INVESTIGATION OF ALUMINUM COOLING COIL IN CONDENSER APPLICATION USING COMPUTATIONAL FLUID DYNAMIC (CFD)

MOHD HAIRUL NIZAM MOHAMED

A dissertation submitted in partial fulfillment of
the requirement for the award of
Bachelor of Mechanical Engineering

Faculty Mechanical Engineering
Universiti Malaysia Pahang

MAY 2008

ABSTRACT

Heat exchanger or condenser has been used extensively in the world to transfer heat from one liquid to other liquid are widely used in air-conditioning, boiler, chiller and so on. The thesis present the improvement and development of heat transfer that occur in the condenser by changing the coil inside the condenser to predict the thermal performance in the condenser. Aluminum is chosen as our material because of the fact that aluminum has good machinability also it is easy to design and machine. In fact the marketable of aluminum are more impressive compared to copper where aluminum is cheaper and easy to find. This aluminum material coil will increase the efficiency of the condenser due to a few factors. The specific heat at constant pressure (c_p) is the main factor that will increase the efficiency of the condenser. The condenser real-time model is done by using SolidWork design software. A method of determining thermal performance of a condenser is chosen by simulating the condenser using Computational Fluid Dynamic (CFD) to obtain the result. The result we gain from COSMOSFloWorks then will be compare among those two materials. By replacing the copper coil to aluminum coil we expected and achieve further improvement that aluminum coil are better material to transfer heat rather than aluminum coil.

ABSTRAK

Kondenser banyak digunakan meluas diserata dunia untuk memindahkan haba dari satu bahan cecair kepada cecair yang lain dan banyak digunakan dalam industri penghawa dingin, penyejuk bekuan dan lain-lain industri lagi. Tesis ini menerangkan pembaharuan dan penambahbaikan pemindahan haba yang berlaku didalam kondenser dengan menukar koil yang terdapat didalamnya. Aluminium dipilih dalam sebagai bahan kerana aluminium merupakan bahan yang bagus dari segi kebolehannya untuk direka bentuk dah mudah unduk diproses. Dari segi pasaran pula aluminium sangat mudah didapati dan lebih muarah jika dibandingkan dengan timah. Dengan menggunakan aluminum koil sebagai bahan didapati kecekapan kondenser meningkat disebabkan beberapa factor. Antara faktornya adalah kebolehan haba untuk memindah pada satu tekanan (c_p) memainkan peranan utama yang akan meningkatkan kadar kecekapan condenser. Kondenser direka bentuk seperti asal dengan menggunakan perisian SolidWork. Untuk mengkaji kebolehan memindahkan haba oleh kondenser dengan menggunakan simulasi Computational Fluid Dynamic (CFD) untuk mendapatkan jawapan. Hasil daripada simulasi COSMOSFloWorks kita akan bandingkan jawapan antara dua bahan tersebaut. Dengan menggantikan aluminium koil kita dapati bahawa kondenser dapat ditingkatkan kecekapannya dan dapat dibuktikan bahawa aluminium merupakan bahan yang lebih baik untuk digunakan dalam memindahkan haba.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	**ii**
	DEDICATION	**iii**
	ACKNOWLEDGEMENTS	**iv**
	ABSTRACT	**v**
	ABSTRAK	**vi**
	TABLE OF CONTENTS	**vii**
	LIST OF TABLES	**x**
	LIST OF FIGURES	**xi**
	LIST OF SYMBOLS	**xii**
	LIST OF APPENDICES	**xiii**
1	**INTRODUCTION**	**1**
	1.1 Introduction	1
	1.2 Objective	2
	1.3 Project scopes	3
	1.4 Project Background	3
	1.5 Problem Statement	4
2	**LITERATURE REVIEW**	**6**
	2.1 Introduction	6

