

PERFORMANCE EVALUATION OF COMPACT  
SOLAR WATER HEATER WITH BLACK CHROMIUM COATING

DG. NOOREMAH BINTI AG. SAID

A thesis submitted in fulfilment of the  
requirements for the award of the degree of  
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering  
Universiti Teknologi Malaysia

MARCH 2007



**UMS**  
UNIVERSITI MALAYSIA SABAH

## UNIVERSITI TEKNOLOGI MALAYSIA

**BORANG PENGESAHAN STATUS TESIS\*\*\***

**JUDUL : PERFORMANCE EVALUATION OF COMPACT SOLAR  
WATER HEATER WITH BLACK CHROMIUM COATING**

**SESI PENGAJIAN: 2006/2007**

Saya DG. NOOREMAH BINTI AG. SAID  
(HURUF BESAR)

mengaku membenarkan tesis \* (PSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknologi Malaysia dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknologi Malaysia.
2. Naskah salinan di dalam bentuk kertas atau mikro hanya boleh dibuat dengan kebenaran bertulis daripada penulis.
3. Perpustakaan Universiti Teknologi Malaysia dibenarkan membuat salinan untuk tujuan pengajian sahaja.
4. Tesis hanya boleh diterbitkan dengan kebenaran penulis. Bayaran royalti adalah mengikut kadar yang dipersetujui kelak.
5. Saya membenarkan Perpustakaan membuat salinan tesis ini sebagai bahan pertukaran di antara institusi pengajian tinggi.
6. \*\* Sila tandakan (/)

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan).

TIDAK TERHAD

mgjinal  
**(TANDATANGAN PENULIS)**

Alamat Tetap: No. 26, Kg.Benoni,  
89600 Papar, Sabah.

Tarikh: 30 Mac 2007

Disahkan oleh  
Jamaliah Idris  
**(TANDATANGAN PENYELIA)**

Prof. Dr. Jamaliah Idris

Tarikh: 30 Mac 2007

**CATATAN: \***

Potong yang tidak berkenaan

\*\* Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa / organisasi berkenaan dengan menyatakan sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

\*\*\* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau disertasi bagi pengajian secara kerja kursus dan penyelidikan atau Laporan Projek Sarjana Muda.



**UMS**  
UNIVERSITI MALAYSIA SABAH

## BAHAGIAN A - Pengesahan Kerjasama\*

Adalah disahkan bahawa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara \_\_\_\_\_ dengan \_\_\_\_\_

Disahkan oleh:

Tandatangan : ..... Tarikh : .....

Nama : .....

Jawatan : .....  
(Cop rasmi)

\* Jika penyediaan tesis/projek melibatkan kerjasama.

## BAHAGIAN B - Untuk Kegunaan Pejabat Fakulti Kejuruteraan Mekanikal

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat  
Pemeriksa Luar : Prof. Dr. Kamaruzzaman bin Sopian  
Department of Mechanical & Material Engineering  
Faculty of Engineering  
Universiti Kebangsaan Malaysia  
43600 UKM, Bangi  
Selangor

Nama dan Alamat  
Pemeriksa Dalam I : Prof. Amer Nordin bin Darus  
Jabatan Termo Bendalir  
Fakulti Kejuruteraan Mekanikal  
UTM, Skudai

Pemeriksa Dalam II :  
(Tiada)

Nama Penyelia lain :  
(jika ada)

Disahkan oleh Timbalan Pendaftar di Fakulti Kejuruteraan Mekanikal:

Tandatangan: ..... Tarikh : 29/3/07

Nama : MOHAMED TAJUDDIN BIN OSMAN



**UMS**  
UNIVERSITI MALAYSIA SABAH

"I/We\* hereby declare that I/we \* have read this thesis and in my/our\* opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Master of Mechanical Engineering."

Signature : 

Name of Supervisor : PROF. DR. JAMALIAH HJ. IDRIS

Date : 30 March 2007

I declare that this thesis entitled "Performance Evaluation of Compact Solar Water Heater with Black Chromium Coating" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Dg. Nooremah binti Ag. Said

Date : 30 March 2007



# B a b u   d a n   U w a n ]

kujunjung kasih kalian

✓uat Ayahandaku  
Harapanmu, kusemat di sanubariku  
✓uat ✓ondaku  
Doa dan pengorbananmu, kusanjung tinggi

>>Untuk **Kak Mie, Abg. Azhar, Kak Nida, Cadah, Cami dan Pea**  
Terima kasih atas sokongan dan kasih kalian.

:) I mah



**UMS**

UNIVERSITI MALAYSIA SABAH

## PENGHARGAAN

*Dengan nama Allah yang Maha Pengasih lagi Maha Penyayang  
Kalungan kasih, selawat & salam buat rasul junjungan, Muhammad S.A.W*

Alhamdulillah, setinggi kesyukuran saya rafa'kan kepada Allah Rabb al-'Alamin kerana atas 'inayahNya dapat jua saya menyiapkan tesis ini.

