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Performance Evaluation of Plate-Fin-And Tube Heat Exchanger with Wavy Fins- A Review

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Abstract
The plate fin-and-tube heat exchangers are widely used in variety of industrial applications, particularly in the heating, air-conditioning and refrigeration, HVAC industries. In most cases the working fluid is liquid on the tube side exchanging heat with a gas, usually air. It is seen that the performance of heat exchangers can be greatly increased with the use of unconventionally shaped flow passages such as plain, perforated offset strip, louvered, wavy, vortex generator and pin. The current study is focused on wavy-fin. The wavy surface can lengthen the path of airflow and cause better airflow mixing. In order to design better heat exchangers and come up with efficient designs, a thorough understanding of the flow of air in these channels is required. Hence this study focuses on the heat transfer and friction characteristics of the air side for wavy fin and tube heat exchanger.

I. Introduction

Extended or finned surface are widely used in compact heat exchangers to enhance heat transfer and reduce their size. The plate fin-and-tube heat exchangers are widely used in variety of industrial applications, particularly in the heating, air-conditioning and refrigeration, HVAC industries. There are many different types of geometry for heat exchangers available and being used. The plate-fin and tube geometry is one of the most common configurations. There are different types of plate-fin geometry, the most common being the plain fin, where the fins are parallel plates attached to a hot element in the form of tubes or some other shape. These fins act as a sink, absorbing the heat out of the hot element with the help of conductive heat transfer. And then dissipating this absorbed heat onto the outside environment which is at a lower temperature. It has also been shown that the performance of heat exchangers can be greatly increased with the use of unconventionally shaped flow passages by Webb [4] and Wang et al. [5]. Some examples of such enhanced surfaced compact cores include plain, perforated offset strip, louvered, wavy, vortex generator and pin. Of these, as shown in Fig. 1, the wavy fins are particularly attractive for their simplicity of manufacture, potential for enhanced thermal-hydraulic performance, and ease of usage in plate fin-and-flat tube heat exchangers[1] The wavy surface can lengthen the path of airflow and cause better airflow mixing. As the wavy surfaces increase the flow path, it also increases the above mentioned surface area, thereby aiding in better heat transfer. The better flow mixing can be attributed to the corrugations existing in the flow channel.

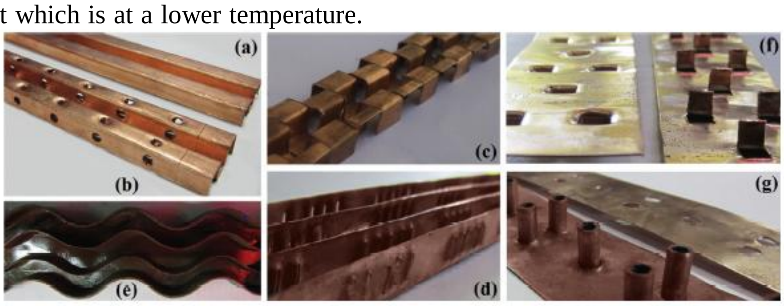


Figure 1. Plate-fin channels: (a) plain (b) perforated (c) offset strip (d) louvered (e) wavy (f) vortex-generator (g) pin [2]

These above mentioned heat exchangers are commonly operated with a hot liquid inside the tubes and air on the outside. The heat from the fluid is transferred to the fin by conductive heat transfer. The fins then dissipate the heat onto the environment by convective heat transfer. The dominant heat resistance of almost 80%-90% for an air-cooled heat exchanger is external, which is on the air side as mentioned by Wang et al. [6,7]. There is not much heat resistance in the tube side or the channel where liquid flow takes place. Hence, there should be a greater focus to reduce the heat resistance on the dominant air side.

The flow of air between the fins is filled with obstructions in the form of tubes, and also the air is in constant contact with the fins. The same air is the carrier of heat from the fins and there by cooling the fins down. In order to design better heat exchangers and come up with efficient designs, a thorough understanding of the flow of air in these channels is required. Hence this study focuses on the heat transfer and friction characteristics of the air side for wavy fin and tube heat exchanger.