	2.2 Condenser Definition	6
	2.3 Condensation	7
	2.4 The Effect of Air on Condensation	8
	2.5 Condensate Extraction	8
	2.6 Heat Transfer Analysis	9
	2.7 Detail Heat Transfer Analysis	11
3	**METHODOLOGY**	**15**
	3.1 Introduction	15
	3.2 Research information	16
	3.3 Simulation of Heat Transfer Process Using COSMOSFloWorks	17
	3.4 Measure the Dimension of condenser	18
	3.5 3D Solid Modeling	18
	3.5.1 Design 3D Solid Model	19
	3.6 Air Flow Analysis	19
	3.6.1 Simulation Air Flow Analysis	19
	3.7 Determining the Parameters	20
	3.7.1 Experiment procedure	20
	3.7.2 Boundary Condition of the Condenser	22
4	**RESULT AND DICUSSION**	**23**
	4.1 Result	23
	4.1.1 Result gain from experiment	24
	4.1.2 Result gain from simulating the condenser (copper coil) using COSMOSFloWorks	27
	4.1.3 Result gain from simulating the condenser (aluminum coil) using COSMOSFloWorks	29
	4.2 Discussions	31
	4.2.1 Comparison between the results	31

5	**CONCLUSION AND RECOMMENDATION**	**32**
	5.1 Conclusion	32
	5.2 Recommendation	32
	References	
	Appendixes A	

LIST OF TABLE

TABLE NO.	TITLE	PAGE
Table 4.1	Result gain from experiment	24
Table 4.2	Result for copper coil	27
Table 4.3	Result of aluminum coil	29

LIST OF FIGURES

FIGURES	TITLE	PAGE
Figure 1.1	Condenser steam bench	2
Figure 2.1	Example of heat exchanger or condenser	7
Figure 2.2	Temperature are plotted against a national path length	10
Figure 3.1	Methodology flow chart	16
Figure 3.2	3D condenser solid modeling	18
Figure 3.3	Schematic diagram of the condenser	21
Figure 3.4	Boundary condition for condenser	22
Figure 4.1	The simulation of copper coil	27
Figure 4.2	The simulation of aluminum coil	29

LIST OF SYMBOL

A	Cooling surface area
C	Specific heat
d	Diameter of condenser tubes
D	Diameter of condenser shell
g	Gravitational constant
h	Heat transfer coefficient
H	Depth of condenser in collecting tank
k	Thermal conductivity
m	Mass flow rate
n	Number of tube rows
N	Condensation number non-dimension
N	Nusselt number
N	Prandtle number
N	Reynolds number
p	Pressure
Q	Heat transfer rate
t	Time seconds
T	Temperature
L	Length of tubes
U	Overall heat transfer coefficient
V	Volume flow rate
x	Thickness of tube wall
p	Density
u	Viscosity
T	Log mean temperature different

LIST OF APPENDICES

APPENDIX	TITLE
A	P7675 Condenser bench arrangement

CHAPTER 1

INTRODUCTION

1.1 Introduction

The steam condenser *Figure 1.1* is a major component of the steam cycle in power generation facilities. It is a closed space into which the steam exits the turbine and is forced to give up its latent heat of vaporization. It is a necessary component of the steam cycle for two reasons. One, it converts the used steam back into water for return to the steam generator or boiler as feedwater. This lowers the operational cost of the plant by allowing the clean and treated condensate to be reused, and it is far easier to pump a liquid than steam.

After the steam condenses, the saturated liquid continues to transfer heat to the cooling water as it falls to the bottom of the condenser, or hotwell. This is called subcooling, and a certain amount is desirable. A few degrees subcooling prevent condensate pump cavitations. The difference between the saturation temperature for the existing condenser vacuum and the temperature of the condensate is termed condensate depression. This is expressed as a number of degrees condensate depression or degrees subcooled. Excessive condensate depression decreases the operating efficiency of the plant because the subcooled condensate must be reheated in the boiler, which in turn requires more heat from the reactor, fossil fuel, or other heat source.