Penghargaan yang tidak terhingga saya rakamkan kepada penyelia projek, Prof. Dr. Jamaliah Idris yang tidak jemu memberi tunjuk ajar. *Syukran...*

Terima kasih yang tidak terhingga kepada Prof. Madya Dr. Kamarul Baharin Tawi, En. Zainal, En. Ayub, En. Malik, En. Adnan (dan semua kakitangan makmal Sains Bahan) yang banyak membantu. Juga buat Dn. Hjh. Ramlah Mohamad untuk nasihat dan jagaan beliau. Penghargaan ini dititipkan juga buat rakan yang sentiasa menghulurkan bantuan dan dorongan, Pn. Hazlinda, Cik Halimatun, En. Eddynoor, Pn. Dk. Ros Rita, Cik Siti Nurul Hajar, Pn. Nurul Akmar, Pn. Maziah, Pn. Ana Sakura, Pn. Faridah, En. Buang, En. Kamel, En. Raffie, Cik Rohani, Cik Haslina, En. Chee, En. Kamal, Pn. Thuraiya, Pn. Maizura, Pn. Oknovia, En. Khairmen dan En. Ekhwan Hakim. *Thanks a lot..*

Terakhir, buat semua taulan seperjuangan yang banyak memberikan sokongan dan buah fikiran, kalungan budi dan untaian kasih penuh ikrami buat kalian. Moga kita semua selamat melalui pulau impian, berjaya mendaki gunung harapan. *Selamat mencapai kemenangan..*

*"Sesungguhnya, atas setiap kepayahan, ada beribu lagi nikmatNya..."*



## ABSTRACTS

Having blessed with abundance sunlight and high solar radiation level, Malaysian is tempted to the ‘green’ solar technology. Yet, application of solar water heating system in Malaysia is not so popular. Facing with the unique Malaysian climate, hot and humid, more cloudy and rainy than clear day and of course, a high initial cost, designers and engineers are challenged to come out with a cost efficient Solar Water Heater (SWH). In this study, a compact SWH prototype has been developed and tested. This unit is equipped with a perforated tube (inserted in the lower header tube) which has different number of hole (in ascending order) in each opening to riser tubes, intended to curb the bottleneck problem. The water circulates by thermosiphon principles. During the heating process, the water flow in the riser tube is more uniform with the presence of the perforated tube. In addition, the absorber plate is coated with black chromium selective coating which enhances the thermal radiation absorption (J.Idris et.al., 2003). Problem that often occurs which reduces the efficiency is the heat loss through solar collector panel (especially the top panel) and connecting pipes. The developed compact prototype not only reduces the heat losses but also reduces the usage of material and hence cost. Experimental results showed that the UTM IV prototype has overall heat loss coefficient reduced from 6.91 to 6.83 W/m<sup>2</sup>K, and instantaneous efficiency rise from 69.4% to 82%, an increase about 12.6%, compared to the UTM II prototype.



## ABSTRAK

Dilimpahi dengan cahaya matahari dan paras radiasi suria yang tinggi, Malaysia tertarik kepada ‘kehijauan’ tenaga suria. Namun, penggunaan pemanas air tenaga suria masih kurang popular di Malaysia. Berdepan dengan iklim yang unik, panas dan lembap, lebih banyak hujan berbanding panas, dan kos permulaan yang tinggi, pereka dan jurutera dicabar untuk menghasilkan sebuah pemanas suria yang efisyen dengan kos yang lebih rendah. Dalam kajian ini, sebuah prototaip pemanas suria yang kompak telah dibangunkan dan diuji. Prototaip ini dilengkapi dengan sebatang tiub yang dilubang-lubangkan (dimasukkan dalam tiub masuk utama) dengan jumlah lubang yang berbeza untuk mengawal aliran air agar lebih seragam bagi mengurangkan masalah ‘bottleneck’. Air mengalir dalam pengumpul suria menggunakan prinsip termosifon. Plat penyerap disaluti dengan salutan kromium hitam terpilih yang mampu meningkatkan kebolehserapan radiasi suria (J.Idris et.al., 2003). Masalah yang sering timbul semasa penggunaan pemanas suria ialah kehilangan haba melalui penutup kaca panel pengumpul dan paip penyambung. Prototaip yang dibangunkan bukan sahaja dapat mengurangkan kehilangan haba, tetapi bahan dan kos untuk pembuatan juga dapat dikurangkan. Keputusan ujkaji menunjukkan pekali kehilangan haba berkurang sebanyak  $0.08 \text{ W/m}^2\text{K}$ , dari  $6.91 \text{ W/m}^2\text{K}$  ke  $6.83 \text{ W/m}^2\text{K}$  dan kecekapan siripan meningkat dari 69.4% ke 82%, peningkatan sebanyak 12.6% jika dibandingkan dengan prototaip UTM II.

## TABLE OF CONTENTS

CHAPTER	TITLES	PAGES
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iii
	<b>ACKNOWLEDGEMENT</b>	iv
	<b>ABSTRACTS</b>	v
	<b>ABSTRAK</b>	vi
	<b>TABLE OF CONTENTS</b>	vii
	<b>LIST OF TABLES</b>	ix
	<b>LIST OF FIGURES</b>	x
	<b>LIST OF NOMENCLATURES</b>	xii
	<b>LIST OF APPENDICES</b>	xv
1	<b>INTRODUCTION</b>	1
	1.1 RESEARCH BACKGROUND	4
	1.2 PROBLEM STATEMENT	7
	1.3 RESEARCH OBJECTIVE	8
	1.4 SCOPE OF STUDY	8
2	<b>LITERATURE REVIEW</b>	9
	2.1 INTRODUCTION	10
	2.2 PATENT REVIEW	12
	2.3 MARKET SURVEY	16



3	<b>SOLAR WATER HEATER THEORIES</b>	19
3.1	SOLAR WATER HEATING SYSTEM	20
3.2	FLAT PLATE COLLECTORS	31
3.3	MATERIAL SELECTION	35
4	<b>DESIGN AND DEVELOPMENT OF PROTOTYPES</b>	40
4.1	METHODOLOGY OF STUDY	41
4.2	DEVELOPMENT OF PROTOTYPES	43
4.3	BLACK CHROMIUM COATING	57
5	<b>SYSTEM PERFORMANCE MONITORING</b>	62
6	<b>RESULTS AND DISCUSSION</b>	66
6.1	AMBIENT TEMPERATURE	69
6.2	PLATE TEMPERATURE	72
6.3	COLLECTOR INLET AND OUTLET PIPE FLUID TEMPERATURE	73
6.4	PERFORMANCE CHARACTERISTICS	75
6.5	DESIGN CONCEPTS & PARAMETERS	82
7	<b>CONCLUSION AND SUGGESTIONS FOR FURTHER WORK</b>	85
	<b>REFERENCES</b>	88
	Appendices A – D	93

