

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

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

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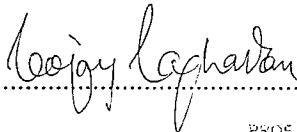
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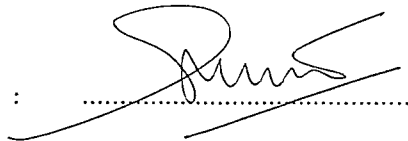
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**ANALYSIS OF FLOW AND HEAT TRANSFER OVER LOUVERED FINS
IN COMPACT GEOMETRIES**

YONG KOK WEE

**A project submitted in full fulfillment of the requirements for the award of the
Master's Degree of Mechanical Engineering**

**Faculty of Mechanical and Manufacturing Engineering
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June 2007

"I declare that this project is the result of my own work except the ideas and summaries for which I have clarified their sources."

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ACKNOWLEDGEMENT

I would like to express my heartiest gratitude to my supervisor, Prof. Dr. Vijay R. Raghavan for his assistance and guidance. With his valuable advice, ideas, support, encouragement and supervision throughout I have been able to complete this task successfully. Also, I would like to thank my teacher Mr. Wan Saiful Islam for his assistance and guidance in computer simulation. My appreciation and thanks to my parents who supported me in all the way of my life. Not to forget my sister and brothers for their love and respect. Thanks to all my beloved ones who have been supporting me and the Ministry of Science, Technology and Innovation (MOSTI) fund for its trust and support.

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 kebolehan pindahan haba. Dalam tesis ini, kajian dilakukan secara simulasi berkomputer untuk menentukan sudut *louver fin* yang optimum dari segi kebolehan pindahan dan ketelusan pengaliran udara. Model yang *dimesh*, telah menjalani peringkat pengesahan dengan formula dari kajian yang terdahulu. Di awal kajian, defininasi adalah dalam aliran dua dimensi. Perisian ANSYS-CFD boleh memberi definisi dalam bentuk tiga dimensi. Pengesahan adalah sah 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 hasil dapatan dari literatur oleh pengkaji yang terdahulu.

TABLE OF CONTENTS

TITLE	i
DECLARATION	ii
ACKNOWLEDGEMENT	iii
ABSTRACT (ENGLISH)	iv
ABSTRACT (BAHASA MELAYU)	v
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
NOMENCLATURE	xii
LIST OF APPENDIX	xiv

I INTRODUCTION

1.1	Background	1
1.2	Importance of the Study	4
1.3	Rationale of the Study	4
1.4	Problem statement	6
1.5	Objectives	6
1.6	Scope	7

II LITERATURE REVIEW

2.1	Davenport's Observation	8
2.2	The Mean Flow Angle	9
2.3	Flow efficiency	10
2.4	The Relation of Flow Efficiency and Heat Transfer	11
2.5	The Relation of Flow Efficiency and Reynolds Number	12
2.6	The Relation of Flow Efficiency and Thickness Ratio	13
2.7	The Disagreements in Findings among the Researchers	14
2.8	Friction Factor Correlation	18
2.9	Thermal Wakes Effect	20
2.10	Assumption of Laminar Flow	21
2.11	Summary of Literature Review	21

III METHODOLOGY

3.1	Introduction	24
3.2	Main Structure of the Methodology	25
	3.2.1 Constructing the Analytical Model	26
	3.2.2 Validation	29
	3.2.3 Finding the Optimum Louver Angle	31
3.3	Solution Procedure	34
3.4	Numerical Analysis as the Tool	36

IV ANALYSIS

4.1	Model Validation	38
4.2	Data and Result	40
	4.2.1 The Required Pumping Power vs. Re	41
	4.2.2 Heat Transfer Rate vs. Reynolds Number	43
	4.2.3 Ratio of the Heat Transfer Rate to the Required Pumping Power vs. Reynolds number	44

4.2.4 Ratio of the Heat Transfer rate to the Required Pumping Power vs. Angle	45
4.3 Evaluation method	47
4.4 Correlation Development	49
V DISCUSSION AND CONCLUSION	
5.1 Discussion	51
5.2 Conclusion	54
5.3 Future Work	55
REFERENCE	56
APPENDIX	
A. GGI and MFR Theory	60
B. Estimation calculation of constant wall temperature	65
C. Finding the louver angle: Flow and Heat transfer Data	66

LIST OF TABLES

TABLE		PAGE
4.1	Comparison between the predicted mean flow angle of this study and the mean flow angle of Achaichia and Cowell (1988b)	39
4.2	Accuracy of equation 4.1	50
C1	Flow and Heat transfer Data - Inlet plane	64
C2	Flow and Heat transfer Data - North plane	65
C3	Flow and Heat transfer Data - East plane	67
C4	Flow and Heat transfer Data - south plane	68
C5	Heat transfer rate –Inlet, North, East and South plane	69

