ANALYSIS OF FLOW AND HEAT TRANSFER OVER LOUVERED FINS IN COMPACT GEOMETRIES

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ABSTRACT

The louvered fin is most widely used in automotive applications. Compared to other geometrical parameters of the fin, the louver angle has a stronger effect on heat transfer. This study is carried out by computational method to determine the louver inclination of a rectangular channel heat exchanger that has the greatest influence on flow and heat transfer and invariant with other geometrical parameters. The meshed CAD model is validated with an established correlation in literature. In the earlier years of study, the mean flow angle was defined in two dimensional flows. ANSYS-CFD is capable of defining a mean flow angle was defined in three dimensional flows. The validation agrees well, with about 5.39% of error. Various graphs are plotted to determine the optimized louver inclination. From the plotted graphs of Nusselt number and pumping power against the Reynolds Number, it is observed that the louver angle has a strong influence on the heat transfer rate. Then, a ratio of heat transfer rate to pumping power is used in the graphs as the non-dimensional number representation to determine the optimum angle. In addition to this study, a general correlation is developed to represent the behavior of louver angle at different ranges of pumping power. With a practical range of Reynolds numbers and louver angles, the optimum angle is found to be 20 degrees. This numerical result has a high confidence level where a good agreement between the meshed models with the established finding is obtained. The study has succeeded in obtaining the result that was set out as the objective.

ABSTRAK

Louver fin adalah yang paling sesuai untuk aplikasi automotif. Berbanding dengan parameter yang lain, sudut *louver fin* adalah paling mendorong kepada perubahan aliran dan keboleh pindahan haba. Dalam tesis ini, kajian dilakukan secara simulasi berkomputer untuk menentukan sudut *louver fin* yang optimum dari segi keboleh pindahan dan ketelusan pengaliran udara. Model yang di*mesh*, telah menjalani peringkat pengesahan dengan formula dari kajian yang terdahulu. Di awal kajian, definisi adalah dalam aliran dua dimensi. Perisian ANSYS-CFD boleh memberi definisi dalam bentuk tiga dimensi. Pengesahan adalah sahih dalam 5.39% ralat. Pelbagai graf telah diplot dan didapati definisi *pumping power* adalah yang paling sesuai digunakan dalam optimisasi. Melalui graf-graf iaitu Nusselt number dan *pumping power* yang diplot berlawanan dengan Reynolds Number, ia didapati bahawa sudut louver mempunyai pengaruh yang kuat terhadap keupayaan pindah haba. Maka, satu nisbah antara keupayaan pindah haba kepada *pumping power* digunakan sebagai perwakilan nombor tidak berdimensi bagi menentukan sudut optimum louver. Sebagai tambahan kepada kajian ini, persamaan matematik yang merangkumi keseluruhan sifat sudut *louver fin* dengan *pumping power* dalam kajian juga dibinakan. Dalam lingkungan *Re* yang pratikal, sudut *louver fin* yang optimum adalah 20 degree. Hasil kajian ini adalah selari dengan hasilan dapatan dari literatur oleh pengkaji yang terdahulu.

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NOMENCLATURE

Symbols

A	Area
α	Louver angle
b	Thickness ratio (ratio of fin thickness over louver length)
β_{mean}	Mean flow angle
c_p	specific heat capacity
D	ideal distance if the flow were aligned with the louver
d	characteristic flow efficiency length scale ratio
F	Fin pitch or fin height
F_l	Fin width
F_p	Fin pitch ratio (ratio of fin pitch over louver length)
G	Mass velocity
h	heat transfer coefficient
$\overline{h}$	Average heat transfer coefficient
i	Specific enthalpy
k	conductivity
L or L_l,	Louver pitch or louver length
L_p	Louver pitch ratio $L_p=1$
m	Mass
$\dot{m}$	Mass flow rate
N	Actual distance traveled by dye
Nu	Nusselt number
η	Flow efficiency
η_{sw}	Flow efficiency based on the finding of Sahnoun and Webb

η_{wt}	Flow efficiency based on the finding of Webb and Trauger
$\eta_{wt,max}$	Flow efficiency at critical Re number based on the finding of Webb and Trauger
p	Pressure
ϕ	Streamlines
ρ	Mass density
Re_L	Reynolds number based on louver pitch
Re_{in}	Reynolds number based on inlet velocity
$Re_{wt,c}$	Critical Reynolds number based on the finding of Webb and Trauger
St	Stanton Number
T	Temperature
U	velocity in horizontal direction
u	velocity in horizontal direction
v	dynamic viscosity
V	velocity in vertical direction
$\dot{W}$	pumping power
x	x-direction
y	y-direction
Δ	difference

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CHAPTER I

INTRODUCTION

1.1 Background

Compact heat transfer surfaces play an important part in heat exchanger technology because they are lighter and more efficient. Newer surfaces are constantly evolving as a result of recent developments in compact heat exchangers. Of the many types of fins that have been studied in compact heat exchangers, such as strip fin, offset fin, wavy fin etc., the louvered fin is most widely used in automotive applications. The various forms of louvered fin flat-tube surface are shown in figure 1.1. According to Kraus et al. (2001), the design of or performance calculation for a compact heat exchanger for rejection of heat in automotive applications, such as a radiator, it is necessary to establish the heat transfer capability and the associated system resistances.