## LIST OF TABLES

TABLES NO.	TITLE	PAGES
Table 1.1	Solar water heating businesses in Malaysia.	6
Table 2.1	Major global solar water heater markets.	10
Table 2.2	Comparison between marketed SWH models in Malaysia.	17
Table 3.1	Classifications of SWHs.	23
Table 3.2	Optimal design parameters for thermosiphon SWH.	33
Table 3.3	Solar water heating system component requirement.	36
Table 3.4	The potential material for SWH components.	36
Table 3.5	The common absorber material.	37
Table 3.6	Comparisons of some selective surfaces & black paints.	37
Table 3.7	Properties of selective surfaces prepared for flat-plate collectors.	38
Table 3.8	BCC formulation developed by UTM researchers.	39
Table 4.1	Specification of prototype UTM I.	44
Table 4.2	Specification of prototype UTM II.	45
Table 4.3	Comparison of the construction materials of the developed prototypes.	55
Table 4.4	Comparison and summary of the newly developed SWH systems.	56
Table 4.5	Material preparation for electroplating process.	59
Table 6.1	Main ambient temperatures of the prototypes.	71
Table 6.2	Main fluid temperatures observed at collector inlet / outlet pipes.	73
Table 7.1	Performance comparison of the developed SWH prototypes.	79



## LIST OF FIGURES

FIGURES NO.	TITLE	PAGES
Figure 1.1	Diurnal pattern of global solar radiation in Malaysia.	2
Figure 1.2	Classification of solar energy application.	3
Figure 2.1	Some designs through the development of SWH	15
Figure 2.2	Price comparison of marketed SWH in Malaysia.	16
Figure 2.3	Cost efficiency comparison of marketed SWH in Malaysia.	18
Figure 2.4	Highest temperature comparison of marketed SWH in Malaysia	18
Figure 3.1	Thermal heat losses from solar collector.	21
Figure 3.2	Classifications of solar water heating systems.	22
Figure 3.3	Thermosiphon solar water heater	24
Figure 3.4	Basic components in a SWH unit.	26
Figure 3.5	Types of solar collectors.	28
Figure 3.6	Solar collectors mounting.	29
Figure 3.7	Basic components in a flat-plate collector system.	31
Figure 3.8	Various configurations of absorber plate & tubing.	31
Figure 4.1	Research procedure.	41
Figure 4.1a	Fabrication methodology of the prototype.	42
Figure 4.2	Recently developed solar water heater prototypes in UTM.	43
Figure 4.3	The UTM I prototype.	44
Figure 4.4	The UTM II prototype.	45
Figure 4.5	The schematic diagram of the proposed UTM III.	47
Figure 4.6	The simplification / modification on UTM III prototype.	47
Figure 4.7	Flat plate solar collector for the proposed UTM III.	48
Figure 4.8	The modified parallel tube.	49
Figure 4.9	Hot water storage tank.	50
Figure 4.10	(a) Storage tank stand. (b) Solar collector panel stand	50
Figure 4.11	Flexible pipes used as connecting piping.	51
Figure 4.12	The proposed prototype: UTM IV.	51



Figure 4.13	The schematic diagram and water flow of the proposed UTM IV.	53
Figure 4.14	The components that made up the proposed UTM IV.	55
Figure 4.15	The sequence of black chromium coating process.	58
Figure 4.16	The schematic diagram of basic electroplating set-up.	60
 Figure 5.1	 Set-up for monitoring thermal performance of a typical passive SWH.	 64
Figure 5.2	Set-up for measuring collector plate temperature.	64
Figure 5.3	Digital scanning thermocouple with immersion and surface probe.	64
Figure 5.4	System performance monitoring for prototypes UTM III & UTM IV.	65
 Figure 6.1	 Various temperatures vs. time for UTM IIIa.	 67
Figure 6.2	Various temperatures vs. time for UTM IIIb.	67
Figure 6.3	Various temperatures vs. time for UTM IV (Day 1).	68
Figure 6.4	Various temperatures vs. time for UTM IV (Day 2).	68
Figure 6.5	Various temperatures vs. time for UTM IV (Day 3).	69
Figure 6.6	Ambient temperature vs. time.	71
Figure 6.7	Plate temperature vs. time.	72
Figure 6.8	Fluid temperature at collector inlet pipe vs. time.	74
Figure 6.9	Fluid temperature at collector outlet pipe vs. time.	74
Figure 6.10	Collector overall heat loss coefficient vs. time.	76
Figure 6.11	Fin efficiency vs. time.	78
Figure 6.12	Collector plate overall efficiency vs. time.	79
Figure 6.13	Heat removal factor vs. time.	80
Figure 6.14	Useful heat energy collected vs. time.	81
Figure 6.15	Instantaneous efficiency vs. time.	82
 Figure 7.1	 A grid solar thermal collector.	 87

