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Enhancement Of Plate-Fin Heat Exchanger Performance with Aid of Various Types of Fin Configurations: A Review

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ABSTRACT

This study is a review of recent studies on heat transfer enhancement in plate fin-heat exchangers (PFHE) with plain and offset (OSF) fins. Thermal designing parameters such as the coefficient of heat transfer, Nusselt number, hydraulic diameter, Colburn factor (j), friction factor (f) and Reynold's number of PFHE was presented in this review for both straight and offset types. According to the results, by replacing plain fins into OSF, the pressure increases because of the increasing of f-factor, while there is a significant increase in Nusselt number and then the heat transfer. The j & f factors, are the most essential two parameters of researching the heat exchanger that were represented as functions of Reynolds number and other geometrical parameters. At the same Reynolds number, the J-factor declines and the friction factor f increases as the fin pitch increases for the same fin height and fin thickness.

1. Introduction

1.1 Heat Exchanger

A heat exchanger (HE) is equipment that transfers thermal energy at various temperatures and in thermal contact between two or more fluids, a solid surface and a fluid, or solid particles and a fluid [1]. Not only are HEs commonly employed in such a procedure, power, petroleum, air conditioning, refrigeration, cryogenic, heat recovery, alternative-fuel, and manufacturing industries, but they serve as essential components in a wide range of industrial goods. The heat exchanger (HE) may be categorized in numerous ways, including the volume of fluids, the heat transfer mechanism, and the kind of fins, including tube and wavy fin (HE)s, louvered fin (HE)s, and so on [2]. (PFHE) is among the most common forms of HE, consisting of alternate flat plates and corrugated fins brazed together to form a box. Parting sheets are the flat plates. The streams

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exchange heat between the dividing sheets. The major heat transfer surfaces are separated plates, while the secondary heat transfer surfaces are fins. Aluminum and stainless steel are the most widely utilized fin materials in high-pressure and high-temperature applications [3]. Figure 1 shows basic components of plate-fin heat exchanger.

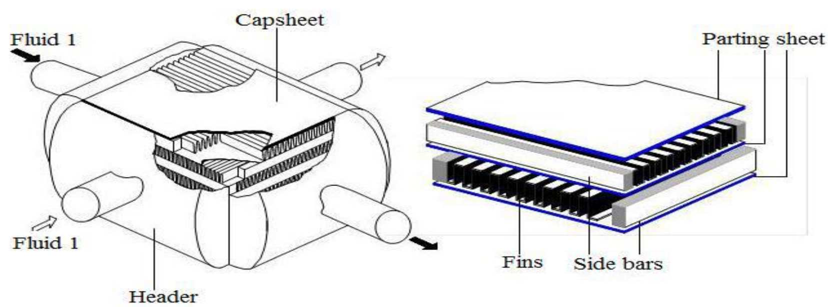


Fig. 1. Basic components of plate-fin heat exchanger

1.2 Fins and Finned Surfaces

Fins are surface extensions that are commonly employed in many kinds of HE to enhance the heat transfer rates between a surrounding fluid and the solid surface. Geometrically altered fins are frequently integrated, which, in addition to raising the surface area density of the HE, develops the convection coefficient of heat transfer. OSF, Louvered fins, Wavy fins, Plain fins, and Pin fins are examples of these improved surface compact cores [4]. Plate fin compact heat exchangers (CHE), with their finned surfaces providing a rather high surface area density, are increasingly being utilized in numerous automobiles, cooling systems and conditioning systems, propulsion systems, thermal energy storage, cryogenic, and other heat recuperative implementations. A wide range of finned surfaces commonly utilized includes plate fins, pin fins, (OSF)s, louvered fins, and wavy fins. The fin geometry influences the performance of a (PFHE) [5]. Plain fins with rectangular, trapezoidal, or triangular passages and interrupted fins are the most prevalent fin configurations (OSF).

1.3 Plain Fins

Plain fins are straight and continuous. Plain fins are typically triangular or rectangular in cross-section. In addition, triangular design fins are easier to fabricate than other types of fins. However, the simple fins have a decreased heat transfer rate during laminar flow and structural fragility. Plain fins are commonly utilized for critical pressure decreases [6].

Bose *et al.,* [7] Offered comprehensive mathematical research of the rectangular (PFHE) that was carried out to evaluate the heat transfer distinctive j-coefficient and the heat exchanger core pressure drop characteristic f-factor as a product of heat exchanger geometry and Reynold's number. They employed the Finite Volume Method to study the performance of the plain rectangular. They determined that under a certain range of fin geometry, namely (1h/s4) and (0.04t/s0.14), and a laminar region of (200 Re 800), the f & j factors varied in a nonlinear manner. They also discovered that when Re and (t/s) increased, f & j decreased, while h/s increased. A regression analysis was performed to determine a relationship between the f & j factors and Re, as well as the non-dimensional geometric factors h/s and t/s. Such correlations were rather helpful in determining the coefficient of heat transfer and pressure drop characteristic during HE design challenges.