LIST OF FIGURES

FIGURE		PAGE
1.1	Forms of louvered fin-flat tube surface as illustrated by Hesselgreaves (2001).	2
1.2	Section through louvered fin as illustrated by Achaichia and Cowell (1998a)	3
2.1	Mean flow angles in louver arrays from Achaichia and Cowell (1988b).	9
2.2	(a) Critical Reynolds number versus louver angle; (b) Flow efficiency versus Reynolds number by Zhang and Tafti (2003)	16
2.3	Comparison of flow efficiency predicted by researchers by Zhang and Tafti (2003)	17
2.4	Geometrical parameters for Chang and Wang (1997) correlation.	19
3.1	Main structure of the methodology.	25
3.2	Dimensions of flat tube with rectangular channel and louver fins.	26
3.3(a)	3-dimensional view of the fins stack	27
3.3(b)	Side view of the fins stack	27
3.3(c)	Fluid region as the control volume.	27
3.3 (d)	The meshed control volume	28
3.4	Boundary conditions and regions.	29
3.5	Direction of air entering and leaving the control volume.	32
3.6	Solution procedure	35

4.1	Relation of the required pumping power with Reynolds number for different louver angles.	40
4.2	Vector plot showing the direction of flow in louver fins.	40
4.3	Relation of Nusselt number with Reynolds number for various louver angles.	43
4.4(a)	Relation of the ratio of heat transfer rate to the required pumping power with Reynolds number for various louver angle (300 to 1000).	44
4.4(b)	Relation of ratio heat transfer rate to pumping power with Reynolds number for various louver angle.	45
4.5(a)	Heat transfer over pumping power vs. louver angle at various pumping power.	46
4.5(b)	Heat transfer over pumping power vs. louver angle at various mass flow rate.	47
4.6	The ratio of heat transfer over pumping power reference to pumping power 0.001 watt vs. louver angle.	48
4.7	Ratio of heat transfer to pumping power reference to mass flow rate 0.0002kg/s vs. louver angle.	48
4.8	Graph of the average ratio of heat transfer rate to pumping power vs. louver angle.	49
5.1	The schematic relation of truncation errors and round off errors with number of steps.	52
5.2	Graph of flow efficiencies with different louver angles and fin pitch ratios at a thickness ratio of 0.1	53
5.3	Graph of flow efficiencies vs. louver angles.	53

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
\bar{h}	Average heat transfer coefficient
i	Specific enthalpy
k	conductivity
L or L_l	Louver pitch or louver length
L_p	Louver pitch ratio $L_p=L$
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
ν	dynamic viscosity
V	velocity in vertical direction
\dot{W}	pumping power
x	x-direction
y	y-direction
Δ	difference

LIST OF APPENDICES

A.	GGI and MFR Theory	60
B.	Estimation calculation of constant wall temperature	65
C.	Flow and Heat transfer Data	66

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.

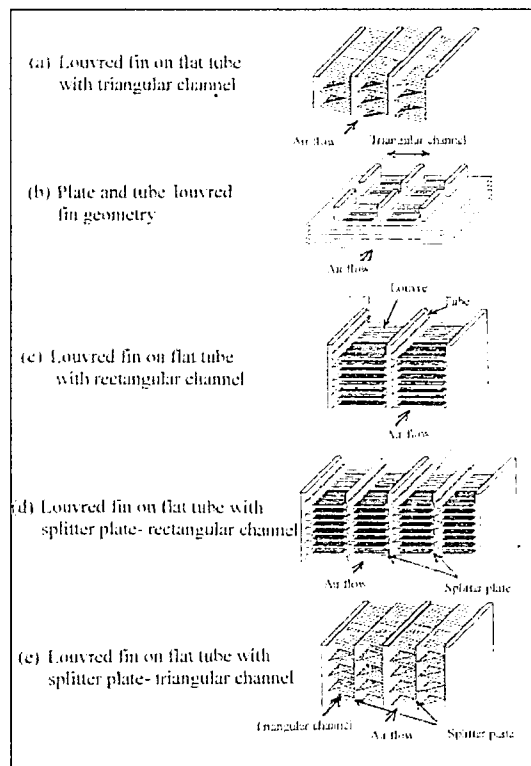


Figure 1.1: Forms of louvered fin-flat tube surface as illustrated by Hesselgreaves (2001).

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 un-louvered surfaces.

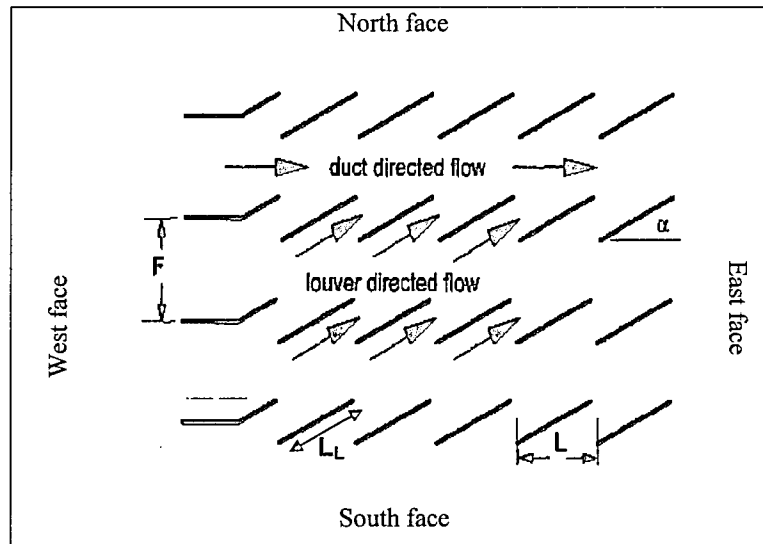


Figure 1.2: Section through louvered fin as illustrated by Achaichia and Cowell (1998a)

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 $\pm 15\%$ 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.