## NOMENCLATURES

$A_c$	collector plate area ( $\text{m}^2$ )
$A_i$	storage tank insulation external surface area ( $\text{m}^2$ )
$b$	tube bond width (m)
$C$	specific heat of water concentration ratio (J/kg K), annual heating cost of alternative heating system
$d_i$	tube inner diameter (m)
$d_o$	tube outer diameter (m)
$D_i$	storage tank inner diameter (m)
$D_o$	storage tank outer diameter (m)
$D_{ins}$	storage tank insulation outer diameter (m)
$D_{o-\lambda}$	% of solar constant for wavelength shorter than $\lambda$ (%)
$E_\lambda$	solar spectral irradiance averaged over small-bandwidth centered at $\lambda$ ( $\text{W}/\text{m}^2 \mu\text{m}$ )
$E_h$	energy required for heating (J)
$E_s$	heat energy gained from solar system (W h)
$f$	factor in collector top heat loss coefficient
$F$	fin efficiency
$F_p$	collector plate efficiency factor
$F_R$	collector plate heat removal factor
$h_f$	film heat transfer coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$h_{fg}$	latent heat of vaporization of water (J/kg)
$h_o$	surface film heat transfer coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$h_s$	fouling heat transfer coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$h_w$	wind convection heat transfer coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$H$	instantaneous solar radiation intensity ( $\text{W}/\text{m}^2$ )
$H_{max}$	maximum value of instantaneous solar radiation ( $\text{W}/\text{m}^2$ )
$i$	annual interest rate (%)
$I$	extraterrestrial solar radiation flux ( $\text{W}/\text{n}^2$ )
$I_p$	current for actual plating (A)
$I_{sc}$	solar constant ( $= 1353 \text{ W}/\text{m}^2$ )
$j$	current density ( $\text{A}/\text{dm}^2$ )
$k_b$	thermal conductivity of bond ( $\text{W}/\text{mK}$ )
$k_{bi}$	thermal conductivity of collector back insulation ( $\text{W}/\text{mK}$ )
$k_c$	thermal conductivity of collector plate ( $\text{W}/\text{mK}$ )
$k_{ins}$	thermal conductivity of storage tank insulation ( $\text{W}/\text{mK}$ )
$L$	collector plate length (m)



$m$	term in fin efficiency
$m_c$	collector fluid flowrate (kg/s)
$m_d$	draw-off mass flowrate (kg/s)
$m_{evap}$	rate of evaporation (kg/s)
$m_s$	mass of water in storage tank (kg)
$M$	air mass
$n$	refractive index, year
$N$	number of glass covers
$P$	tube pitch (m)
$q_b$	heat transfer rate at base of fin to bond ( $\text{W}/\text{m}^2$ )
$q_v$	heat transfer rate from top of fin above bond ( $\text{W}/\text{m}^2$ )
$q_u$	total heat transfer rate from plate to fluid ( $\text{W}/\text{m}^2$ )
$Q_s$	heat loss rate from storage tank (W)
$Q_u$	rate of solar energy delivered to storage tank (W)
$r$	thermal resistance ( $\text{m}^2\text{K}/\text{W}$ )
$S$	Solar heat flux absorbed ( $\text{W}/\text{m}^2$ )
$S_c$	initial acquisition cost of solar system
$S_m$	annual maintenance cost of solar system
$S_s$	supplementary heating cost for solar system
$S_t$	total annual cost of solar system
$T_a$	ambient temperature ( $^\circ\text{C}$ )
$T_b$	temperature of bond junction of plate to tube ( $^\circ\text{C}$ )
$T_e$	temperature of environment ( $^\circ\text{C}$ )
$T_f$	collector fluid bulk temperature ( $^\circ\text{C}$ )
$T_{f,m}$	collector mean fluid temperature ( $^\circ\text{C}$ )
$T_h$	required hot water temperature ( $^\circ\text{C}$ )
$T_i$	initial cold water temperature ( $^\circ\text{C}$ )
$T_m$	approximate mean temperature ( $^\circ\text{C}$ )
$T_{mu}$	feed/make-up water temperature ( $^\circ\text{C}$ )
$T_p$	mean plate temperature ( $^\circ\text{C}$ )
$T_s$	storage tank temperature ( $^\circ\text{C}$ )
$T'_s$	new storage tank temperature ( $^\circ\text{C}$ )
$T_x$	fin temperature at section x ( $^\circ\text{C}$ )
$T_1$	temperature at inlet to collector ( $^\circ\text{C}$ )
$T_2$	temperature at outlet of collector ( $^\circ\text{C}$ )
$U_b$	collector plate bottom heat loss coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$U_c$	collector plate overall heat loss coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$U_s$	storage tank heat loss coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$U_t$	collector plate top heat loss coefficient ( $\text{W}/\text{m}^2\text{K}$ )
$v$	wind velocity (m/s)
$V$	volume ( $\text{m}^3$ )
$W$	collector plate width (m)
$x$	coordinate across fin/collector plate
$x_{bi}$	collector plate thickness (m)
$x_c$	collector bottom insulation thickness (m)
$x_{ins}$	storage tank insulation thickness (m)
$y$	coordinate along collector plate in flow direction



## Greek

$\alpha$	absorptivity finite
$\beta$	term in fin efficiency
$\varepsilon_g$	emissivity of glass
$\varepsilon_p$	emissivity of collector plate
$\phi$	term in collector plate heat removal factor
$\eta_i$	collector instantaneous efficiency (%)
$\eta_c$	collector mean instantaneous efficiency (%)
$\eta_m$	mean system efficiency (%)
$\eta_s$	efficiency of alternative heating system (%)
$\lambda$	wavelength ( $\mu\text{m}$ )
$\mu$	absolute viscosity ( $\text{kg}/\text{m s}$ )
$\nu$	kinematic viscosity ( $\text{m}^2/\text{s}$ )
$\theta$	zenith angle ( $^\circ$ ), time (s)
$\rho$	density ( $\text{kg}/\text{m}^3$ ), reflectivity
$\sigma$	Stefan-Boltzmann constant ( $= 5.67 \times 10^{-8} \text{ W}/\text{m}^2\text{K}^4$ )
$\tau$	transmissivity
$\tau_1$	time constant in solar radiation approximation (h)
$\tau_2$	time constant in ambient temperature approximation (h)
$\Sigma H$	daily integrated total solar radiation ( $\text{W h}/\text{m}^2$ )

## Dimensionless quantities

Gr	Grashof No.
Gz	Graetz No.
Nu	Nusselt No.
Pr	Prandtl No.
Re	Reynolds No.