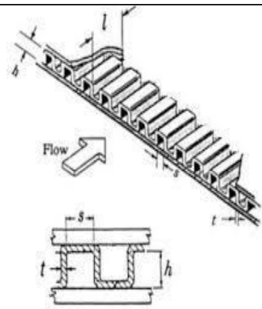
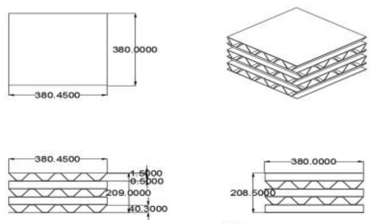
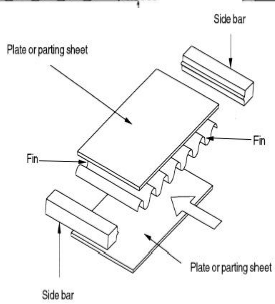
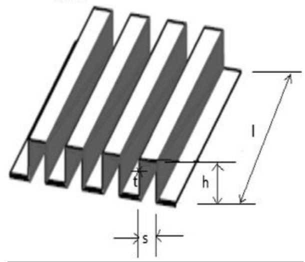
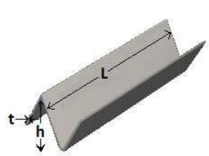
Onah *et al.,* [8] They experimentally assessed the thermo-hydraulic performance of the provided (HE) with trapezoidal fins at varied mass flow rates. The mass flow rate of the fluids is proportional to the temperature reduction of the fluids after passing through the exchanger, according to the results. Increased mass flow rate improves heat exchanger efficiency. Inappropriate insulation affects heat transfers in heat exchanger cores by producing an energy imbalance. The planned results give benchmark data to assess and estimate heat exchanger performance for energy recovery applications.

Mohan *et al.,* [9] They empirically evaluated the changes in heat transfer characteristics utilizing a wavy fin positioned in a plate heat exchanger during laminar and turbulent flow regimes. The wavy fin has the maximum j-factor for the laminar area and the f-factor increases as the pitch increase with a constant fin height and length. The j-factor falls as the pitch increases, although thermal performance is strong in the low-velocity area.

Sundar *et al.,* [10] They reported heat transfer correlations for rectangular plain fins. The equations provided for the heat transfer factor in terms of j-factor and f-factor allow computation for all values of Re number, containing laminar - turbulent areas. When compared to other sources, the correlations for the f & j factors were determined to be satisfactory. The implementation of heat transfer and f-factor formulas to a compacted plate type HE yields extremely high consistency with the experimental results. The HE designers could utilize the aforementioned correlations to decrease the amount of tests and prototype revisions for comparable applications.

Rao *et al.,* [11] They reported heat transfer and f-factor correlations for plate-fin triangular plain fin surfaces (CHE). The Fluent software tool was used to accomplish the numerical computations. For various Re values, the f & j factors were determined. These numbers were compared to j & f factors data from previous research. The correlations were demonstrated using two separate equations over the low and high Re areas, as well as dimensionless geometric factors. They determined that the results obtained from such expressions are consistent with the data from previous similar investigations. When compared to other references, the correlations for the f & j factors were determined to be good. Table 1 displays a summary of the plain fin papers.

Table 1
Summary of the plain fin papers

Author	Ranges	Geometry	Working fluid	Regime	Temperature Range
Bose *et al.,* [7]	Re number range of 200-800		Water	Laminar	Constant temperature boundary condition
Onah *et al.,* [8]	2.45<Pr<8.81		Water	-	T_{hot} in= 345 K T_{cold} in= 284 °C
Mohan, *et al.,* [9]	Reynolds Number from 200 to 2000		Water	Laminar	Water temperature was 80 °C
Rao *et al.,* [10]	Reynolds number 100–7,500		Air	Laminar - Turbulent	Temperature of inlet air (Tin) 300 K
Rao *et al.,* [11]	Re numbers Laminar 300 ≤ Re ≤ 1000 Turbulent 1000 < Re ≤ 10000		Air	Laminar - Turbulent	The inlet temperatures of the air fixed as 300 K

1.4 Offset Strip Fins

Offset strip fins are among the most extensively utilized components for heat transfer improvement in airplanes, cryogenics, and several other non-mass production sectors [12]. The new thin boundary layer on the fin plate of every (OSF) fin module is periodically disrupted and reattached, resulting in the best heat transfer performance surfaces. Their coefficient of heat transfer ranges between 1.5 and 4 times that of simple fins. Many studies have been undertaken to examine the heat transfer and pressure drop characteristics of (PFHE) with an emphasis on the Offset Fins (OSF) type of fin (PFHE). This is why the focus has been placed on predicting the j and f factors and measuring the thermal performance of HE [13]

Himangshu and Kwan [14] Studied the characteristics of the coefficient of heat transfer and pressure drop in an OSF fin heat exchanger with a 3-dimensional numerical model & steady state. The dimensionless enactment factors, such as "the heat transfer performance factor" and the "pumping power factor" were examined and obtained a relationship between them. Then, the prediction of j & f factors was generalized for different Pr numbers. General correlations for the f&j factors were derived by them which could be used to examine heat transfer and fluid flow Characteristics of OSF in the laminar, transition, & turbulent regions of the flow.

Tinaut *et al.,* [15] Presented heat transfer and flow f-factor correlations for planar parallel plates and OSF plates above the limits employed in (CHE)s. The hypothesized correlations enable good prediction of empirical data for heat exchanged and pressure losses in compact (PFHE)s. The correlations encompass the whole flow spectrum, from laminar to turbulent. The results obtained from such expressions agreed with the data from previous comparable investigations. The solution chosen in the transitional regime could be considered as an appropriate expression for determining a closed-form problem. They came to the conclusion that applying heat transfer and f-factor expressions to a PFHE (with both parallel and OSF plates) yields extremely excellent agreement with experimental results.

