate channels. By using the correlations of Dittus and Boelter and some expressions of Kays and Crawford they obtained their correlations. For the validation of their results they compared there correlations with correlations of Weitng[6].

Although their were some differences between the results but there correlations have been found acceptable upon comparing their results to the data obtained from other correlations.

Randall.F.Barron[20], shows that Cryogenic heat exchanger, has showed the effect of longitudinal wall heat conduction on the performance of cryogenic heat exchangers. Cryogenic heat exchangers operate at low temperatures where the longitudinal wall heat conduction results in serious performance deterioration this is because they have small distances (on the order of 100 to 200 mm or 4 to 8 in) between the warm and cold ends i.e. they have short conduction lengths. Because of the natural requirement of high effectiveness for cryogenic heat exchangers, the NTU values are usually large (as high as 500 to 1000), so the effect of longitudinal conduction is most pronounced for heat exchangers having short conduction lengths and large NTU. The wall longitudinal heat conduction reduces the local temperature difference between the two streams, thereby reducing the heat exchanger effectiveness and the heat transfer rate.

6. CFD Analysis

Heat exchanger designs continued to expand and develop through the 1960's and more industries gained interest in using compact heat exchangers to increase efficiency. Compact heat exchanger technologies spread from the automotive industry to the air conditioning industry, several manufacturing industries, and even to the magnetic railway industry (Shah, McDonald, & Howard, 1980).[21] The 1980's brought an increase in computing power and function that led compact heat exchanger research away from experimental solutions in favor of Computational Fluid Dynamics (CFD). CFD provided low-cost means to simulate the physics occurring inside heat exchangers relatively accurately, without the need to construct and test physical apparatus before a final design was developed.

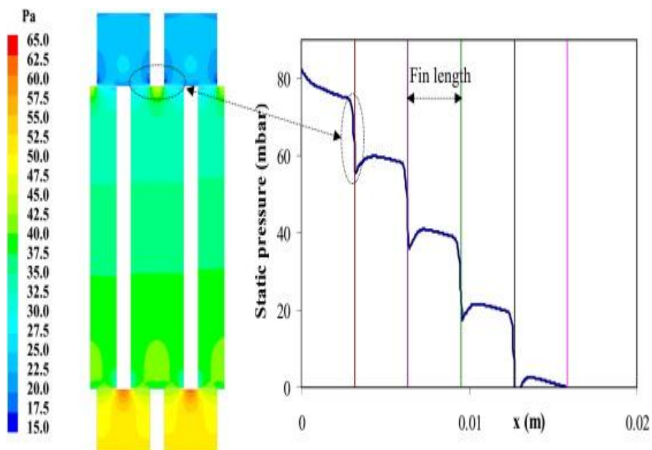

Fig. 6. CFD Analysis in offset plate fins

It took several years, and decades in some cases, for the computing power to be able to accurately predict the physics in a timely fashion for the incredibly small geometries in compact heat exchangers. That breakthrough allowed for significant advancements in the industry. Optimization processes were more easily obtained, and more complex geometries could be tested with the use of CFD.The Fig.6& 7 Shows the CFD Analysis in different field Fig.5 show fluid flow in OSFs geometry and Fig.6 shows that (a) velocity field, (b) Velocity distribution, and (c) temperature field in OSFs geometry.

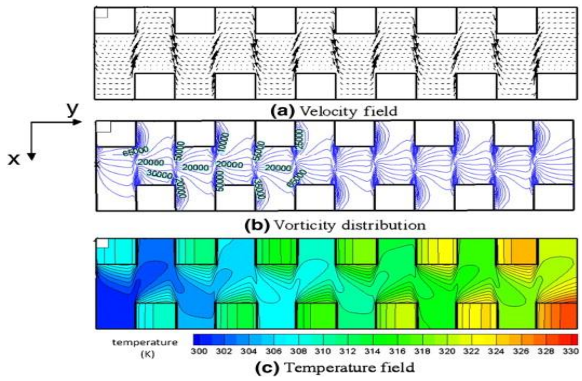

Fig. 7. CFD Analysis in offset plate fins (a) Velocity field (b) velocity distribution (c) Temperature field

In the time since CFD became prevalent in heat exchanger design, several systems of commercial codes have been developed to allow for rapid testing and simulations. The programs continue to become more accurate, and as computers continue to become more powerful and swift in their calculations, the use of CFD will expand to new applications.

The technologies available today are leaps and bounds ahead of the resources available to those designing the MSBR in the 1960's. Computing power has made hydrodynamics and heat transfer incredibly more accurate in comparison to hand drawings and manual calculations done in the initial MSBR design (Bettis, et al., 1967). The computer programs developed at ORNL for optimization of the heat exchanger designs were rudimentary compared to the commercial software packages available today. Performing CFD analyses in FLUENT, with automated optimization available in ANSYS Workbench, is much more sophisticated than the analog computer models used in the 1960's for overall plant operation (Burke, 1972) and heat exchanger design (Bettis, Pickel, Crowley, Simon-Tov, Nelms, & Stoddart, 1971).

CONCLUSION

This paper gives a detailed description of OSFs types of geometries 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 exchange devices will certainly lead to more widespread use of plate-fin heat exchangers in other applications as well.

This review paper discuses the considerable experimental, Numerical and CFD work which has been done on heat transfer growth through offset-strip fin experimental work. 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 large scale on considerable range of curvature ratio, low range of curvature ratio, low range of Prandtl number and Reynolds numbers temperature etc.

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