## LIST OF APPENDICES

NO.	TITLE	PAGES
Appendix A	Specification of UTM III and UTM IV	93
Appendix B1	Isometric drawing – UTM IV	94
Appendix B2	Orthographic drawing – UTM IV	95
Appendix B3	Exploded drawing – UTM IV	96
Appendix B4	Isometric drawing – UTM IV: tank	97
Appendix B5	Orthographic drawing – UTM IV: tank	98
Appendix B6	Orthographic drawing – UTM IV: parallel tubes	99
Appendix B7	Isometric drawing – UTM IV: parallel tubes	100
Appendix B8	UTM IV: solar collector panel.	101
Appendix B9	UTM IV: solar collector housing.	102
Appendix B10	UTM IV: solar collector insulation.	103
Appendix B11	UTM IV: solar absorber plate.	104
Appendix B12	UTM IV: solar collector glazing.	105
Appendix C	Specifications of TES 1312 digital thermocouple.	106
Appendix D1	Outdoor test data collected : UTM III.	107
Appendix D2	Outdoor test data collected : UTM IV.	108
Appendix D3	Example of performance calculation.	109
Appendix D4	Calculated performance of the developed prototype.	114

## **CHAPTER I**

### **INTRODUCTION**

The fuel crisis and the increasing prices of petroleum products have been a catalyst to the exploration of new and renewable energy sources. These resources comprise biomass, biogas, solar, wind and geothermal energies. These energy resources are abundant and non-exhaustible. In Malaysia, though we are fortunate enough to be blessed with indigenous oil and natural gas resources, the use of renewable energy is crucial as to prolong the fossil fuel reserves and not to waste the renewable energy sources. Thus, the government in Seventh Malaysia Plan (RMK-7, for year 1995 – 2000) had replaced the Four Fuel Diversification Policy with the Five Fuel Diversification Policy that includes renewable energy. These potential energy resources have been extensively utilized in industries, universities or even in some remote areas. We have our palm oil mill industries, which supply the energy needed for processing the palm oil from its waste. There are also a hefty number of commercial projects on solar, hydro and biomass energy (Alias et.al., 1999).

Solar energy, instead of non-exhaustible and cheap, is pollution-free and safe to use. Being a maritime country close to the equator, Malaysia naturally has abundant and free solar energy throughout the country. In fact, Malaysia has high solar radiation level that ranges from 6.5 kWh/m<sup>2</sup> in January to 6.0 kWh/m<sup>2</sup> in August (Gurmit and Foo, 1996). However, it is extremely rare to have a full day with completely clear sky even in periods of severe drought. The cloud cover cuts off a substantial amount of sunshine and thus solar radiation. On the average, Malaysia receives about 6 hours of sunshine per day (Malaysian Meteorological Service – MMS, 2004). There are basically five diurnal patterns of sunlight existed in Malaysia; clear day, cloudy, rainy, afternoon rain and the day when the solar radiation is greater than the solar constant (Mohd. Yusof, 1996).

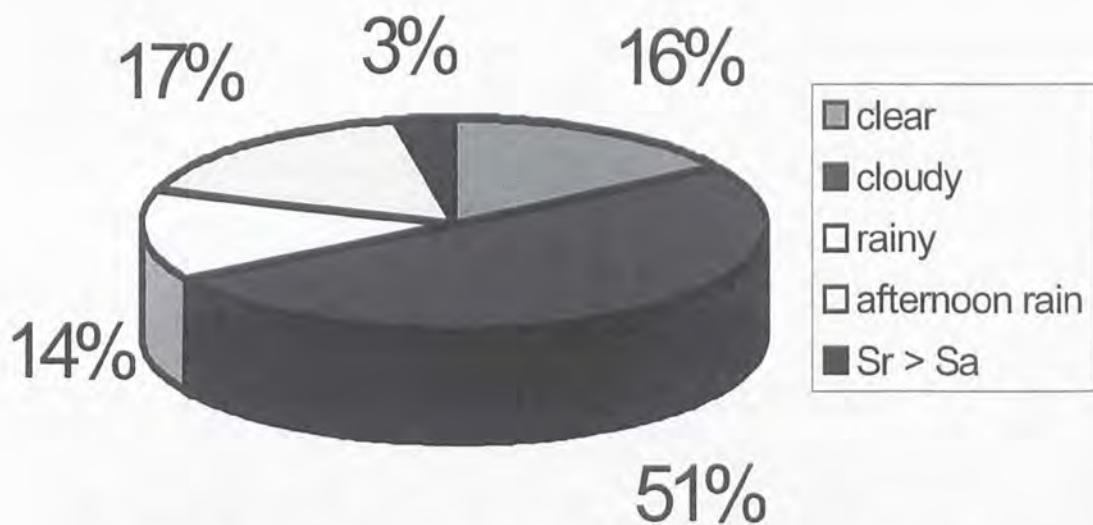


Figure 1.1 – Diurnal Pattern of Global Solar Radiation in Malaysia.

Solar energy applications are classified into photovoltaic and thermal energy applications (Figure 1.2). Photovoltaic applications comprise of power generation such as electrification, water pumping and empowering a solar car. Thermal energy applications otherwise include water heating, air (space) heating, foods drying / cooking and distilling salty water for drinking. Nowadays, hot water is an essential in domestic and commercial application including hotel, hospital, recreation club, textiles and papermaking industries.

Photovoltaic technology uses solar cell to convert solar radiation energy to electricity. Solar cell consists of three elements; semiconductor which absorb the solar radiation, semiconductor junction that separates the photo – generated carriers (electrons – holes) and the contacts on the front and back of the cell that allow the current to flow to the external circuit. Basically, there are two type of solar cell used; crystalline silicon (in a wafer form) or thin films solar cell. Due to the poor light absorber property, solar cell has a relatively low efficiency.

