UNIVERSITI PUTRA MALAYSIA

SIMULATION AND OPTIMIZATION OF THERMOSYPHON SOLAR WATER HEATER FOR KUALA LUMPUR CLIMATE USING TRNSYS SOFTWARE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfillment of the Requirements for the Degree of Masters of Science

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Special Dedication

This thesis is dedicated to
My affectionate parents
My beloved sisters: Shilla and Helia
For their patient, love and support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
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April 2005

Chairman : Associate Professor Ir. Nor Mariah Adam, PhD

Faculty : Engineering

Solar energy can be utilized for hot water supply in Malaysia but demand is at night and in the early morning. Auxiliary heater can help reduce this mismatch.

The objective of this project is to develop a transient simulation program (TRNSYS) by set the system using suitable parameters for Kuala Lumpur, to determine the optimal system design and the system performance during the year for 150liter/day hot water consumption for five persons.

TRNSYS is a transient system simulation program which is use for thermal analysis of a variety of time dependent systems. The modular nature of TRNSYS permits simulation of a great variety of particular components of a physical system and facilitates the add-ons to the program of mathematical model which is not included in standard TRNSYS

library. A typical thermosyphon solar domestic hot water (DHW) system can be modeled by connecting thermosyphon collector storage subsystem (Type 45), Typical Meteorological Year (TMY) weather data reader (Type89), radiation processor (Type 16), heating load component (Type 14), integrator (Type 24) and online plotter (Type65).

It was observed that the collector should be tilted at $\phi + (7^\circ \rightarrow 37^\circ)$ which is faced to south, according to Kuala Lumpur latitude (ϕ=3.14°).In terms of storage tanks configuration the vertical system has better performance rather than horizontal one. The optimal system designs are: N_r=10, D_r =5 mm, D_o, D_i=15mm, H_r when the H_t is $1m^2$ should be more than 0.8m and the optimum tank height is about 1m. In case of tank volume it is highly depend on the set point (hot water temperature to load), but for most of the cases is between 125-150 liter. The optimum collector area for 150 liter/day consumption is about $2m^2$; there is no effect in increasing the collector area.

It is concluded that the system without auxiliary water heater can not reach the requirements, if the set point is 55°C. In most of the month of the year the mean monthly water temperature is more than 50°C. The auxiliary is needed for cooler months like June, July and November. The auxiliary heating consumption in solar system is about 90% less than the geyser (see Figure5.19).

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

SIMULASI DAN PENGOPTIMUMAN PEMANAS AIR SURIA THERMOSIFON BAGI CUACA KUALA LUMPUR DENGAN MENGGUNAKAN PERISIAN TRNSYS

Oleh

SEYED HAMIDREZA ZAHEDI

April 2005

Pengerusi : Prof. Madya. Ir. Nor Mariah Adam, PhD

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Tenaga suria boleh di gunakan untuk penjanaan air panas di Malaysia tetapi permintaan adalah tinggi untuk waktu malam dan waktu pagi. Penggunaan pemanas tambahan boleh membantu mengurangkan perbezaan bekalan air panas dengan permintaan.

Objektif kajian adalah untuk membangunkan program TRNSYS dengan menggunakan parameter yang sesuai untuk Kuala Lumpur supaya satu sistem optimum dapat diwujudkan untuk penggunaan sebanyak 150l/hari penggunaan air panas untuk lima orang dan sekali gus prestasi sistem berkenaan.

TRNSYS merupakan satu program sistem simulasi transient yang boleh digunakan untuk menganalisis sistem termal untuk pelbagai sistem bergantung kepada masa. Sifat TRNSYS sebagai sistem bermodular membolehkan simulasi pelbagai komponen sesuatu sistem fizikal dan melicinkan cara menambahkan program model matematik

yang tidak wujud di dalam data TRNSYS. Satu sistem suria termosifon lazim (DHW) boleh dimodelkan dengan menghubungkan sub-sistem penstoran penadah termosifon (Type45), pembaca data cuaca Metrologi Tahunan Lazim (TMY), pemproses radiasi (Type16), komponen beban pemanasan (Type14) dan juga pengkamil (Type24) dan pemplot secara online (Type 65).

Keputusan menunjukkan penadah harus condong pada $\phi + (7^\circ \rightarrow 37^\circ)$ mengikut latitude Kuala Lumpur (ϕ=3.14°). Dari segi bentuk tangki penstoran, tangki menegak mempunyai prestasi lebih baik daripada tangki mendatar. Rekabentuk optimum sistem adalah N_r=10, D_r =5 mm, D_o, D_i=15mm, H_r apabila H_t adalah $1m^2$ dan melebihi 0.8m ketinggian optimum tangki 1m. Untuk keadaan isipadu tangki bergantung kepada titik ditentukan, (suhu air panas melawan beban), lazimnya 125-150l. Keluasan optimum untuk penggunaan 150l sehari adalah sekitar $2m^2$ dan tidak memberi seberang kesan tambahan kawasan tadahan.

