ISSN 2395-1621

Review on Heat Transfer Enhancement Using the Wavy Fin

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ABSTRACT

One way to enhance the heat transfer on the air-side of the heat exchanger is to modify the fin geometry. The wavy fin is one of the most popular fin types in plate fin heat exchangers, particularly where superior heat transfer performance is demanded under tight pressure drop allowance. They are uninterrupted surface with cross section shape similar to that of plain fins except for the undulations in the flow direction. This paper has made a comprehensive review of the experimental and theoretical efforts made by the scientific community for optimizing the shape of the finned surfaces in order to increase heat transfer effectiveness and decrease the dimensions and the weight of heat exchangers and many experimental and numerical investigations have been conducted for various kinds of internally finned tubes for both laminar and turbulent flows. The issues and prospect of the wavy fins is discussed here with reference to the open literature.

Keywords—Wavy fins, Heat Transfer, Laminar flow, Wavelength, fin height.

ARTICLE INFO

Article History :

Received:2nd November 2015

Received in revised form:

4th November 2015

Accepted : 5th November 2015

I. INTRODUCTION

The Internally finned surfaces are widely used in many engineering fields to enhance heat transfer. Some of the typical applications include electrical and electronic equipment cooling, compact heat exchangers and gas turbine blade cooling. Many researchers have studied the problem of optimizing the shape of the finned surfaces in order to increase heat transfer effectiveness and decrease the dimensions and the weight of heat exchangers and many experimental and numerical investigations have been conducted for various kinds of internally finned tubes For both laminar and turbulent flows, the finned tubes exhibited substantially higher heat transfer coefficients when compared with corresponding non-finned tubes [2] .Extended or finned surfaces are widely used in compact heat exchanger to enhance the heat transfer and reduce the size. Common among these are automobile radiators, charge air coolers, automobile air-conditioning evaporators and condensers to meet the demand for saving energy and resources [3]. The plate fins on the wavy fin heat sinks are not parallel. The waviness is introduced based on two hypotheses: (a) The waviness of the fins might interrupt the boundary layers, and (b) The flow between the fins may deflect and impinge on other fin surfaces. Both hypotheses suggest the possibility of higher heat transfer rates. [4].Very few studies carried out on Wavy fins to enhance the heat transfer rate. These studies are reviewed in details furthermore and differentiated under sub heading.

ISSN 2395-1621

II. EXPERIMENTAL WORK

A Some of the researchers studied on waviness structure, thickness of fins, fin pitch, wavelength, wavy amplitude, height, length are reviewed.Kuvannarata T. [1] the heat transfer coefficient and air-side pressure drop were plotted against the frontal velocity, it was found that the heat transfer coefficient and pressure drop increase with frontal velocity. Wang Q. [2] studies the influences of different fin patterns on heat transfer and pressure drop performance and simplified the actual physical model. Fin is analysed at inlet/outlet air temperatures of 373/323 K, and the cooling water inlet temperature is about 300 K. Under such operation condition, it is reasonable to assume the air to be incompressible with constant physical properties. Therefore, the working fluid (dry air) is assumed to be incompressible with constant physical properties, and the flow is assumed to be turbulent, steady, three dimensional with no viscous dissipation [2] Air and hot water were used as working fluids. The main components of the systems were the heat exchangers, water flow loop, air supply, instrumentations and data acquisition systems. The wind tunnel system was designed to suck room air over the finned side of the heat exchangers by a 15 kW centrifugal fan. The speed of the fan could be adjusted by a frequency inverter. The tunnel was a rectangular duct 270 · 220 mm in cross-section. To minimize heat loss to the surroundings, the tunnel surface was insulated with a 10 mm thick glass wool layer. Being supported by stands of perforated steel plate, the tunnel system was kept 75 cm above the floor level of the laboratory.