Tariq and Khan [16] Improved the design of (PFHE). In their study, they introduced a multi-objective optimization technique that included the Genetic algorithm, differential evolution, and adaptive simulated annealing methods. Cross-flow (PFHE) was incorporated into the model geometry (OSF). The findings indicate that the DE-GA-ASA approach may be employed effectively for the design optimization of (PFHE). Moreover, the impact of the variation in fin and HE variables on the optimum design was investigated. The investment and operational expenses were separately optimized to provide a thorough examination of the impact of fin and HE shape factors on their fluctuation. Furthermore, TOPSIS, a multi-criteria decision-making approach, is provided for selecting the ultimate optimal option from a set of non-dominated solutions.

Jiang *et al.,* [17] Used theoretical and experimental research to examine the thermal-hydraulic properties of cryogenic helium gas flowing via several OSF channels. The findings indicate that under real cryogenic operating circumstances, the (OSF) performance was greatly affected not only by fin geometrical structures but also by other influencing coefficients. The findings discussion has shown that the provided correlations were more suited for estimating the thermal-hydraulic performance of OSF channels in cryogenic (PFHE)s.

Marțian *et al.,* [18] The purpose of this research was to use empirical analysis to identify the analytical form of the thermal and hydraulic performance for a family of BPHEs with aluminum (OSF) placed in transversal flow (TOFs) throughout a large Re range of 103 to 104. The Nusselt correlation was ideal within 5% of the experimental results, as was the f-factor. The relationship with other models from previous comparable research leads us to the same finding that constructing a generic model was not practicable owing to variances in the material and manufacturing technique of TOFs. To confirm the correlations for varieties of fluids, the second series of testing was performed on the same BPHE but with a hydraulic oil VG46 for the hot stream, which is a wholly distinct liquid from the water utilized in the initial tests. It was discovered that in this scenario, the results do not differ from the experimental values by extra than 5% for heat and 15% for pressure drop.

Tiwari *et al.,* [19] analyzed the performance characteristics of a counter flow HE by utilizing CFD to forecast fluid flows and heat transfer employing the calculation technique of fluent simulation software. The findings demonstrate that as the mass flow rate grows, the efficacy rises, as does the theoretical as well as the experimental total heat transfer factor since the Re number increases as the mass flow rate increases. The J-factor was raised since it was proportionate to the coefficient of heat transfer, and the overall heat conductance rose as a result. Lastly, the pressure drops in the HE varies with the variable mass flow rate.

Bhowmik and Kwan [20] Used quantitative analysis to analyze the heat transfer and pressure drop properties of an OSF heat exchanger utilizing a steady-state, 3-dimensional mathematical model. The fcor and jcor factors were shown to have a shared correlation, which may be utilized to examine flow and heat transfer in laminar, turbulent, and even transition zones. The correlated jcor was used to forecast the Nusselt number, and the influence of Pr numbers was determined. For various fluids, three alternative performance requirements for heat exchangers were examined. JF and j/f 1/3 were determined to be appropriate performance criteria for Pr=7 and Pr=50, respectively.

Hu And Herold [21] Proposed an experimental setup for studying heat transfer and pressure loss in liquid-cooled offset fin (CHE)s. The liquid-cooled experimental results revealed that the Pr number had a greater effect on the Nu number of the offset fin shape than in prior air-cooled models. A mathematical heat transport study was carried out. The Pr number varied from 3 to 150. The Pr number was discovered to have a significant impact on the j-factor of offset fin arrays. The j-factor for liquids is overestimated in air simulations. The error suggests an underestimation of the surface temperature, which might result in significant design flaws when examining the surface temperature distribution and heat flow uniformity in the cold plates.

Wen *et al.,* [22] Investigated the effects of OSF fin geometry on entrance dissipation based thermal resistance (EDTR) produced by heat transfer (Rht) and fluid friction (Rff). They employed the design of experiment (DOE) and response surface approach (RSM). The findings revealed that fin height, fin interrupted length, and fin spacing were all definitely linked with Rht, however, fin thickness and (PFHE) length were negatively correlated with Rht. Rff was roughly an order of magnitude bigger than Rht, and Rff rose practically linearly with rising Re when geometric factors were held constant. Rff rose as fin thickness and (PFHE) length grew while reducing as fin height, fin interrupted length, and fin space increased. In addition, the Multi-Objective Genetic Algorithm (MOGA) was used. The findings demonstrate that the optimum outcomes for OSF fins based on EDTR objective functions were superior to those based on standard objective functions (PFHE).

Wen *et al.,* [23] Studied the effect of fin design parameters on the performance of (PFHE)s through an improved approach that included a Kriging response surface with a multi-objective genetic algorithm, with the model geometry being a OSF fin. The findings demonstrated that when the intake channel flow was laminar (Re 1000), it was advantageous to trade off the j&f factors. Furthermore, multi-objective optimization was used to maximize the total heat flow rate, overall yearly cost, and the number of entropy production units of (PFHE) with the stated mass flow rate in the provided space. The findings of the first two and three goals revealed that the fin design parameters were almost identical, with the exception of the latter interrupted length being significantly shorter.