II. Wavy Fin

When the fins have periodic corrugations in their geometry in the form of a wave, then it is called a wavy fin. The wavy pattern may be smooth or of a herringbone pattern. These periodic corrugations having a definite angle of corrugation that helps in better mixing of flow, thereby providing higher heat transfer. These corrugations in a wavy fin help in increasing the flow length in a limited space than that of the plain fin. This type of geometry is being widely studied and used these days due to its attractive heat transfer performance as demonstrated in their studies conducted by Nishimura et al. [8] and Wang et al. [9]. The important parameters in the study of wavy fin are the wavy angle and the wavy height, fin pitch, fin length, fin thickness, longitudinal pitch, transverse pitch, waviness amplitude, colburn factor, friction factor, and

The nomenclature of wavy fin and tube heat exchanger are.
Longitudinal pitch is the distance between the centers of two tubes lengthwise. Transverse pitch is the distance between tubes in the transverse direction.

pressure drop which will be explored in detail in this study.

The basic ideas behind having different types of fins or extended surfaces are different. The most common one is to induce boundary layer separation in the channels, so as to provide better mixing, as is the case in wavy channels, and thereby increasing the heat transfer rate. Figure 2 shows a three dimensional image of a wavy fin heat exchanger.

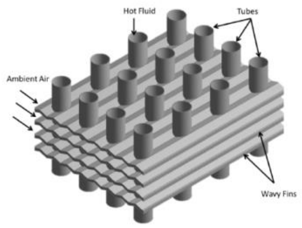


Figure 2. Wavy fin heat exchanger with tubes in inline arrangement

The front view of the wavy fin staggered configuration heat exchanger with perpendicular tubes with in-line arrangement is shown in Figure 3

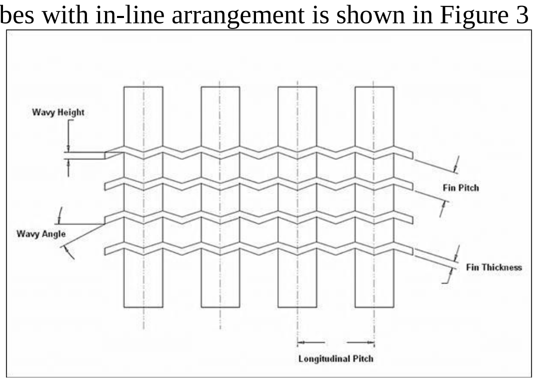
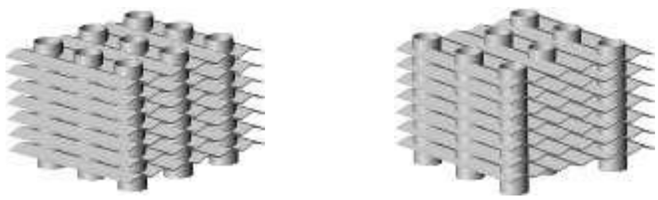


Figure 3. Front view of the wavy fin heat exchanger with nomenclature.

Fin thickness, as the name suggests is the thickness of each fin. Fin spacing is the distance between the fins. The fin pitch is the sum of fin thickness and fin spacing. Wavy angle is the angle the fins create with horizontal axis. The vertical distance the wavy corrugation extends is termed as wavy height.



a. Wavy in lined b.Wavy Staggered

Figure 4. Different fin and tube arrangement

III. Literature Review

The great advantages and different application of wavy fin and tube heat exchangers are the factors that motivate many investigators to study the performance of these heat exchangers. Therefore numerous experimental and numerical studies have been conducted on characteristics of each plate-fin channels. The earliest experimental data are given in the classical Kays and London[10]