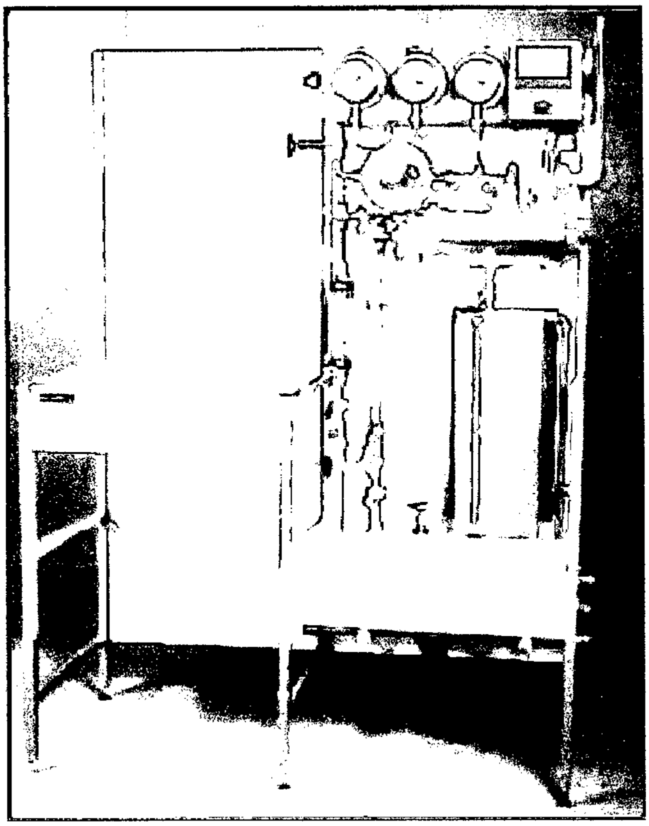

Figure 1.1 Condenser steam bench

1.2 Project Objectives

By the end of this project, two objectives are expected to be achieved:

- To analyze heat transfer process in condenser system due to the different of tube materials.

- To analyze condenser efficiency due to deficient heat transfer process caused by different tube materials. By achieving these objectives, the efficiency difference between a condenser with copper tube and with aluminum tube can be known.

1.3 Project Scopes

The scope of this project can be divided into two main sections:

- The project will use Computer Aided Design (CAD) software to design the condenser. Using the CAD software we can design the condenser just like the real one.

- The simulation of heat transfer process in the condenser will be done by utilizing Computational dynamic (CFD) software. There will be comparison between the heat transfer rate between the copper tube and aluminum tube.

1.4 Project Background

University Malaysia Pahang have bought new Cussons P7675 Steam Bench Consists of a sturdy framework and panels of all steel construction, fitted with a student work surface, interconnecting back panel and adjustable feet. The steam bench includes a water-cooled multi-tube condenser; a steam feed line to supply a regulated supply of steam at reduced pressure and a condensate tank complete with a sight glass. Cooling water flow rate is metered in the supply line and regulated by a control valve in the drain line. Bourdon type pressure gauges are provided from pressure indications and thermocouples are used to measure temperature, which may be individually selected for display on an analogue temperature meter.

Steam bench designed for investigating the overall heat transfer coefficient of condenser tubes for varying conditions of condenser inlet and outlet pressure and rate of cooling water flow, together with demonstration of vacuum creating capability of condensing steam in a closed system. The bench comprises, a multi-tube surface condenser with steel body and copper tubes, and fitted with a relief valve set to vent to atmosphere at 1 bar and a steam discharge line including an isolating valve and pressure and temperature measuring points; a mild steel fabrication condensate tank fitted with 0-50 cm graduated scale, an overflow pipe and a drain line including an isolating valve; steam feed pipe work, including an isolating valve, and fitted with pressure and temperature measuring points; condenser cooling water supply and drain pipe work, with an isolating valve and a safety flow meter in the supply line and a control valve in the drain line, both lines being fitted with temperature measuring points.

To increase the efficiency of the condenser bench, we could change the pipe line of the condenser from copper pipe to aluminum pipe because the aluminum pipe has more advantages rather than copper pipe. The aluminum pipes are cheaper than copper pipe. Aluminum pipe have high specific heat rather than copper. Copper have higher melting point than aluminum but this does not affect the chosen material because in the condenser the highest temperature can not melt this two materials.

1.5 Problem statement

- Increasing condenser's efficiency

  The main point to change from copper pipe to aluminum pipe is to increase the efficiency of the condenser.

- Cost reduction

  Copper pipe are higher cost compared to the aluminum pipe because the price of the aluminum pipe is cheaper then the aluminum pipe and east to find in the local market.

- Cooling down

  The copper pipe need more time than the aluminum pipe to cooling down the water inside the condenser.

Therefore, theoretical process and simulation model need to develop to investigate the entire problems that have been state.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature studies on condenser, its efficiency and heat transfer process that occur in a condenser unit.