On the other hand, thermal energy application is a more direct way to harness solar energy. Solar thermal radiation is directly absorbed by a solar energy absorbing material (usually a blackbody), which then converts the radiation energy to heat energy due to its optical response and particulate nature of the material. The heat energy is then transmitted to a heat – transferring medium (i.e. water or air) either ready for use or for the next process (if required). Blackbody is known as a perfect absorber of radiation (only an ideal concept since all real matter will reflect some radiation).

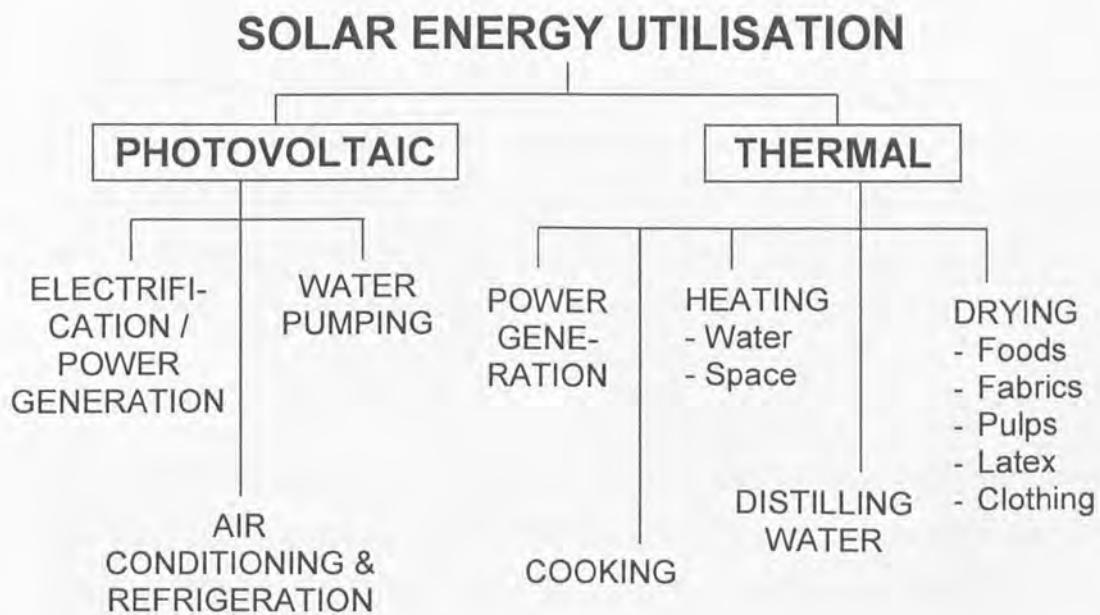


Figure 1.2 – Classification of Solar Energy Application.

## 1.1 RESEARCH BACKGROUND

Solar water heating system (SWHs) is a well-established industry with more than half a century of development and well-established standards and codes of practices. Numerous SWHs with a variety of uses had been designed. Most of the design emphasizes on the thermal performance, suitability and durability of the system. The type of system installed is dependent on local climate and water usage.

In spite of having so much sunshine, solar energy applications (including solar water heating) are not very popular in Malaysia. Though has an extensively long-history worldwide, solar water heaters only entered Malaysian market in seventies (Mohd. Yusof, 1996). Presently, only 3% of households who have the income capability to buy and use SWH are using them (Gurmit and Foo, 1996). Though there is some villages involve in Solar Electrification Project handled by the government, you can scarcely found SWHs in the rural area. The main cause is its high initial cost. This seems to be a waste of the solar energy. Unsurprisingly, it was reported that the public awareness of solar technology has increased and new demand for economy priced solar heaters in Malaysia exceeds supply. The total industry sales of solar heaters for domestic application have increased from 1400 units in 1988 to 3000 in 1991. It is also estimated that 5,460 unit of solar water heating system were sold in 1990, and the sales hit at least RM10.4 million. In 1994 some 9,500 units of domestic solar water heaters were installed while in 1995 another 2,000 unit were sold (Gurmit and Foo, 1996).

The hotel industry is said to have a very good potential in using solar water heaters as the industry uses 24.62% of the total energy just to heat water. More than 20 hotels in Sabah and Sarawak use SWH systems. In fact, some housing developers have installed SWH in new houses, the first being in Taman Mutiara in Penang. Another is Taman Tun Dr. Ismail-SEA Park with SWH from Matsushita.



Others large application of SWHs in Malaysia are in places like Johor Bahru Medical Centre, University Hospital, Shell Group of Companies, Tiram Kimia, G.S Gill, Ramly Burger etc. Based on the standard 60 gallon (264 l) unit, these domestic SWH systems were expected to contribute an annual electricity savings of 23 800 MWh in 1994 (Gurmit and Foo, 1996).

SWHs in Malaysia have achieved market acceptance without extensive promotional activities by the vendors. Instead, SWH has gained significance through the natural process of socialization. The FINESSE study exposed that SWH is seen as a symbol of modernity that reflects the latest trend in household fixtures and has the ability to enhance the owner's self image. For that reason, SWH becomes one of the better-known renewable energy applications in Malaysia. Solar application will be widespread if a solar water heater is considered to be just another standard appliance, and of course if the cost is lower than the marketed model.

Despite of being not very popular in Malaysia, we do have local institutes, manufacturers and agencies that manufacture and do research on solar water heating systems. As for now, there are at least fifteen companies manufacturing or distributing solar water heaters and its components in Malaysia (Table 1.1). In 1987 Shell Malaysia Trading Sdn. Bhd. and Sime Darby Malaysia formed a joint venture company Renewable Energy Systems (RES) to develop, manufacture and market AZTEC solar water heater system in Malaysia to capture 75 % of local market (Gurmit and Foo, 1996). This system use German technology that utilizes plastic collectors (EPDM). In 1997, Solar Research Design (Microsolar Malaysia) invented multi-valve, tube-in-tube, thermosiphon solar water heating system, which hit the scale at 82°C and ensures 60°C hot water even on cloudy days (Teoh, 2000).