Table 1: Specification of wavy fins parameters

No.	Fin pitch (F_p)	Fin height (F_h)	Fin length (L_d)	Fin thickness (δ)	Wavy amplitude ($2A$)	Wavelength (L)
1	2.0	8.0	65.0	0.2	1.5	10.8
2	2.25	8.0	65.0	0.2	1.5	10.8
3	2.5	8.0	65.0	0.2	1.5	10.8
4	2.0	8.0	53.0	0.2	1.5	10.8
5	2.25	8.0	53.0	0.2	1.5	10.8
6	2.5	8.0	53.0	0.2	1.5	10.8
7	2.0	7.0	43.0	0.2	1.5	10.8
8	2.25	7.0	43.0	0.2	1.5	10.8
9	2.5	7.0	43.0	0.2	1.5	10.8
10	2.0	8.0	43.0	0.2	1.5	10.8
11	2.0	10.0	43.0	0.2	1.5	10.8

Table 1 shows the specifications of the wavy fins tested having samples core sizes are about 250 × 200 mm due to the different fin height. All tested fins were checked before brazing and overall heat exchangers quality after brazing was excellent. The tested wavy fin and flat tube heat exchanger was installed in the test system. In their work, the exchanger height was less than the tunnel dimensions, and the bypass flows were eliminated by a thin layer of foam plastic sandwiched between the heat exchanger core and tunnel edge. Upon completion of the hot water side links, the water tube was completely insulated with a 15 mm thick layer of glass wool. The test was performed in a range of Reynolds number, which is based on hydraulic diameter of fin entrance and maximum air velocity [3]Sikka K [4] designed the wavy fin heat sinks for a vertical orientation of the base plate. For a vertically-oriented heated flat plate in a quiescent ambient, a natural convection boundary layer flow is generated from the lower plate edge. In fig.1 shows four wavy fin heat sinks termed as the corrugated, anti-corrugated, serpentine, and anti-serpentine heat sinks. The plate fins on the wavy fin heat sinks are not parallel. The waviness is introduced based on two hypotheses: (a) The waviness of the fins might interrupt the boundary layers, and (b) The flow between the fins may deflect and impinge on other fin surfaces. Both hypotheses suggest the possibility of higher heat transfer rates. The surface areas of the four wavy fin heat sinks are comparable to the longitudinal-plate, pin, and cross-diagonal fin heat sinks.

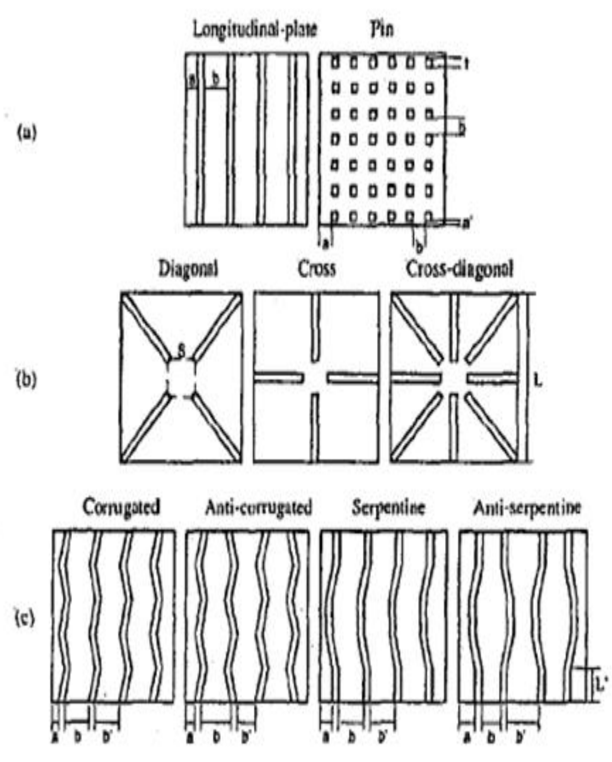


Fig.1: a) conventional heat sinks b) fluted heat sink c) Wavy fin heat sink.