Boleh dirumuskan bahawa sistem tanpa pemanas bantuan tidak dapat memenuhi permintaan jika titik ditentukan adalah 55°C. Pembantu pemanas diperlukan untuk musim sejuk seperti Jun dan November. Pengunaan pemanas tambahan untuk sistem suria adalah 90% kurang daripada jumlah sistem yang menggunakan elektrik sepenuhnya.

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TABLE OF CONTENTS

Page

CHAPTER

1 INTRODUCTION

2 LITERATURE REVIEW

3 METHODOLOGY

4 RESULTS AND DISCUSSIONS

5 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AEH	Auxiliary Electric Heater
COP	Coefficient of Performance
CPC	Concentrating Collector
DHW	Domestic Hot Water
ETC	Evacuated Tube Collector
FPC	Flat Plate Collector
ICSSWH	Integrated Collector/Storage Solar Water Heater
KL	Kuala Lumpur
RC	Reverse Circulation
SDWH	Solar Domestic Water Heating
SWH	Solar Water Heater
TMY	Typical Meteorological Year
TRNSYS	Transient System Simulation
TSWH	Thermosyphon Solar Water Heater

LIST OF SYMBOLS

A	Total collector array aperture or gross area (consistent with $F_R(\tau\alpha)$, F_RU_L)
A_c	Collector area
a_0	Intercept of collector efficiency vs.$\Delta T/ I_T$, $F_R(\tau\alpha)_n$
a_1	Negative of first order coefficient of the collector efficiency vs. $\Delta T/ I_T$
a_2	Negative of second-order coefficient of the collector efficiency vs. $\Delta T/ I_T$
C_P	Specific heat of fluid
D_h	Diameter of collector header
D_i, D_o	Diameter of collector's inlet and outlet connecting pipes
D_r	Diameter of collector's riser
f	Solar fraction
F_RU_L	Combined first and second-order coefficient of collector efficiency vs. $(T_i-T_a)/I_T$
$F_RU_{L/T}$	Negative of second-order coefficient of collector efficiency vs. $(T_i-T_a)/I_T$
$F_R(\tau\alpha)_n$	Intercept of collector efficiency vs. $(T_i-T_a)/I_T$
$F_RU'_L$	Combined first and second-order coefficients of collector efficiency vs. vs. $(T_i-T_a)/I_T$
g	Gravitational constant
G_{test}	Collector's test flow rate
H_{aux}	Height of auxiliary heating element above the bottom of tank
H_c	Vertical distance between the outlet and inlet of collector
H_o	Vertical distance between outlet of the tank and inlet of the collector
H_r	Height of collector's return above the bottom of the tank

H_t	Height of the tank
H_{th}	Height of auxiliary thermostat above the bottom of the tank
I_T	Total incident radiation on a flat surface per unit area
L_h	Length of collector's header
L_i, L_o	Length of inlet and outlet connecting pipes
$\overset{g}{m}_h$	Mass flow rate of hot stream entering tank
$\overset{g}{m}_L$	Mass flow rate of load
$\overset{g}{m}_i$	Inlet fluid mass flow rate
$\overset{g}{m}_o$	Outlet fluid mass flow rate
N_{B1}	Number of bends in inlet and outlet connecting pipes
N_r	Number of parallel collector's riser
Q_u	Energy gain of total collector array
$\overset{g}{Q}_{env}$	Rate of energy loss from the tank
$\overset{g}{Q}_{in}$	Rate of energy input to the tank from hot fluid stream
$\overset{g}{Q}_{sup}$	Rate of energy supplied to the load by tank
$\overset{g}{Q}_{aux}$	Required heating rate including efficiency effects
$\overset{g}{Q}_{fluid}$	Rate of heat addition to fluid stream
$\overset{g}{Q}_{loss}$	Rate of thermal losses from heater to environment
$\overset{g}{Q}_{max}$	Maximum heating rate of heater

T_a	Ambient temperature
T_h	Temperature of hot fluid entering tank
T_{main}	Average cold water source temperature
T_{env}	Temperature of heater surrounding for heat loss calculation
T_{load}	Water temperature delivered to the load
T_i	Inlet temperature of fluid to collector
T_D	Temperature of water delivered by tank to load
T_I	Initial temperature of preheat portion of tank
T_R	Temperature of fluid returns to heat source
T_L	Temperature of fluid stream entering the tank
T_{pi}	Pipe inlet temperature
T_o	Fluid outlet temperature
T_{set}	Set temperature of heater internal thermostat
T_{po}	Pipe outlet temperature
U_i, U_o	Heat loss coefficient for inlet and outlet connecting pipes
$(UA)_t$	Overall heat loss coefficient for storage tank
$(UA)_p$	Overall heat loss coefficient for pipes
V_h	Volume of fluid entering tank from the heat source over time interval Δt
V_L	Volume of fluid entering tank from load over time interval Dt
V_t	Volume of the storage tank
W_c	Width of the collector
β	Collector tilt angle
γ	Collector azimuth angle