Junqi Dong et al. [11] carried out three-dimensional numerical simulations and experimental study of air flow and heat transfer characteristics over the wavy fin heat. The numerical simulation results compared with the wind tunnel test data. In this paper the results of friction factor and heat transfer performance test data and the numerical simulated results for fully developed turbulent region of air flow in the wavy fin are presented. The major findings were, it is shown that the *j* factor increases with waviness amplitude. The wavy fin wit bigger waviness amplitude have bigger heat transfer coefficient under the same *Re* Somchai Wongwises et al. [12**]** studied, the effects of fin thickness on the heat transfer and friction characteristics of fin and-tube heat exchangers having herringbone wavy fin configuration on a well insulated open wind tunnel and herringbone wavy fin- and tube heat exchanger made from aluminium plate fin and copper tube. The results are presented as plots of the Colburn factor and friction factor against the Reynolds number based on the fin collar outside diameter. From the results, it is found that for number of tube rows (N) = 2, the Colburn factor increases with increasing fin thickness and for N ≥ 4, the Colburn factor decreases with increasing fin thickness. The friction factor increases with increasing fin thickness when fin pitch (Fp) ≤ 1.81 mm.

Y.B. Tao et al. [13] carried out three-dimensional numerical simulations for laminar flow of wavy fin-and-tube heat exchangers by using body-fitted coordinates (BFC) method. The air side heat transfer and fluid flow characteristics of wavy fin-and-tube heat exchanger were performed by taking into account the fin efficiency effect. The simulation results of average Nusselt number, friction factor and fin efficiency were compared with experimental correlations and Schmidt approximations, the good agreements validate the model code. The study shows that the average Nusselt number of the wavy fin-and-tube heat exchanger increases with the increase of Reynolds number but the friction factor and average fin efficiency decrease. For wavy fins, the distributions of the local Nusselt number, local fin efficiency are more complicated due to the effect of the wavy angle. The local Nusselt number decreases sharply at the inlet region, and then it increases at near to the first wave crest. The fin efficiency at the inlet region of wavy fin is larger than that of plain plate fin. Thus by increasing the fin area and wavy angle at the inlet and decrease the fin area and wavy angle at the outlet, which could not only enhance heat transfer but also decrease material consume and pressure drop.

Mao-Yu Wen et al. [14] studied the experimental design of the fin-and-tube heat exchanger for three different fins (plate fin, wavy fin, and compounded fin) in a wind tunnel. The heat transfer coefficient, the pressure drop of the air side, the Colburn factor *(j)* and the fanning factor *against* the air velocity (1-3m/s) and Reynolds number (600-2000) have been studied .The results of the wavy fin to the flan fin show that the pressure drop, heat transfer coefficient, *f* factor and *j* factor increases about 10.9-31.9 %, 11.8-24 % , 2.2-27.5 % and 0.5-2.7% respectively.

Junqi Dong et al. [15] studied the air side thermal hydraulic performance of the wavy fin-and-flat tube aluminum heat exchanger. Experimental tests were conducted under different operating conditions for 16 sets of wavy fin geometry parameters. Correlation was developed for the heat transfer and pressure drop performances of a wavy fin heat exchanger by the multiple regression method. It is showed that the amplitude and length of a wavy fin were the most important factors for the heat exchanger's overall thermal hydraulic performance.

Albetel Septimiu et al. [16] studied the wavy fin with straight section and without straight section for hydraulic performances of an oil to air compact heat exchanger by Autodesk's simulation software. The found that that a straight section at inlet and outlet of the wavy fin is beneficial in terms of overall performance of the fin.

Arafat A. Bhuiyan et al. [17**]** numerical investigated the heat transfer and pressure drop for the Plain and wavy fin and tube Heat exchanger considering in lined and staggered tube arrangements for laminar flow regime .The effects of different geometrical parameter such as Longitudinal pitch, Transverse Pitch ,Fin Pitch (Fp), on the heat transfer and the pressure drop were investigated for the laminar flow range for the four fin configurations were studied. Wavy fin show larger heat transfer performance as indicated by higher Colburn factor (j). Increase in the longitudinal pitch cause a decrease in the heat transfer and pressure drop performance. Increase in the transverse pitch cause a decrease in the heat transfer and pressure drop performance.