Table 1.1 – Solar Water Heating Businesses in Malaysia.

<b>Company (Brand)</b>	<b>Business type</b>	<b>Product type</b>
Alfons Solar Sdn Bhd	Distributor	PV modules, inverters, solar heating systems
Aumada Energy & Technologies Sdn. Bhd. (SOLAHAERT)	Distributor	Solar Water Heaters (SWH)
Gading Kencana Sdn Bhd	Wholesale and consultancy	Solar garden lights, energy efficient homes and buildings, PV systems, SWH systems.
Green Age Solar Technology SDN BHD	Retail sales	Solar air-conditioning system, solar freezer/refrigeration system, SWH system
Intelligent Power System Technology	Retail sales, service	SWH systems, packaged solar and wind power systems.
Pacific Engineering Sdn Bhd (PECOL)	Manufacturer, distributor, service	Solar Water Heaters (SWH)
PECOL ASIA	Retail sales, service	Solar Hot Water Systems
Renewable Energy Systems (AZTEC)	Distributor	Solar Hot Water Systems
Shanghai Guanyang Solar Water Heater	Manufacturer	Solar Hot Water Systems
Solar Research Design (Microsolar Malaysia)	Manufacturer, retail sales, wholesale supplier, exporter	SWH systems, SWH components.
Solarex, Malaysia	Wholesale supplier, exporter	Solar garden lights, SWH systems, Non-PV solar air-conditioner and refrigerator.
Solarplus Technologies (M)	Manufacturer	SWH systems
Solartech Sdn. Bhd.	Manufacturer	Solar Water Heaters (SWH)
Summer Sales and Service	Manufacturer	Solar Water Heaters (SWH)
YN Solar	Manufacturer, service	Solar Water Heaters (SWH)

Most solar water heaters (SWH) are simple system and have simple operation principles. A 264 liters (60 gallons) SWH is usually enough to provide hot water for 4-5 persons. The most common SWH used is Thermosiphon SWHs. This system operates under natural convection flow circulation and has simple features such as flat plate collectors, its absorber sheets and storage tank. While baths and showers usually require water at 37 – 43°C, this system is capable of heating water up to 60°C (Experimental Building Station, 1976).

## REFERENCES

- Adnan Shariah and Bassam Shalabi (1997). "Optimal Design For A Thermosyphon Solar Water Heater." *Journal of Renewable Energy*.
- Alias Mohd. Noor, Farid Nasir Ani and Kannan, K.S. (1999). "Renewable Energy Scenario In Malaysia." Proc. of ISREPA 99. Skudai, Malaysia.
- Arakawa Junji (2001). "Solar Water Heater." (JP 2001091060).
- Arakawa Junji (2001). "Solar Water Heater with Floats." (JP 2001091061).
- Arakawa Junji (2001). "Solar Water Heater and Hot Water Collecting Pipe." (JP 2001091062).
- American Society of Heating and Air-Conditioning Engineers. *Testing Procedure for Thermal Performance Calculation*. ASHRAE 93. 1986
- American Society of Heating and Air-Conditioning Engineers. *Solar Water Heater Components Testing Procedures – Solar Collector Panel and Storage Tank*. ASHRAE 95. 1987
- Asrul Effendy Suhaimi (2001). Pengoptimuman Salutan Kromium Hitam untuk Aplikasi Terma Tenaga Suria. Universiti Teknologi Malaysia: BEng. Thesis.
- Australian Standard Institute. *Tests Procedure for Solar Water Heating Systems*. Australia Standard 2984. 1987
- Bansal, N.K. and Sharma, V.K. (1985). "Glazing Materials for Solar Collectors." in Garg, H. P. (Ed) "Solar Water Heating Systems." Proc. of the Workshop on Solar Water Heating Systems. New Delhi, India: D. Reidel Publishing Company.
- British Standards Institution. *Solar Heating Systems - Testing Procedures*. London, BS 5918. 1989
- British Standards Institution. *Thermal Performance of Solar Collector*. London, BS 6757. 1989
- Chee Moh Lin (2003). Kajian Tentang Sistem Termosifon Aktif bagi Pemanas Air Suria dengan Menggunakan Salutan Kromium Hitam. Universiti Teknologi Malaysia: BEng. Thesis.

- David Faiman, Haim Hazan And Ido Laufer (2001). "Reducing The Heat Loss At Night From Solar Water Heaters Of The Integrated Collector-Storage Variety." *Journal of Renewable Energy*.
- Duffie, J.A. and W.A. Beckman (1991). "Solar Engineering of Thermal Process" New York: Wiley. 184-190, 250-327.
- Experimental Building Station, Departmental of Construction (1976). "Domestic Solar Water Heating." Brisbane: (NSB 143).
- Garg, H. P. (1982). "Treatise on Solar Energy: Fundamentals of Solar Energy." New Delhi, India: John Wiley and Sons Ltd. Vol. 1.
- Garg, H. P. (Ed) (1985). "Solar Water Heating Systems." Proc. of the Workshop on Solar Water Heating Systems. New Delhi, India: D. Reidel Publishing Company.
- Gurmit Singh K. S. and Foo Hee Boon (1996). "Blowing in the Wind: Malaysia's Renewable Energy Scene." Petaling Jaya: Centre for Environment, Technology and Development Malaysia (CETDEM).
- Haslina Aarif (2003). Study of Thermosiphon Solar Water Heater System with Passive Design Using Black Chromium Coating. Universiti Teknologi Malaysia: BEng. Thesis.
- Hazlinda Kamarudin (2007). A Study on Properties and Performance of Newly Improved Formulation Black Chromium Coating for Solar Water Heater. Universiti Teknologi Malaysia. MEng. Thesis. Unpublished.
- Hollands K. G. T. (1965). "Honeycomb Devices in Flat Plate Collectors." *Journal of Solar Energy*. 9. 159.
- J. Idris, H. Kamarudin and DNA Said (2002). "New Design Solar thermal System with Black Chromium Coating", Abstract & Poster for Expo Science & Technology 2002, Kuala Lumpur.
- J. Idris, H. Kamarudin and DNA Said (2003). "New Black Chromium Selective Coating for Solar Water Heating System". Abstract & Poster for 31<sup>st</sup> International Exhibition of Invention, New Techniques and Products of Geneva.
- Jamaliah Idris and Dg. Nooremah Ag. Said (2005). "New Black Chromium Selective Coating for Solar Water Heating System". Abstract & Poster for Industrial Art & Technology Exhibition, INATEX 2005.