The louvered fin is the preferred fin geometry in radiators because (i) it can be manufactured by automated process (ii) it can be accommodated in a small space, as compactness is important in an automobile, and (iii) unlike other types, it gives high heat duty which reduces the radiator frontal area, which is advantageous for the aerodynamics of the automobile.

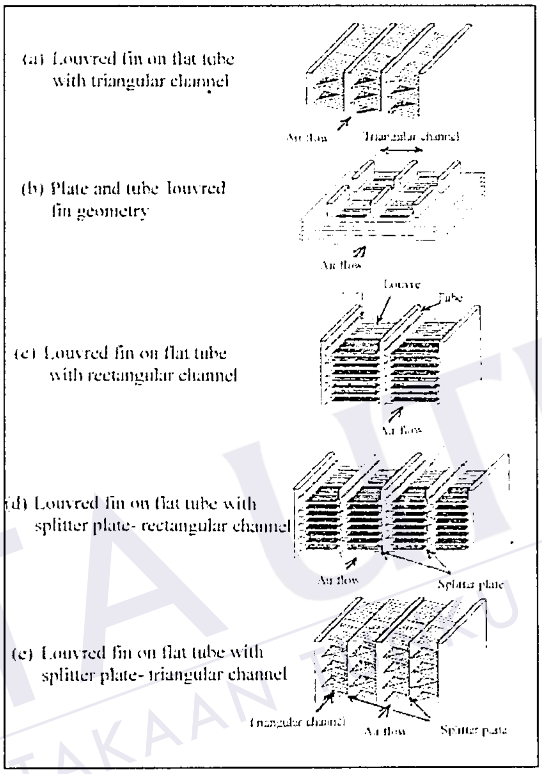

Figure 1.1: Forms of louvered fin-flat tube surface as illustrated by Hesselgreaves (2001).

The hydrodynamic characteristics of a stack of louvered fins have a complex dependence on a number of variables such as fin pitch, fin material, fin thickness, number of louvers, louver pitch, louver height and louver angle. The geometric parameters that can be varied include louver pitch L, louver length L_L, louver angle α, and fin pitch F as shown in figure 1.2. Louver pitch is the same as louver length since it is the same length of the louver forming cuts in the metal. As describe by Shah and

Sekulic (2003), such finning enhances heat transfer by a factor of 2 or 3 compared with unlouvered surfaces.

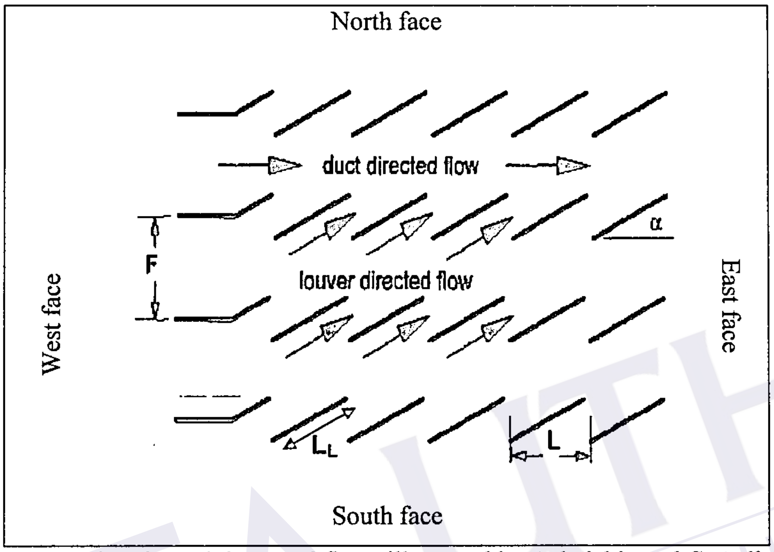

Figure 1.2: Section through louvered fin as illustrated by Achaichia and Cowell (1998a)

At first sight, the function of the louvered fins seems to be as turbulence generators. This was found not true because the louvered fins act rather by causing the fluid flow to be deflected from its incident direction and become aligned with the plane of the louvers which was shown by Beauvais (1965) in large-scale models. Thus, the louvered fins tend to act as multiple flat plates with their associated leading edge laminar boundary layers which enhance heat transfer without a disproportionate increase in flow resistance.