Hu and Heroldi [24] Used an experimental investigation to develop Laminar models and quantify heat transfer and pressure drop performance of liquid-cooled offset fin cold plates WPFs. The model geometry was wavy plate-fins. The Pr number has a significant impact on the offset fin cold plate's heat transfer performance. Thermal field growth in the fin array and thermal boundary layer formation on the fins were both significant for higher Pr numbers. When the Pr number grew, the average Nu number of the fin array increased due to both of these factors. A laminar flow model was defined, taking into account the impacts of the Pr number, Re number, and fin shape. The heat transfer and pressure drop of OSF arrays with Pr numbers ranging from 0.7 to 150 might be calculated using the model. The model estimates 94% of j-factor test data and 90% of f-factor test data within a +20% margin of error.

Yang and Li [25] Numerical investigation was utilized to examine the heat transfer and flow f-factors for (OSF) employed in (PFHE)s. The effect of geometrical features on the thermal hydraulic performance of OSF fins was thoroughly investigated. The fin and the fin-channel properties must be evaluated. The experimental findings demonstrate that the suggested correlation calculates 92.5% of the j data and 90% of the f data within 20% of the mean, with RMS errors of less than 15%. When compared to current correlations, the suggested ones provide well-adapted computations for OSF fins with varying fin thicknesses covering a wide range of blockage ratios, whereas prior ones only adjust to thinner fins and diverge from practice at higher blockage ratios.

Wen *et al.,* [26] Using a genetic algorithm in conjunction with the Kriging response surface approach, they optimized the arrangement of the OSF fin in (PFHE). The findings demonstrate that the ideal HE's heat transfer rate improved by 145 W while its power consumption dropped by 48.5%. Moreover, as compared to traditional genetic algorithms, a genetic algorithm integrated with the Kriging response surface approach eliminates the need for experimental correlations. This article's optimal strategy may be utilized to solve a variety of challenging engineering issues. When the fin dimensions (h = 9.5 mm, t = 0.1 mm, s = 2.6 mm, l = 3 mm) were adjusted, the overall performance of (PFHE)s with OSF fins was the best.

Rahul and Kumar [27] Offered a novel design strategy to account for the potential of mixing and matching fin types. A network of two-stream (PFHE)s was studied for multi-stream (PFHE)s with mix-and-match fin sorts. They employed a mixed integer nonlinear programming (MINLP) model, which was turned into a nonlinear programming (NLP) model and addressed in enumeration grouping for a few remaining binary variables. There are four types of fins: plain fin, louvered fin, (OSF), and wavy fin. An approach based on the premise of constant fluid physical characteristics and a single phase was established in this design. Other major testing of (PFHE) design included phase change and other physical characteristics. Because of the different heat transfer factor and physical qualities produced by phase variation, developers are required to divide the whole HE into innumerable little parts, ensuring the precision of the heat transfer factor and pressure drop.

Gu *et al.,* [28] The heat transfer and flow properties of a novel type of (FPHE) with extraordinarily low-pressure drop at the gas side were studied. They used experimental and computational methods to calculate the new structure's convective heat transfer and pressure drop. To identify the optimum model, 3-dimensional numerical simulation results using the CFD package "FLUENT6.3" were compared to experimental data. The performance curves of Re/Nu number and Re/f-factor were achieved based on simulation findings, and the impact of different fin types and plate spacing on surface performance was investigated. The experimental results and numerical simulations were found to be in good agreement. All numerical objectives for Nu values and f-factors varied by no more than 15% from the experimental outcomes. The types of fins have a significant influence on the overall performance of finned plate channels. OSF finned plate channel (SFPC) thermal performance was far more essential than plain finned plate channel (PFPC) (PFPC).

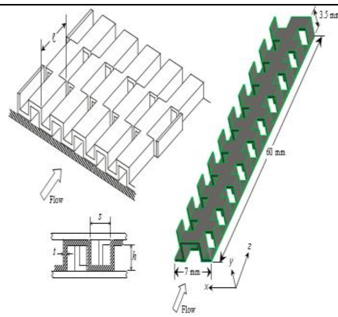
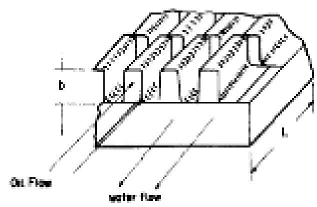
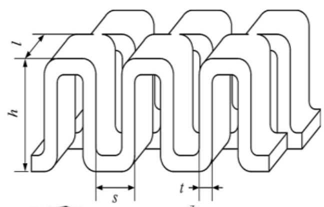
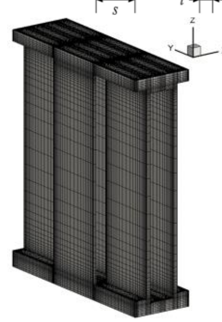
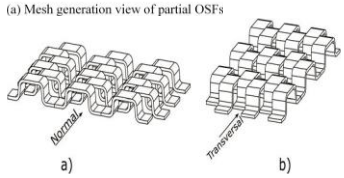
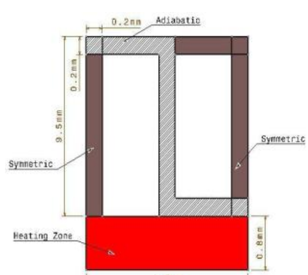
Du *et al.,* [29] Using a heat transfer experimental platform, the researchers examined the thermal-hydraulic performance of an aluminum double flow channel (PFHE) with a staggered fin. The geometry type of the model was offset (PFHE). The experimental correlations for the heat transport j & f factors were established. On the oil side, the suggested correlations showed appropriately well analytical capacity, which was computed by 95% of the tested data, and the average variation of j-factor was less than 3%. On the air side, 85% of the tested data was computed, with an average j-factor variation of roughly 3%. They determined that the simulated outcomes were consistent with the experimental data.