2.2 Condenser Definition

A device used to transfer heat from a fluid flowing on one side of a barrier to another fluid (or fluids) flowing on the other side of the barrier. Heat exchangers see *Figure 2.1* is normally used only for the transfer and useful elimination or recovery of heat without an accompanying phase change. The fluids on either side of the barrier are usually liquids, but they may also be gases such as steam, air, or hydrocarbon vapors. Most often the barrier between the fluids is a metal wall such as that of a tube or pipe. However, it can be fabricated from flat metal plate or from graphite, plastic, or other corrosion-resistant materials of construction [13].

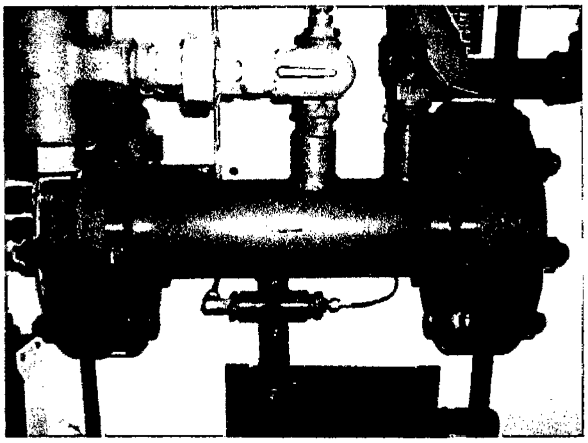

Figure 2.1 Example of heat exchanger or condenser

2.3 Condensation

Condensation occurs when a saturated vapour is in contact with a surface whose temperature is equal to or below the saturation temperature. Usually a film of condensate is formed on the surface, as condensation proceeds the thickness of this film becomes the major thermal resistance opposing condensation. This mechanism of condensation is known as film-type condensation.

An alternative type of condensation, know as drop-wise condensation occurs when the wall is not uniformly wetted by the condensate which appears in many small droplets at various points on the surface. Individual droplets form and grow, may coalesce with adjacent droplets, to form rivulets. Gravity overcomes adhesion and the rivulet will flow to the bottom of the surface capturing and absorbing droplets in its path and leaving dry surface in its wake. Film-type condensation is more common and much more dependable than drop-wise condensation. Drop-wise condensation is particularly hard to promote, requiring clean non-wettable surface which in practice rapidly become fouled and induce wetting of the surface and the formation of film-type condensation. This is unfortunate as drop-wise condensation heat transfer coefficient can be an order of magnitude higher than those obtained in film-type condensation. It is consider that film type condensation occur in this apparatus [13].

2.4 The Effect of Air on condensation

There will be some air present in the condenser which arises from air dissolved in the boiler feed water. As the temperature rises in the boiler the air comes out of solution and is carried through the system with the steam into the condenser. Air may also enter into the system due to inward leakage.

The presence of air impairs the efficiency of the condenser as it reduces the heat transfer from the steam to the cooling water. This effect may be very significant, the pressure of as little as 1% of air by weight may reduce the heat transfer by as much as 50%

2.5 Condensate Extraction

The condensation of steam in a closed vessel caused a large reduction in pressure due to the reduction in volume as the steam condenses into water. In a flow situation the steam must pass from high pressure system through a pressure reduction stage to the low pressure which exists in the condenser. This pressure reduction usually occurs across a steam turbine or steam engine or, as in the case of this unit, a pressure reducing valve. It is common practice for condensers to operate at a partial vacuum in which case condensate and air must be removed by a vacuum pump. For condensers operating at a positive pressure the condensate can be used to produce low pressure flash steam by further reduction in pressure to atmospheric pressure. In this apparatus the condenser is operating at a slight positive pressure (between 0.1 and 0.2 bar) which is controlled by the steam pressure reducing valve setting. Slight sub-cooling will therefore be required to prevent loss of condensate by flash off in the collecting tank.