According to Cowell et al (1995), this behavior of flow has been experimentally confirmed by many others- by Davenport (1980), using smoke traces; by Wong and Smith (1973) and Antoniou et al. (1990) using hot-wire anemometry; by Button et al. (1984), using LDA; and by others (Hiramatsu and Ota (1982), Tanaka et al. (1984), Tura

(1986), Hiramatsu et al. (1990), Webb (1990) using water channels and flow visualization techniques. Further evidence of this behavior comes from the numerical analyses of flow through louvered arrays published by Achaichia and Cowell (1988a), Baldwin et al (1987), and Ikuta et al (1990).

1.2 Importance of the Study

Past studies have shown that the flow in the compact heat exchanger is strongly dependent on geometrical parameters. Thus, the optimum heat transfer rate could be obtained by manipulating the geometrical parameters of the fin. In this study was done by selecting the most influential geometrical parameter. In general, the efficiency of the compact heat exchanger increases with air velocity and louver angle, while decreasing with fin pitch and thickness ratio. According to Zhang and Tafti (2003), louver angle has a stronger effect on heat transfer as compared to the other geometrical parameters. Therefore, selecting the louver inclination is a mean to reduce pressure loss without extensive modification in the design of the compact heat exchanger, yet achieve the required heat transfer duty with limited fan power.

1.3 Rationale of the Study

The louvered fin on flat tube with rectangular channel (figure 1.1) is the preferred type of compact heat exchanger for automobile applications. Correlating the friction factor for such an important geometry was done by the past researcher as shown in equations 2.18 to 2.24. However, these correlations are generalized and the percentage of deviation between these is as large as ± 15% and no consideration of the louver thickness parameter. Zhang and Tafti (2003) determined that for small louver angles there is a significant thickness ratio effect on the heat transfer and the flow efficiency, defined in section 2.3. Determining the optimum condition of the louver angle by using generalized correlations of Chang and Wang (1997) is unlikely to lead to the right answers. Therefore in this study the ratio of heat transfer rate to pumping power is considered to determine the optimum angle.

In a typical reliability test of a radiator, the air flow is conducted at 10 m/s (corresponding to a typical Reynolds number of 1000). Analogy of a real situation for such a reliability test is one where the heat load from engine becomes high when the automobile encounters a long upward slope. In such a case when the ram air velocity becomes low, the heat rejection of the radiator can no more depend on the ram air velocity, and has to depend on the fan.

Below Reynolds number of about 300, Davenport (1980) noted that an inconsistency occurred in the heat transfer due to the thickness of the boundary layer developing on the louvers. This idea was also confirmed by the results of Achaichia and Cowell (1988). A review of the past literature, in section 2.7 of this thesis, showed that the heat transfer correlation is yet to have a confirmation of which correlation has the strongest agreement. Besides, such a low Reynolds number is not in the practical range. To exclude this uncertainty, therefore, Reynolds numbers below 300 are not considered in this study.

The importance of the thermal wake on the local heat transfer coefficients along a particular louver had been studied experimentally by Kurosaki et al. (1998), and numerically by Suga and Aoki (1991) and Zhang and Tafti (2001). Zhang and Tafti

(2001) state that neglecting thermal wake effects at low flow efficiencies can introduce errors as high as 100% in the heat transfer. To perform such a study in large scale experiment would induce even more errors when the heating on louver fins is not uniform. Therefore, to avoid such large errors, it is preferable to do this study fully by a computational method. Furthermore, errors are eliminated at validation stage. The results are validated by comparison with previous published correlations. The purpose of validation is to verify that the mesh distribution and solution procedure are suitable before the study is carried further.

1.4 Problem Statement

This study is carried out numerically to determine the louver inclination that has the greatest influence on flow and heat transfer of the compact heat exchanger with rectangular channels, in which, other geometrical parameters are invariant. The study is directed towards automobile applications, although the results can be extended to other situations.

1.5 Objectives

The objectives of this study are:

(i) To develop a model using Computational Fluid Dynamics to analyze the flow and its heat transfer from compact louvered fins.

(ii) To validate the model with the published work on flow through the compact finned passages.

(iii) To determine the optimum louver inclination from the viewpoint of flow and heat transfer for automobile application.

1.6 Scope

The scope of this study is:

(i) Using ANSYS-CFD software to represent the analytical model of rectangular channel compact heat exchanger with louvered fin on flat tube. The model is with fin pitch ratio (ratio of fin pitch over louver length) of 1.5 and thickness 0.05 mm. The model is 2 cm^3 in size and no gravitation effect is considered in such size of control volume. The fin base temperature of the model is assumed as constant temperature.

(ii) The mathematical model, whose validity is confirmed by the previous published research is used in this work.

(iii) A 3-D approach is used in view of the capability of ANSYS-CFD to define a mean flow angle by ratio of average volume, though in earlier studies, the mean flow angle was defined by the ratio of two dimensional flows.