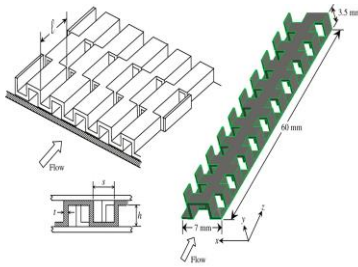
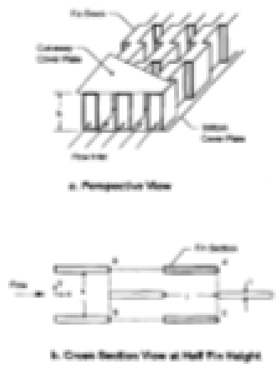
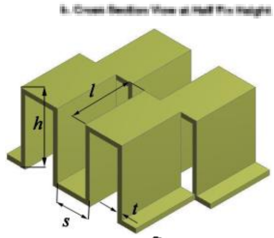
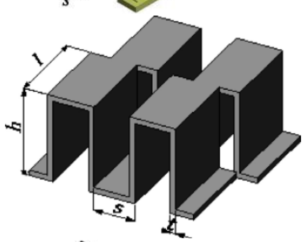
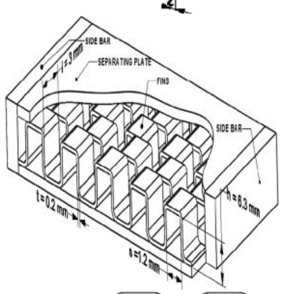
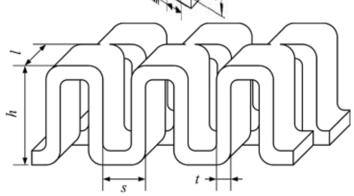
Xu *et al.,* [30] Used the commercial simulation program ANSYS Fluent to create a numerical model to examine the effects of the working medium, operating circumstances, and fin structural factors on the flow and heat transfer performance of sub-atmospheric and low-temperature helium in OSF fins. Based on the findings, when the Re number was lower than 2500, the Colburn coefficient of heat transfer of helium was in the center, while it was the lowest when Re was greater than 2500. The helium Fanning friction coefficient in the operating state was greater than that of air and nitrogen in the same working conditions. Furthermore, the findings revealed that short fin height was selected for high Re and high fin height was carefully selected for low Re. By raising the fin spacing and decreasing the fin thickness, the overall performance could be improved.

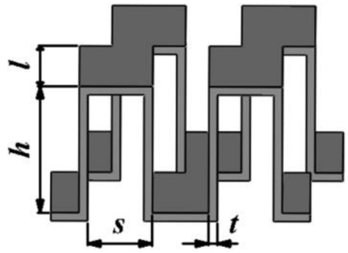
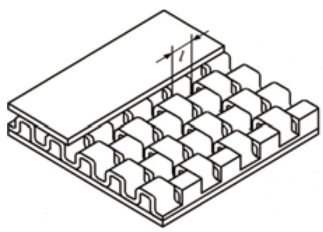
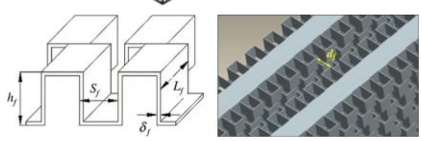
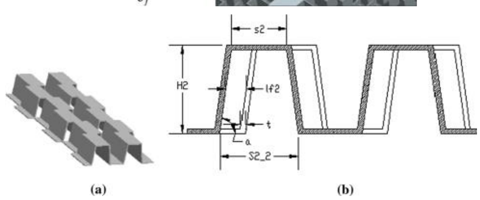
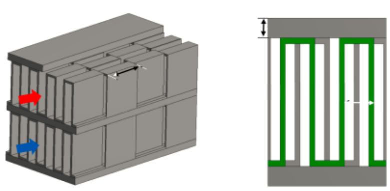
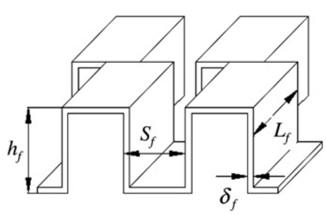
Peng and Ling [31] Developed a mathematical mode technique, which was combined with a few experimental efforts, to acquire the performance of fins with innovative configurations in (PFHE)s and to examine the pressure drop and heat transfer characteristics over OSF fins in (PFHE) at low Re number in detail. (PFHE) 3D heat transmission and pressure drop were theoretically investigated by determining governing equations in two phases of greater complexity. The experimental findings were in perfect accordance with the mathematical calculations. The mathematical analytical approach provided in this research might later be utilized to calculate the performance of new types of fins.

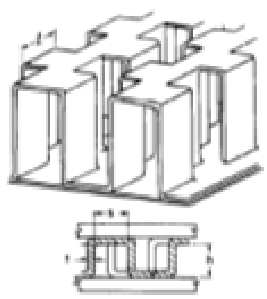
Joshi and Webb [32] Proposed systematic approaches for calculating the heat transfer factor (j & f factors) of the OSF heat exchanger surface shape by utilizing a numerical solutions in the laminar regime and a semi-empirical method in the turbulent regime. Data on friction coefficients were collected on eight scaled-up, idealized geometries. The friction model produced these results with a standard variation of 9.5%. Flow conceptualization investigations on the flow in the fin wakes and its impact on transition were completed. Three different geometries were investigated. A wake width-based Re number can be used to correlate flow patterns in the wake. To calculate the heat transfer factor and friction coefficient, experimental correlations were created. Table 2 shows a summary of the papers which used the Offset Strip Fin.