2.6 Heat Transfer Analysis

Consider a horizontal tube shell and tube surface condenser in which steam is condensed at the saturation temperature. Assuming that the shell of the condenser is perfectly insulated then:

Q = heat received by water = heat transfer from steam

$$Q = \dot{m}_w CW\,(TW1 - TW2) = U\,A\,\Delta T \quad (2.1)$$

Where $\dot{m}_w$ = mass flow of cooling water

C_W = specific heat of water

T_{W1} = water inlet temperature

T_{W2} = water outlet temperature

U = overall heat transfer coefficient

A = heat transfer area

ΔT = temperature difference

In most cases the temperature difference ΔT is not constant over the whole surface area and ΔT may then be replaced by a logarithmic mean temperature different (LMTD). The LMTD is defined as:

$$\Delta T = \frac{\text{Initial temp. diff.} - \text{Final temp. diff.}}{\log_e\left[\dfrac{\text{Initial temp. diff.}}{\text{Final temp. diff.}}\right]}$$

If the two fluid steams flow in the same direction (parallel flow):

$$\Delta T = \frac{(T_{S1} - T_{W1}) - (T_{S2} - T_{W2})}{\log_e\left[\dfrac{T_{S1} - T_{W1}}{T_{S2} - T_{W2}}\right]} \quad (2.2)$$

Where T_{S1} = steam inlet temperature

T_{S2} = condensate outlet temperature

Whereas if the two steams flow in opposite direction (contra-flow):

$$\Delta T = \frac{(T_{S1} - T_{W2}) - (T_{S2} - T_{W1})}{\log_e\left[\frac{T_{S1} - T_{W2}}{T_{S2} - T_{W2}}\right]} \tag{2.3}$$

These two situations are illustrated in *Figure 2.2* in which temperature are plotted against a national path length for the general case in which desuperheating and condensate cooling also occur. Unlike a concentric tube heat exchanger it is not possible to plot the graph against a true length scale which is common to both streams due to the complexity of the flow paths used in practical condensers. The diagram is therefore provided as an aid to consideration of the overall heat transfer characteristics.

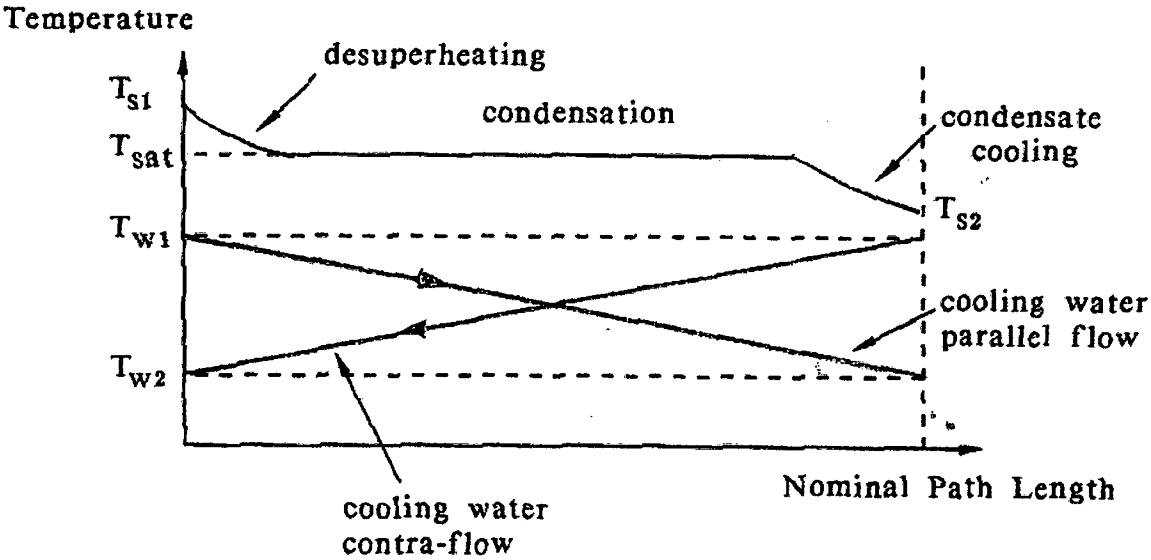

Figure 2.2 Temperature are plotted against a national path length

If the steam is not superheated and the condensate is not cooled below the saturation temperature, T_{SAT}, the expression for the log mean temperature difference simplifies to:

$$\Delta T = \frac{T_{W2} - T_{W1}}{\log_e\left[\frac{T_{sat} - T_{W1}}{T_{sat} - T_{W2}}\right]} \tag{2.4}$$

2.7 Detailed Heat Transfer Analysis

A detailed study of the heat transfer processes within the condenser may be made by considering separately the heat transfer from steam to tube, conduction through the tube wall and forced convection heat transfer from the tube to the water. The overall heat transfer across a section of tube wall may be considered by adding together the temperature difference across each thermal barrier.