- Loh Swee Keong (2002). Effect of Barium Sulphate Deposition on the Optical Properties of Black Chromium Coating. Universiti Teknologi Malaysia: BEng. Thesis.
- Malaysian Meteorological Service – MMS (2004).  
<http://www.kjc.gov.my>.
- Martin Andrew s/o Arlando (2001). Development of Solar Panel System for Thermal Energy Application. Universiti Teknologi Malaysia: BEng. Thesis.
- Mathur, S.S. and Bansal, N.K. (1985). "Domestic Thermosyphon Water Heating Systems." in Garg, H. P. (Ed) "Solar Water Heating Systems." Proc. of the Workshop on Solar Water Heating Systems. New Delhi, India: D. Reidel Publishing Company.
- Michael Glover (Ed) (1979). "Corrosion Prevention in Solar Water Heating Systems." Quebec, Canada: Canadian Government Publishing Centre.
- Minardi J.E. and Chuang, H.N. (1975). "Performance of a Black Liquid Flat-Plate Solar Collector." *Journal of Solar Energy*. 17. 179
- Mohd Nazri Sharum (2002). The Effect of BaSO<sub>4</sub> on Black Chromium Optical Properties on Copper Substrate. Universiti Teknologi Malaysia: BEng. Thesis.
- Mohd. Yusof Hj. Othman (1996). "Penjanaan Tenaga Kesinambungan yang Meyakinkan." Bangi: Penerbit Universiti Kebangsaan Malaysia.
- Montgomery, R.H. and Livingstone, J.L. (1986). "The Solar Water Heater Handbook: a Guide to Residential Solar Water Heaters." Canada: John Wiley & Sons Inc.
- Morrison G. L. (1997). "Developments in Solar Water Heating." *ASME (Singapore) Yearbook*. 45-54.
- Morrison G. L., Behnia M., Cook M., Groenhout N. And Mills D. R. (1999). "Optimal Design of Advanced Solar Water Heaters." Proc. of the Sixth Australian Natural Convection Workshop.
- Morrison G. L. and Wood B. D. (2000). "Packaged Solar Water Heating Technology, Twenty Years of Progress." *Renewable Energy World* Review Issue 2000 – 2001, 170-183.
- Nizamil Fairuz Yahya (2001). Optimisation of Plating Parameters and Performance Analysis of Black Chromium Coating for Solar Thermal Energy Applications. Universiti Teknologi Malaysia: MEng. Thesis.

- Norhalilah Kasauk (2000). Membuat, Mereka bentuk dan Menguji Pemanas Air Tenaga Suria untuk Sistem Penyejukan. Universiti Teknologi Malaysia: BEng. Thesis.
- Ong, K.S. (1994). "Solar Water Heater – Engineering And Application." Kuala Lumpur: University Malaya Publication.
- Plante, Russell Howard (1983). " Solar Domestic Hot Water: Practical Guide to Installation and Understanding." Canada: John Wiley & Sons Inc.
- Rohani Ngandi (2002). Formula Baru Salutan Kromium Hitam untuk Aplikasi Terma Tenaga Suria. Universiti Teknologi Malaysia: BEng. Thesis.
- Romizal Amir Rosdi (2001). Pembangunan Panel Suria untuk Pemanas Air Tenaga Suria Menggunakan Salutan Kromium Hitam. Universiti Teknologi Malaysia: BEng. Thesis.
- Saiful Bari (2000). "Optimum Orientation of Domestic Solar Water Heaters for the Low Latitude Countries." *Journal of Solar Energy*.
- Shalee d/o Ramakrishnan (2000). The Microstructures and Optical Properties of Black Chromium Coating on Solar Panel Materials. Universiti Teknologi Malaysia: BEng. Thesis.
- Sinson D.A. (1979). "How to Build a Solar Water Heater." Quebec, Canada: Brace Research Institute.
- Solar Research Design Sdn. Bhd. (Microsolar Malaysia – 2003)  
<http://www.microsolarsystem.com>
- Souka A.F. (1976). "Double Exposure Flat-Plate Collector." *Journal of Solar Energy*. 9. 117
- Sukhatme, S. P. (1990). "Solar Energy: Principles of Thermal Collection and Storage." New Delhi: Tata McGraw Hill Publishing Company Limited.
- Suppah Rao s/o Ramanaidu (2000). The Optical Properties and Microstructures of Black Chromium Coating for Solar Thermal Energy Application. Universiti Teknologi Malaysia: BEng. Thesis.
- Swartman R.K. and Ogunlade O. (1966). "An Investigation on Packed-Bed Collectors." *Journal of Solar Energy*. 10. 106.

Teoh, Siang Teik (2000). "Tubular Heating Pipe Solar Water Heating System with Integral Tank." (US 6014968).

Thomason H.E. and Thomason H.J.L. Jr. (1976). "Solar Heat Collector." (US 3989031).



**UMS**  
UNIVERSITI MALAYSIA SABAH