

CONTENTS

	Page
Acknowledgement	iii
Abstract in English	iv
Abstract in Thai	vi
List of Tables	xii
List of Figures	xiii
Abbreviations and Symbols	xvi
Statement of Originality	xviii
Chapter 1 Introduction	1
1.1 Dimple surface	1
1.1.1 Heat transfer performance on dimple surface	1
1.1.2 Literature review	1
1.2 Tube heat exchanger	5
1.2.1 Dimple tube	5
1.2.1.1 Heat transfer performance on dimple surface	5
1.2.1.2 Literature review	5
1.2.2 Oval and flat tube	7
1.2.2.1 Heat transfer performance on oval and flat tube	7
1.2.2.2 Literature review	8
1.3 Research objectives	12
1.4 Potential benefits	13
1.5 Scope of the study	13
Chapter 2 Effects of Dimple Configurations on Heat Transfer and Friction Factors for Air Flow Over Flat Plate Having Dimple Surface	

2.1 Introduction	14
2.2 Problem definition	14
2.2.1 Problem conditions and main assumptions	14
2.2.2 Numerical method	15
2.3 Results and discussions	17
2.3.1 Data reduction	17
2.3.2 Result of base case	18
2.3.3 Effect of dimple shape	19
2.3.4 Effect of attack angle of dimple	21
2.4 Summary and conclusion	24
Chapter 3 Heat Transfer Behavior of Flat Plate Having Spherical Dimple Surface	
3.1 Introduction	25
3.2 Experimental setup and procedure	25
3.3 Data reduction	27
3.4 Results and discussion	29
3.4.1 Validation of the experiment	29
3.4.2 Case of Staggered arrangement	30
3.4.2.1 Temperature distribution	30
3.4.2.2 Effects of dimple pitch	31
3.4.3 Case of inline arrangement	33
3.4.3.1 Temperature distribution	33
3.4.3.2 Effects of dimple pitch	34
3.4.4 Empirical correlation	36
3.5 Summary and conclusion	37
Chapter 4 Heat Transfer Behavior of Flat Plate Having 45° Ellipsoidal Dimple Surface	
4.1 Introduction	38
4.2 Experimental setup and procedure	38
4.3 Results and discussion	40
4.3.1 Case of Staggered arrangement	40
4.3.2 Case of inline arrangement	42

4.3.3 Empirical correlation	44
4.4 Summary and conclusion	45
Chapter 5 Thermal Characteristics of Air Flow Over Flat Tube with Ellipsoidal Dimple Surface	
5.1 Introduction	48
5.2 Experimental setup and procedure	48
5.3 Data reduction	49
5.3.1 Single tube in cross flow	49
5.3.2 Tube bank in cross flow	50
5.4 Results and discussion	51
5.4.1 Single tube in cross flow	51
5.4.2 Tube bank in cross flow	52
5.4.3 Empirical correlation	53
5.5 Summary and conclusion	54
Chapter 6 Numerical Simulation and Flow Visualization	
6.1 Introduction	55
6.2 Numerical simulation of flat-dimple tube	55
6.2.1 Problem conditions and main assumptions	55
6.2.2 Numerical method	56
6.2.3 Data reduction	58
6.2.4 Results and discussions	58
6.3 Flow visualization and flow structure	60
6.3.1 Smoke visualization	60
6.3.2 Effect of flow structure on temperature distribution	61
6.4 Summary and conclusion	62
Chapter 7 Conclusions and Recommendations for The Future	
7.1 Summary of discussion	63
7.1 Summary of conclusion	64
7.2 Recommendation for future work	65

References	66
List of Publications	69
Appendix	
Appendix A Publication	70
A.1 Paper in International Journals	71
A.2 Papers in International Conferences	81
Curriculum Vitae	97

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
 Copyright© by Chiang Mai University
 All rights reserved

LIST OF TABLES

	Page
Table 1.1 Conclusion of the literature review for dimple surface	4
Table 1.2 Tube dimensions considered by Min and Webb (2004) for numerical calculation	11
Table 1.3 Conclusion of the literature review for dimple tube	12
Table 1.4 Conclusion of the literature review for oval and flat tube	13
Table 3.1 Geometric dimensions of spherical dimple surface	29
Table 4.1 Geometric dimensions of ellipsoidal dimple surface	42
Table 6.1 Computational domain size	61
Table 6.2 Basic mesh dimensions and numbers of cell	61