Chi-Chuan Wang et al. [18] studied the airside performance of the wavy fin-and-tube heat exchangers having a larger diameter tube (Dc = 16.59 mm) with the tube row ranging from 1 to 16. It is seen that number of tube row has a significant effect on the heat transfer performance, and the heat transfer performance deteriorates with the rise of tube row. The effect of fin pitch on the airside performance is comparatively small for N = 1 or N = 2. However, a notable drop of heat transfer performance is seen when the number of tube row is increased and normally higher heat transfer and frictional performance is associated with that of the larger fin pitch.

Nae-Hyun Kim et al. [19] study, the heat transfer and friction characteristics of heat exchangers having herringbone wave fins were experimentally investigated. Eighteen samples which had different fin pitches (1.34 mm to 2.54 mm) and tube rows (one to four) were tested. The waffle depth was 1.14 mm, and the corrugation angle was 11.7^0. He found that the *f factors* increase as the fin pitch increases. Both the *j* and *f* factors decrease as the number of tube rows increases. As the Reynolds number increases, the effect of tube row diminishes, at least for *j* factors.

Igor Wolf et al. [20] investigated numerically the heat transfer on the air-side of a fin-and-tube heat exchanger for air conditioning system having three row of circular tube in staggered arrangement. Refrigerant flows through the tube and air is directed across the tube bundle. To effectively improve the performances of the heat exchanger, enhanced surface geometries are employed. The wavy pattern was selected because of its popularity owing to better air flow mixing and higher heat transfer compared to plain fins without causing considerable increase in pressure drop.

Carluccio et al. [21] carried out a numerical study with a thermo-fluid-dynamic analysis for an air-oil compact cross flow HEX, which was used in ground vehicles. For the oil side, the geometry of the offset fins did not cause a high level of turbulence, but increased the surface area. On the air side, the wavy fins could enhance the heat transfer coefficient twice, compared to straight triangular fins.

Cheng Yongpan [22**]** in these cases an array of tubes are arranged regularly with staggered or inline configuration, the parallel fins are attached to the tubes perpendicularly. Because the airside thermal resistance often accounts for more than 90% of the overall thermal resistance, a variety of plate fin surfaces in airside are developed to enhance the heat transfer. The plain fin was early proposed, which is basically a continuous plain sheet of metal attached to a set of regularly positioned tubes. In order to further increase heat transfer performance, wavy fin was developed later in which streamwise corrugated flow channels are formed by bending the base sheet. The wavy fin feature relatively reliable and durable performance, and are also easy to manufacture. For the fin-and-tube heat exchanger with interrupted fins for air conditioning system the condensate water or frost may adhere to the fin surface, causing the bridging of the fin spacing, thus the pressure drop is sharply increased and heat transfer performance is greatly deteriorated; furthermore, the condensate water or frost may corrode the metal fins and tubes. However, the wavy fin-and-tube heat exchanger can relieve such problems, and it also owns high reliability and long duration, hence it is extensively adopted in various engineering applications.

IV. Conclusion

The easy manufacturing and designing process as compared to other fin and tube heat exchanger motivates various researchers to study this fin. Various performance parameters such as fin pitch, fin length, fin thickness, longitudinal pitch, transverse pitch, waviness amplitude, Coburn factor, friction factor, and pressure drop were studied in the literature review. Following were the major finding from the literature review

1. The wavy surface lengthen the air flow path and cause better air flow mixing thus increasing the heat transfer rate.
2. Increase in longitudinal and transverse pitch decreases the heat transfer and pressure drop performance.
3. Heat transfer performance deteriorates and the *j* and *f* factor increases as the number of tube row increases.
4. Fins with bigger waviness amplitude have higher heat transfer.
5. Friction factor *(f)* increase as the fin pith and fin thickness increases.

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