$$\begin{Bmatrix} \square T \text{ steam} \\ \text{to water} \end{Bmatrix} = \begin{Bmatrix} \square T \text{ steam to} \\ \text{tube outer wall} \end{Bmatrix} + \begin{Bmatrix} \square T \text{ across} \\ \text{tube wall} \end{Bmatrix} + \begin{Bmatrix} \square T \text{ tube inner} \\ \text{wall to water} \end{Bmatrix}$$

$$\frac{Q}{UA_o} = \frac{Q}{H_s A_o} + \frac{Q x}{k A_m} + \frac{Q}{h_w A_i}$$

$$\frac{1}{UA_o} = \frac{1}{H_s A_o} + \frac{x}{k A_m} + \frac{1}{h_w A_i} \qquad (2.5)$$

where *Ao* = tube outside surface area

Ai = tube inside surface area

Am = tube mean area

hs = steam side heat transfer coefficient

hw = water side heat transfer coefficient

kt = thermal conductivity of tube wall

x = thickness of tube wall

a) Steam Side Heat transfer

With film-type condensation it is the physical properties of the liquid rather than the properties of the liquid rather than the properties of the steam which are used to determine the condensation heat transfer coefficients. An empirical equation derived from experimental studies on the condensation of vapour on a single horizontal tube is:-

Nco = $1.2\ N_{Re}^{-1/3}$

Where Nco = condensation number

$$= \frac{h_s}{k_c}\left[\frac{\mu_c^2}{\rho_c^2 g}\right]^{1/3}$$

k_c = thermal conductivity of condensate

ρ_c = density of condensate

μ_c = viscosity of condensate

g = 9.81 N/kg = $9.81\ m/s^2$

and N_{Re} = Reynolds number for the condensate film

$$= \frac{2}{\mu_c}\frac{m_c}{L}$$

$\frac{m_c}{L}$ = mass flow rate of condensate forming per unit length of tube

From which

$$hs = 1.2\ k\left[\frac{\mu_c^2}{\rho_c^2 g}\right]^{-1/3}\left[\frac{2}{\mu_o}\frac{m_c}{L}\right]^{-1/3} \qquad (2.6)$$

For multiple tubes arranged one above the other in a vertical plane the condensate from one tube flows onto the top of the tube directly below it without splashing. The local heat transfer coefficient for the lower tubes is reduced compared with the top tubes; an empirical relationship for any tube in row n is related to that for the top tube by the expression:

$$\frac{h_n}{h_1} = n^{0.75} - (n-1)^{0.75} \qquad (2.7)$$

The mean or average coefficient $\hat{h}$ can also be determined by summation using the above equation. The results are tabulated below.

Number of Tubes	$\frac{h_n}{h_1}$	Average coefficient $\hat{h}$
1	1.000	h1
2	0.682	0.841 h1
3	0.598	0.760 h1
4	0.549	0.707 h1
5	0.515	0.669 h1
6	0.490	0.639 h1

(2.8)

b) Conduction

For conduction through a thick walled tube a mean surface area Am is used which is defined from a mean diameter

$$Am = \frac{\Pi}{4}\left[\frac{d_o - d_i}{\log_e \frac{d_o}{d_i}}\right]^2 L \qquad (2.9)$$

c) Water Side Heat Transfer Coefficient

The water side heat transfer coefficient may be predicted from the empirical relationship for turbulent heat transfer inside tubes.

$$N_{NU} = 0.023\,(N_{Re})^{0.8}\,(N_{pr})^{0.4}$$

where N_{NU} = Nusselt number

$$= \frac{h_w d_i}{k}$$

N_{Re} = Reynolds number

$$= \frac{V\, d_i\, \rho}{\mu}$$

Npr = Prandtle number

$$= \frac{C_p\, \mu}{k}$$

d_i = internal diameter of tube

kw = thermal conductivity of water

V = mean water velocity

ρw = density of water

μw = viscosity of water

The heat transfer coefficient *hw* is then given by:

$$hw = 0.023\frac{k_w}{d_i}\left[\frac{V\, d_i\, \rho_w}{\mu_w}\right]^{0.8}\left[\frac{C_p\, \mu_w}{k_w}\right]^{0.4} \qquad (2.10)$$