LIST OF FIGURES

	Page
Figure 1.1 A flat plate having dimpled surface	1
Figure 1.2 Vortex flow within its hole	2
Figure 1.3 Compared to other types of heat transfer enhancement approaches	6
Figure 1.4 Vortex generations on dimple surface	6
Figure 1.5 Illustration of the louvered plate fin automotive radiator with in line tubes	8
Figure 1.6 Heat transfer and friction characteristics of circular and oval finned tubes in a staggered tube layout as reported by Brauer (1964)	9
Figure 1.7 Tube geometries considered by Min and Webb for numerical calculation (a) cross-sectional shape, (b) computational domain for the ET-2 oval tube case.	11
Figure 1.8 Photo of oval tube fins used in analysis of Webb and Iyengar	12
Figure 2.1 Details of dimple surface	16
Figure 2.2 Computational grids for dimple surfaces	17
Figure 2.3 Comparison of the heat transfer coefficient and friction coefficient from the numerical simulation and the model	19
Figure 2.4 Dimple configurations	20
Figure 2.5 Effect of dimple shape to the air side heat transfer performance	21
Figure 2.6 Effect of dimple shape to the surface friction coefficient	21
Figure 2.7 Effect of dimple shape to the effectiveness (E)	22
Figure 2.8 Details of: (a) 0° attack angle (b) 35° attack angle (c) 45° attack angle (d) 60° attack angle (e) 90° attack angle	23
Figure 2.9 Effect of attack angle on the air side heat transfer performance	23
Figure 2.10 Effect of attack angle on the surface friction coefficient	24
Figure 2.11 Effect of attack angles to the effectiveness (E)	24
Figure 3.1 Schematic diagram of the experimental setup	27

Figure 3.2 Details of: (a) dimpled-tested surface for staggered arrangement, and (b) individual dimple geometry	28
Figure 3.3 Details of: (a) dimpled-tested surface for inline arrangement, and (b) individual dimple geometry	28
Figure 3.4 Comparison of the Nusselt number under the constant heat flux condition from the experimental and the model in case of plain flat plate	31
Figure 3.5 Temperature distributions of Geometric No.1 at frontal velocity = 4.1 m/s	32
Figure 3.6 Effect of dimple arrangement on heat transfer coefficient for staggered arrangement	33
Figure 3.7 Span-wise averaged h/h_0 , as dependent upon y at frontal velocity is 4.1 m/s in case of staggered arrangement	34
Figure 3.8 Temperature distributions of Geometric No.11 at frontal velocity = 4.1 m/s	35
Figure 3.9 Effect of dimple arrangement on heat transfer coefficient for inline arrangement	36
Figure 3.10 Span-wise averaged h/h_0 , as dependent upon y at frontal velocity is 4.1 m/s in case of inline arrangement	37
Figure 3.11 Comparison of heat transfer correlations with experimental data	38
Figure 4.1 Details of: (a) dimpled-tested surface for staggered arrangement, and (b) individual dimple geometry	41
Figure 4.2 Details of: (a) dimpled-tested surface for inline arrangement, and (b) individual dimple geometry	41
Figure 4.3 Temperature distributions of Geometry No.1 at frontal velocity = 2.9 m/s	43
Figure 4.4 Effect of dimple arrangement on heat transfer coefficient for staggered arrangement	44
Figure 4.5 Comparison of heat transfer coefficient for staggered arrangement of spherical dimple surface and the ellipsoidal dimple surface	44
Figure 4.6 Temperature distributions of Geometry No.6 at frontal velocity = 4.1 m/s	45
Figure 4.7 Effect of dimple arrangement on heat transfer coefficient for inline	46