Table 2: Heat sink Dimensions

Heat Sink	b (mm)	b' (mm)	a (mm)	a' (mm)	L' (mm)	S (mm)	A[illegible]
Longitudinal-Plate	12.7	-	6.35	-	-	-	4[illegible]
Pin	6.35	-	6.35	1.59	-	-	4[illegible]
Diagonal	-	-	-	-	-	12.7	2[illegible]
Cross	-	-	-	-	-	12.7	2[illegible]
Cross-diagonal	-	-	-	-	-	12.7	4[illegible]
Corrugated	12.7	12.7	3.17	-	12.7	-	4[illegible]
Anti-corrugated	15.88	9.53	4.76	-	12.7	-	4[illegible]
Serpentine	12.7	12.7	6.35	-	12.7	-	[illegible]
Anti-serpentine	9.53	15.88	7.94	-	12.7	-	[illegible]

They also discussed about that the wavy fin system is modeled assuming that it can be approximated as a sinusoidal wave. This allows the effective flow length to be determined which in turn leads to the enhanced surface area. Assuming a sinusoidal wave has amplitude (*A*) and a wave length (λ). The equation of the sinusoidal wave is

$$\frac{L_e}{\lambda} = 2\frac{\sqrt{1+\gamma^2\pi^2}}{\pi}E\left(\frac{\gamma\pi}{\sqrt{1+\gamma^2\pi^2}}\right)$$

(1)

The ratio (L_e/λ) approaches unity when ($\gamma \rightarrow 0$), i.e., when waviness is small or not present. The elliptic integral can be solved for in most mathematical software or using handbook approximations. Figure 2 shows basic cell of wavy fin geometry.

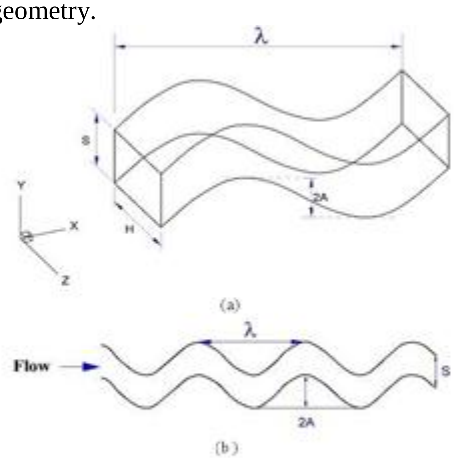


Fig.2: Basic cell of wavy fin geometry: (a) characteristic dimensions of a wavy fin channel and (b) top view of a wavy channel.

Xiaoze Du [5] studied on the influences of locations on the wavy fin surface and the row number of the longitudinal vortex generators. One delta winglet pairs at the middle of the wavy fin surface and the minimum row number, *n* = 1, with the average *PEC* is 1.23, has the best heat transfer performance of all conditions, which can be recommended for practical applications.Gholami A.A. [6] discussed about the effects of using the wavy rectangular winglet, conventional rectangular winglet configuration and without winglet as baseline configuration, on the heat transfer characteristics and flow structure and concluded that the wavy rectangular winglet can significantly improve the heat transfer performance of the fin and tube compact heat exchangers with a moderate pressure loss penalty. In addition, the numerical results have shown that the wavy winglet cases have significant effect on the heat transfer performance and also, this augmentation is more important for the case of the wavy up rectangular winglet configuration. Hossain et.al [7] found that the flow is steady up to critical Reynolds number which depends on the geometric configuration. Beyond a critical Reynolds number, a self-sustained oscillatory flow has been observed. They also studied the effect of variation of minimum height, amplitude and wavelength on flow and heat transfer. Decreasing channel height and increasing amplitude cause the flow to become more unstable and thereby increasing friction factor and heat transfer with variation of wavelength having minimal effect. Wen et. al [8] investigated three different fins including wavy fins and found that the heat transfer enhancement for the wavy channel is more as compared to other ones. Niceno et. Al [9] numerically performed analysis of two dimensional steady and time dependant fluid flow and heat transfer through periodic wavy and arc shaped channels. They found that the flow remains steady up to a critical Reynolds number and beyond a critical value at which transition to an unsteady regime is observed. Heat transfer rate increases as a result of self-sustained oscillations.

III.OBSERVATIONS

AKuvannarata T. [1] experimentally determined the air-side heat transfer and friction characteristics of all tested samples the thicknesses of the herringbone wavy fins examined in this study were 0.115 and 0.250 mm. The heat transfer coefficient and air-side pressure drop were plotted against the frontal velocity for the tested samples 1 and 6, as shown in Fig. 3.