(iv) Reynolds number in the range of 300 to 1200 and louver angles in the range of 15^0 to 30^0 are considered.

CHAPTER II

LITERATURE REVIEW

2.1 Davenport's Observation

Davenport (1980) first recognized that the degree of flow alignment with the louver plane is a function of the flow Reynolds number. He also noted that the fluid flow tended to be down the gap between fins at very low Reynolds numbers because the laminar boundary layers on the louvers are sufficiently thick to effectively block off the gaps between adjacent louvers in the same fin.

Davenport linked the fluid flow down the gap with an inconsistent heat transfer effect when the *j* factor curves show a tendency to flatten off at low Reynolds number (below Re = 300). This idea was confirmed by the results of Achaichia and Cowell (1988b) when they undertook a two-dimensional finite-difference analysis of the fully developed periodic flow situation in an infinite louver array with infinitely thin louvers. The resulting curves are given in Figure 2.1.

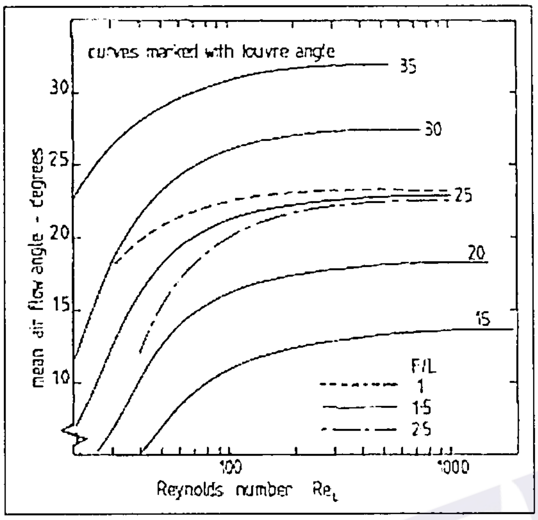

Figure 2.1: Mean flow angles in louver arrays from Achaichia and Cowell (1988b).

2.2 The Mean Flow Angle (β_{mean})

The mean flow angle (β_{mean}) was first introduced by Achaichia and Cowell (1988a) Referring to figure 1.2, it was defined as arctangent of the ratio of flows out and into of the north and west faces, respectively. They equated the mean flow angle with other parameters to describe the fall-off effect as shown in equation (2.1). Similarly, Zhang and Tafti (2003) defined it as arctangent of the ratio of average normal velocity across the top boundary to that across the west boundary but in an individual block surrounding a given louver and expressed as in equation (2.2).

$$\beta_{mean} = 0.936 - (243 / \mathrm{Re}_L) - 1.76(F / L) + 0.995\alpha \qquad (2.1)$$

$$\beta_{mean} = \tan^{-1}\left(\frac{\int v dx / L}{\int u dy / F}\right) \tag{2.2}$$

2.3 Flow efficiency (η)

Flow efficiency is used to describe the percentage of the fluid flowing along the louver direction. 100% efficiency represents ideal louver-directed flow while 0% represents complete duct-directed flow. Two kinds of definition of flow efficiency have been used in the past studies. In experimental dye injection studies flow efficiency is defined as the ratio of actual transverse distance (N) traveled by the dye to the ideal distance (D) if the flow were aligned with the louvers.

$$\eta_{\exp} = \frac{N}{D} \tag{2.3}$$

In numerical simulation, flow efficiency is defined as ratio of mean flow angle (β_{mean}) to louver angle (α).

$$\eta = \frac{\beta_{mean}}{\alpha} \tag{2.4}$$

2.4 The Relation of Flow Efficiency (η) and Heat Transfer (St)

Flow efficiency measures not only the tendency of the fluid flow to follow the louver direction but also the capability of heat transfer from the louvered fins. The louvers tend to act as multiple flat plates as shown by Beauvais (1965) in large-scale models.

In an attempt to relate the mean flow angle and its heat transfer effect, a correlation had been proposed by Achaichia and Cowell (1988b) that makes use of the theoretical results in Figure 2.1. A simple polynomial equation was developed to describe the ratio of mean flow angle to louver angle as a function of louver angle, the ratio of fin pitch to louver pitch and Reynolds number.

$$\frac{\beta_{mean}}{\alpha} = \frac{0.936 - (243/\mathrm{Re}_L) - 1.76(F/L) + 0.995\alpha}{\alpha} \tag{2.5}$$

Incorporating this ratio with experimental results from Achaichia and Cowell (1988b), the following expression for Stanton number was obtained.

$$St = \frac{h}{Gc_p} = 1.18(\beta_{mean}/\alpha)\mathrm{Re}_L^{-0.58} \tag{2.6}$$

This expression had ignored the duct flow component since it is negligible at Reynolds numbers of practical interest and the above equation is found to describe all

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