arrangement	
Figure 4.8 Comparison of heat transfer coefficient for staggered arrangement of spherical dimple surface and the ellipsoidal dimple surface	48
Figure 4.9 Comparison of heat transfer correlations with experimental data	48
Figure 5.1 Schematic diagram of the experimental setup	51
Figure 5.2 Details of: (a) dimpled-flat tube arrangement, (b) individual dimpled-flat tube geometry and (c) individual dimple geometry	51
Figure 5.3 Average span-wise Nusselt number of cylinder, flat tube and flat-dimple tube	55
Figure 5.4 Average heat transfer coefficient for cylinder, flat tube and flat-dimple tube	55
Figure 5.5 Average heat transfer coefficient to frontal velocity for tube bank	56
Figure 5.6 Comparison of Nu correlations with experimental data	57
Figure 6.1 Details of a flat-dimple tube	60
Figure 6.2 Computational grids for a flat-dimple tube	61
Figure 6.3 Comparison of average heat transfer coefficient of experimental results and numerical results of flat-dimple tube and cylinder	63
Figure 6.4 Drag coefficients of flat-dimple tube and cylinder in comparison of numerical results and the model	64
Figure 6.5 Flow visualization of: (a) spherical dimpled surface, and (b) ellipsoidal dimpled surface	65
Figure 6.6 Temperature distribution along the stream line of spherical dimple surface of Geometric No.1 at frontal velocity 4.1 m/s	66

ABBREVIATION AND SYMBOLS

Symbol

A	Area (m^2)
C_d	Drag coefficient
C_f	Friction coefficient
D	Dimple diameter or tube width (mm)
D_{minor}	Dimple diameter on minor axis (mm)
D_{major}	Dimple diameter on major axis (mm)
D_h	Hydraulic diameter (mm)
H	Wind tunnel height
h_x	Local heat transfer coefficient ($\text{W}/\text{m}^2\text{K}$)
h	Average heat transfer coefficient ($\text{W}/\text{m}^2\text{K}$)
h_0	Average heat transfer coefficient of flat plate without dimple ($\text{W}/\text{m}^2\text{K}$)
h_x	Local heat transfer coefficient ($\text{W}/\text{m}^2\text{K}$)
Nu	Average Nusselt number
Nu_x	Local Nusselt number
Nu_D	Average Nusselt number base on tube width
Nu_0	Baseline average Nusselt number of flat plate without dimple
Pr	Prandtl number
q''	Heat flux (W/m^2)
Re_x	Reynolds number
Re_L	Reynolds number base surface length (include dimples surface)

Re_D Reynolds number base on tube width
 Re_{Dh} Reynolds number base on hydraulic diameter

S_L Stream-wise pitch (mm)

S_T Span-wise pitch (mm)

T Temperature ($^{\circ}C$)

V Velocity (m/s)

x Spanwise coordinate

y Streamwise coordinate

Greek letters

μ Dynamic viscosity of air ($N \cdot s/m^2$)

ρ Density of air (kg/m^3)

k Thermal conductivity of air ($W/m \cdot K$)

Subscripts

f Fluid

L Surface length

S Surface

x x -direction

∞ Free air stream

STATEMENTS OF ORIGINALITY

1. A new technique of heat transfer enhancement of heat exchanging surface is proposed in order to serve the heat exchanger application.
2. The study focuses on the dimple surface which is the special method for improving the heat transfer rate without the significant pressure drop.
3. The novel design of flat tube heat exchanger having dimples surface is proposed. The new design will have better performance than the conventional type.

ข้อความแห่งการริเริ่ม

1. วิทยานิพนธ์นี้ได้นำเสนอวิธีการเพิ่มการถ่ายเทความร้อนให้กับพื้นผิวที่ต้องการถ่ายเทความร้อน เพื่อใช้ในการออกแบบเครื่องแลกเปลี่ยนความร้อน ทำให้สามารถลดการใช้วัสดุในการผลิตเครื่องแลกเปลี่ยนความร้อนได้
2. ในการศึกษาครั้งนี้จะใช้วิธีทำให้พื้นผิวเป็นแอ่ง โดยประกอบไปด้วยแอ่งรูปทรงรีและทรงกลม ซึ่งเป็นวิธีที่ได้รับการพิสูจน์แล้วว่าช่วยเพิ่มการถ่ายเทความร้อนโดยไม่เพิ่มความดันสูญเสีย
3. งานวิจัยนี้ยังได้ศึกษาการถ่ายเทความร้อนของอากาศผ่านกลุ่มท่อแบนที่ผิวมีแอ่งรูปทรงรี ซึ่งเพิ่มการถ่ายเทความร้อนให้กับท่อแบนได้