Table 2
Summary of the Offset Strip Fin papers

Author	Ranges	Geometry	Working fluid	Regime	Temperature Range
Himangshu and Kwan [14]	10<Re<3500 0.7<Pr<50		Water	Laminar - Turbulent	Constant temperature boundary condition
Tinaut *et al.,* [15]	2000<Re< 10000		Oil- water	Laminar - Turbulent	Entering temperatures of 85°C (water) and 120°C {oil)
Tariq and Khan [16]	120<Re <10^4		Air - Gas	Laminar - Turbulent	T Inlet hot (K)620 T Inlet cold (K) 315
Jiang *et al.,* [17]	200<Re<120 00	 (a) Mesh generation view of partial OSFs	Helium gas	Laminar - Turbulent	Mean temperature (300 K at 12 bar, 77 K at 6 bar and 20 K at 2 bar). Tw= 310, 85 & 30 K
Marțian *et al.,* [18]	Re range of transitional to turbulent regime [10^3-10^4].		Water	Turbulent	Hot stream temperature 86.3°C Cold stream temperature 16.8°C
Tiwari *et al.,* [19]	Mass flow rate 0.005-0.02		Air	Laminar	constant temperature = 333K constant heat flux = 20000 w/m^2

Bhowmik and Kwan [20]	10 < Re < 3500		Water	Laminar - Turbulent	The temperature difference between the fluid and the fins ranged from 15°C to 80°C.
Hu and Herold [21]	Prandtl number ranges from 3 to 150		Water and polyalphaolefin	Laminar	T fluid inlet = 10, 20 and 60°C,
Wen *et al.,* [22]	120 < Re < 10000		Air	Laminar	T inlet hot side(K)= 393.15 T outlet cold side(K)= 303.15
Wen *et al.,* [23]	200< Re<3000		Gas	Laminar - Turbulent	T outlet cold side(K)= 293.15 T inlet hot side(K)=373.15
Hu and Heroldi [24]	Re number changes from 3900 to 11,400.		Alpha aluminum oxide nanofluids	Laminar	-
Yang and Li [25]	Re number is from 300 to 8000		Air	Laminar - Turbulent	-

Wen *et al.,* [26]	Re of 800		Air	Laminar	T inlet = 300 K Constant temperature boundary condition (373.15 K) was used on the surface of the upper and lower parting
Rahul and Kumar [27]	Re number ≤ 1000		Air	Laminar	The air enters at temperature (249 K)
Gu *et al.,* [28]	800<Re<8000		Air	Laminar - Turbulent	The maximum air temperature can be 300°C
Du *et al.,* [29]	120 < Re < 104 Oil- air		Oil- air	Laminar	Inlet temp. Th1 (C) 137.3°C outlet temp. Th1 (C) 108.22°C
Xu *et al.,* [30]	The Re range in this study is 1000–5000		Air –helium- Nitrogen	Laminar - Turbulent	Inlet temperature/ K Air 300 Nitrogen 80 Helium 3
Peng and Xiang [31]	Re number ranged from 10 to 200		Oil- air	Laminar	The air inlet temperature was the ambient temperature and the oil inlet temperature should be over 60°C

Joshi and Webb [32]	200<Re<4000		Water	Laminar - Turbulent	-

1.5 Plain and OSF

Studying the Plain and OSF fins of the PFHE with a comparison between them have been a subject of interest among many researches.

Yang *et al.,* [33] thoroughly researched the features of traditional fin efficiency and fin performance. They studied the numerical performance of (OSF) and plain fins using well-validated 3D models. The analytical findings showed that the higher the value of the real fin effectiveness, the greater the thermal performance of the fin surface. In the relatively low Re area, the fin performance of the OSF fin outperformed that of the plain fin with the same cross-section, however, plain fins outperform when (Re>1000). OSF fins with (Affe/t2=120) outperform others when (c>0.07) for a certain mass flux in the fin channel. Additionally, OSF fins with big δ were well chosen in the low Re zone, but those with small δ are better suited for usage in conditions of relatively high Re number.

Yang *et al.,* [34] Investigated the enhancement in heat transfer for (OSF)s through employing (PFHE). They presented a solution approach defined as a relative entropy generation distribution factor to accurately describe the thermodynamic performance of various path configurations in (PFHE). The model geometries are standard (OSF) and plain fin. The analytical findings suggest that the comparatively small results in higher performance, whereas the parameter or, which adds to the highest degree of heat transfer enhancement of the OSF fin, ought to be estimated after the other two geometric parameters are chosen.

Morteza and Faramarz [35] They evaluated the functioning of the fins in five typical configurations: plain, perforated, offset strip, wavy, and pin (PFHE). They used a computational fluid dynamics technique in their analysis to model the heat transfer and fluid flow processes of four popular coolants in (PFHE)s. They evaluated the five fins after modeling them. According to the findings, the coolant with the highest Pr number will experience the greatest pressure reduction. At the same Re values, coolant type has no discernible influence on the f-factor, which is solely dependent on fin shape. Generally, the findings demonstrated that heat exchanger designers may employ the same f-factor correlation.