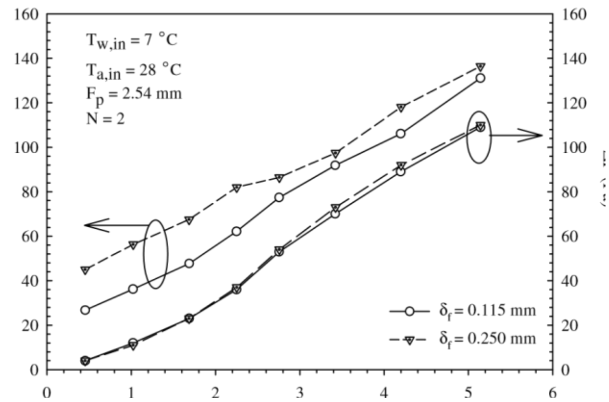
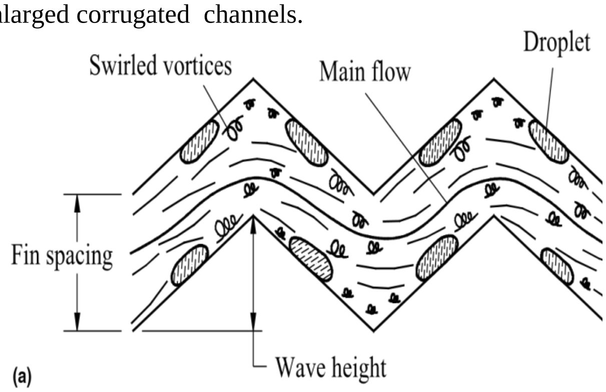


Fig. 3: Effect of fin thickness on the heat transfer coefficient and pressure drop for 2-row configuration: test results for (a) F_p = 1.41 mm and (b) F_p = 2.54 mm.

A schematic showing the influence of fin thickness in corrugated channels for smaller and larger fin spacing is shown in fig 4 a. apparently the airflow may interact with the condensate droplet, giving way to swirled motions. For a larger fin thickness, the corresponding fin spacing is comparatively small. As seen in fig 4 b, for a larger fin spacing, the main flow may not be effectively directed by the corrugated channel whereas the main flow can flow along the corrugated channel more effectively provided that the fin spacing is less than wave height ($F_s < P_d$). This phenomenon had been confirmed by a numerical visualization of the flow pattern within corrugated channels from McNab et al. [10]. Analogous results were also reported by Wang et al. [11]. Who conducted a flow visualization experiment within enlarged corrugated channels.



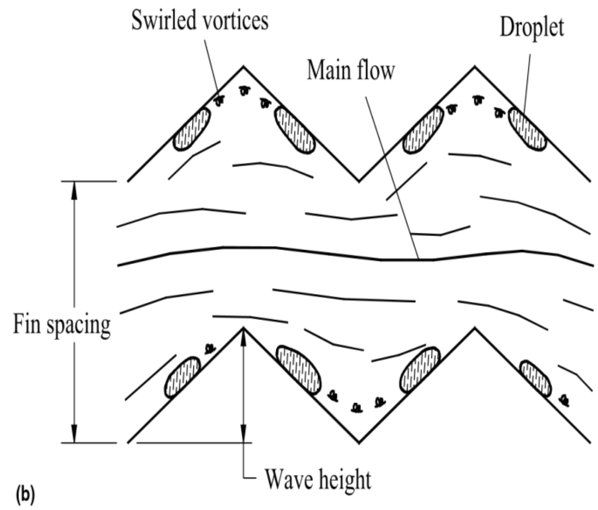


Fig. 4: Schematic showing the interactions between directed airflow and generated swirled flow for small and large fin spacing: smaller fin spacing.

IV. CONCLUSION

The wavy fin is one of the most popular fin types in plate fin heat exchangers, particularly where superior heat transfer performance is demanded under tight pressure drop allowance. They are uninterrupted surface with cross section shape similar to that of plain fins except for the undulations in the flow direction.This paper focused with almost all the issues that need attention of scientific community to arrive at best optimised fin geometry and shape to enhance the heat transfer effect in many applications.

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