Wang *et al.,* [36] Used the CFD approach to establish a novel easy mathematical modeling method for the numerical examination of (PFHE)s. The basic method and the CFD package FLUENT were used to validate the mathematical simulations for HEs with two fins at low Re values. Model geometry included plain and OSF fins. They discovered that the distribution of fluid velocity and temperature in the duct of the OSF fins was more uniform on cross-sections than in the duct of the plain fin. The fluid velocity close to the wall was increased for OSF fins, resulting in a smaller thermal boundary layer, better heat transfer factor, and pressure drop.

Kim *et al.,* [37] The (PFHE) was determined utilizing computational and experimental analyses for the plain and OSF models. The study findings show that the prediction model correlates the experimental outcomes with the parameters Re number and fin pitch. The quantity of heat transfer resulted in an increase in the hot airflow rate and a decrease in the cold airflow rate. Furthermore, the heat transmission of the OSF shape is greater than that of the basic rectangular fin shape. In the experimental study, the heat transfer of the OSF shape is equivalent to 13.4% greater than that of the plain fin when Re = 6112 for the hot airflow and Re = 2257 for the cold airflow. The (effectiveness-NTU) approach is used in a prediction model. The variance in heat transfer and pressure drop between the computational and experimental values for the plain fin is 1.9% and 5.9%, respectively.

Ozturk *et al.,* [38] The researchers investigated the effect of fins on the performance of a compact heat exchanger. They performed a numerical analysis with CFD software fluent. Six offset strips, three louvers, and three plain fin cases were chosen for their analysis. In terms of the findings of the investigation, both the j&f factors drop as the frontal speed rises. The f-factor decreases affectedly when the velocity becomes 5 times more than the primary velocity. It can be seen that the louvered fin has maximum pressure drop and coefficient of heat transfer among all the determined cases (plain fin, louvered fin, and OSF) whereas the plain fin shows the poorer performance among the same cases.

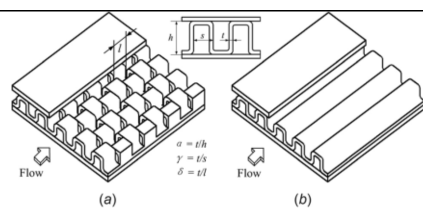
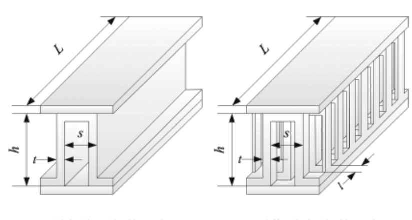
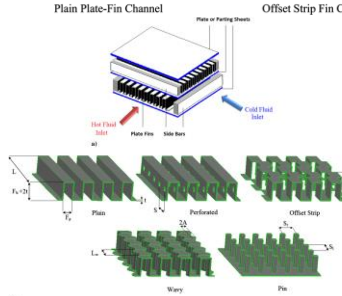
Yang *et al.,* [39] Used experimental and statistical analysis to evaluate heat transfer and flow friction parameters in one-side heated vertical channels with plain fins, OSF, and perforated fins. Because of heating condition and Pr number consequences, the experimental J-factor of the OSF is equal to (20%), less than the results of "Manglik & Bergles" correlation. While the experimental f-factor showed a similar fit with the values of "Manglik & Bergles" correlation with a relative error of (10%) because the f-factor is mostly impacted by Re number. In laminar flow, the J-factor drops by around 15%, while in turbulent flow, it drops by about 20%. In the turbulent flow area, however, there is no gap between the J-factor of liquid and air.

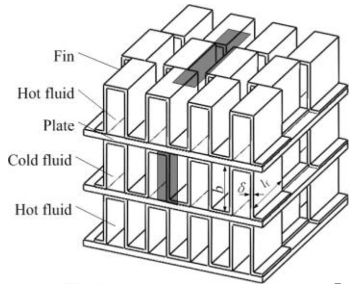
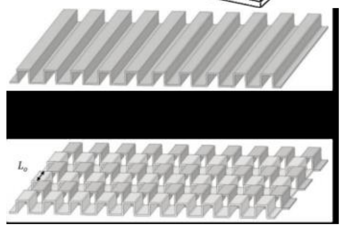
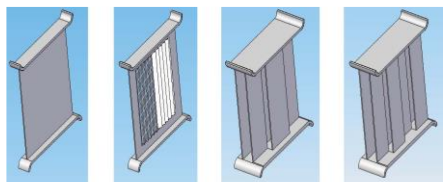
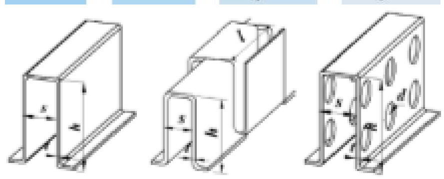
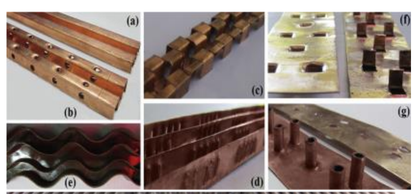
Aliabadi *et al.,* [40] Through experimental analysis, they offered a comparative value of seven community configurations of channels employed in (PFHE). Plain, perforated, offset strip, louvered, wavy, vortex-generator, and pin geometries were embedded in the model. Based on the findings and comparison procedure with other research, the VG channel demonstrated a significant advancement in the heat transfer factor and a specific decrease in the heat exchanger surface area. As a result, it may be used as a high-quality interrupted surface in the (PFHE). Furthermore, with low Re values, the wavy channel performs well. They determined that the VG, wavy, pin, offset strip, perforated, louvered, and plain channels yield the highest heat transfer factor and j-factor values. Furthermore, the pin, VG, wavy, offset strip, louvered, perforated, and plain channels produce the highest pressure drop and f-factor values.

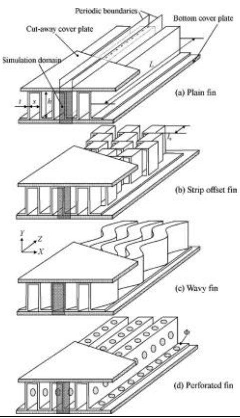
Liu *et al.,* [41] They examined the convective heat transfer factors and the f-factor by analyzing 2-phase flow throughout channels of cold-box HEs for LNG liquefaction. In the experiment, they employed CFX Release 13.0. Concerning model geometry, 3 types of fin shapes were implemented: plain, wavy, and OSF. The analytical findings were then processed to determine the wall shear stress and heat flux, which yielded the f-factors and convective coefficient of heat transfer. The variables are shown as measures of system pressure, flow rate, and local quality. The findings may be utilized to design (PFHE) with identical fin designs and operational circumstances as were used in the calculation. They concluded that system pressure strongly influenced the pressure gradient but had a weak influence on the convective coefficient of heat transfer. The wall superheat had a strong influence on both the pressure gradient and the coefficient of heat transfer. Both quality and mass flow rate had strong influences on both the pressure gradient and the heat transfer factor.

Zhu and Yanzhong [42] They designed four basic fins and computer-generated them by employing three-dimensional numerical simulations on the flow and heat transfer in the four fins that were examined and performed at the laminar flow regime, and CFD simulations are performed for the four basic fins of (PFHE). The (PFHE)s, rectangular plain fin, OSF, perforated fin, and wavy fin were all part of the model geometry. Based on analysis findings, there was a clear correlation between the calculations and the experimental analysis. Furthermore, a data reduction approach for determining the local Nusselt numbers, j&f factors was described, using the heat transfer and pressure drop characteristics in the four fins acquired and evaluated in detail. The flow and heat transfer impacts of OSFs in the strip fin, holes in the perforated fin, and corrugated walls in the wavy fin were investigated. Table 3 illustrate a summary of the papers which dealt with the plain and Offset Strip Fins.

Table 3
Summary of the plain & offset strip fin papers

Author	Ranges	Geometry	Working fluid	Regime	Temperature Range
Yang *et al.,* [33]	300<Re<1500		Air	Laminar	Constant temperature boundary condition is used on the Inlet, outlet, and covered-plate walls
Yang *et al.,* [34]	Re number is from 100 to 10,000.		Air	Laminar - Turbulent	The covered plate wall is at a uniform temperature Tw=295K
Morteza and Faramarz [35]	100 ≤ Re ≤ 1600		Air, water, oil, and ethylene glycol	Laminar	The inlet temperature of the coolant was 300.15K

Wang *et al.,* [36]	300<Re<800		Water	Laminar	Upstream bulk temperature 300K
Kim *et al.,* [37]	Re of the cold airflow ranges from 1115 to 2686, For the hot airflow, from 3056 to 6112		Air	Laminar - Turbulent	The hot air, the temperature are 75°C The temperature are 23 °C for the cold air
Ozturk *et al.,* [38]	500 < Re < 7500		Air	Laminar - Turbulent	Inlet temperature equal to 298K Tw=314K
Yang *et al.,* [39]	350 < Re < 1730		Air	Laminar	The fluid inlet temperature was maintained at about 21°C And the fluid outlet
Aliabadi *et al.,* [40]	Re number range is from 480 to 3770.		Water,	Laminar - Turbulent	Inlet working fluid temperature (298.15K),
Liu *et al.,* [41]	Mass flow rate(kg/s) 150	 (a) wavy (b) serrated (c) plain	Nitrogen	Turbulent	Nitrogen at the temperature range around –170°C

Zhu and Yanzhong [42]	132.3<Re<1323		Water	Laminar	Inlet temperature of 60°C

2. Conclusion

This study includes a full explanation of the plain and OSFs types geometries that may be employed for heat transfer. OSF improvement geometries have been created to make the (HE)s more efficient and compact. PFHEs are now widely used in "cryogenic systems" and "gas-liquefaction facilities" [43]. Plain-fin heat transfer development is primarily due to an increase in the appropriate heat transfer surface area; OSF fins boost heat transfer by increasing the surface area and regenerating the thermal boundary layer in each column, enhancing the flow path, and generating secondary flows (Dean vortices) and chaotic advection [44]. The flow distribution in the PFHE is also highly connected to the examined models' inlet Reynolds number and pressure drop. According to one study, the fin performance of an OSF fin is superior to that of a plain fin with the same cross-section in the low Re area, but plain fins perform better when Re>1000. There is an ideal Re number for each OSF fin and plain-fin that corresponds to the best fin performance [45]. The j & f factors, are the most essential two parameters of researching the heat exchanger that were represented as functions of Reynolds number and other geometrical parameters that were provided in previous research. The f-factor represents pressure drop properties, whereas the j-factor represents heat transfer, and the j/f ratio is known as the efficiency index [46]. According to all research, the j & f factors drop as the Reynolds number increases. At the same Reynolds number, the J-factor declines and the friction factor f increases as the fin pitch increases for the same fin height and fin thickness.

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