δ	Declination angle
ω	Hour angle
η	Overall collector efficiency
ρ	Fluid density
ρ_g	Ground reflectance
Δt	Simulation time step
Δh_i	Height of the i^{th} node
ΔP_i	Change in pressure across i^{th} node
γ	External control function which has values of 0 or 1
θ_z	Solar zenith angle
η_{htr}	Efficiency of auxiliary heater
ϕ	Latitude

CHAPTER I

INTRODUCTION

1.1 Introduction to solar energy

The amount of energy available from the sun outside the Earth's atmosphere is approximately 1367 W/m^2; that is nearly the same as a high-powered hair drier for every square meter of sunlight (Duffie and Beckman 1991). Some of the solar energy is absorbed as it passes through the Earth's atmosphere. As a result, on a clear day the amount of solar energy available at the Earth's surface in the direction of the sun is typically 1000 W/m^2. At any particular time, the available solar energy is primarily dependent upon how high the sun is in the sky and current cloud conditions. On a monthly or annual basis, the amount of solar energy available also depends upon the location. Furthermore, useable solar energy depends upon available solar energy, weather conditions, the technology used, and its application.

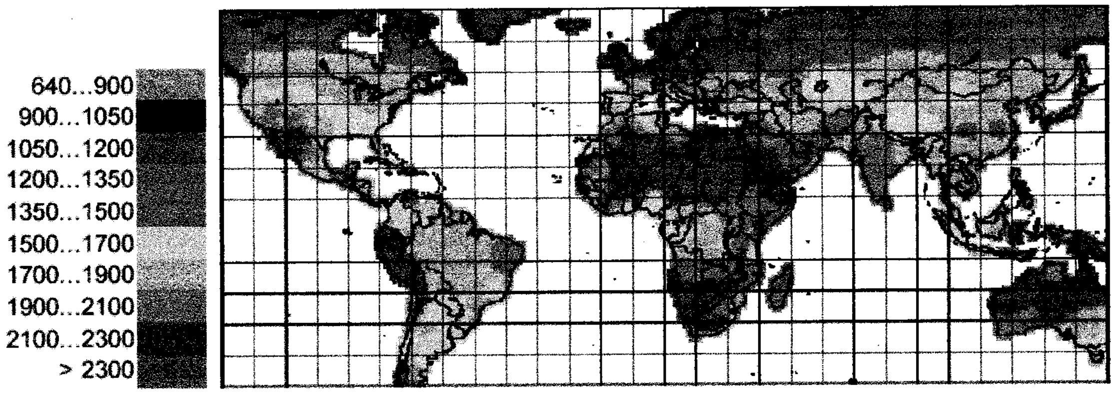

Figure.1.1 Global irradiation in kWh/ m^2 (Geiger 2002)

Solar energy is available abundantly throughout Malaysia. Malaysia has a high solar radiation (See Figure 1.1). The priority to use renewable energy is given to the rural electrification such as installation of Solar PV panels. Villagers at certain remote locations in Sarawak can enjoy the solar-power facility, which can brighten up their nights (The New Straits Times, 3/4/2000). Solar water heaters are quite popular in urban homes and a few hotels. Solar systems also have applications in telecommunications and speed trap cameras.

There are many ways that solar energy can be used effectively. Applications of solar energy use can be grouped into three primary categories: heating/cooling, electricity production, and chemical processes. The most widely used applications are for water and space heating. Ventilation using solar air heating is also growing in popularity. Uptake of electricity producing solar technologies is increasing for the applications photovoltaic (primarily) and concentrating solar thermal-electric technologies. Due to recent advances in solar detoxification technologies for cleaning water and air, these applications hold promise to be competitive with conventional technologies.

The main disadvantage of solar energy is the initial cost. Most types of solar cell require large areas of land to achieve average efficiency. Air pollution and weather can also have a large effect on the efficiency of the cells. The silicon used is also very expensive and the problem of nocturnal down times means solar cells can only generate electricity during the daytime. Solar energy is currently thought to cost about twice as much as traditional sources (coal, oil etc). Obviously, as fossil fuel reserves become depleted, their cost will rise until a point is reached where solar cells become an economically viable source of energy. When this occurs, massive investment will be able to further increase their efficiency and lower their cost.

1.2 Problem statement

Natural circulation loops (thermosyphons) are those systems which make use of inherent properties of heated fluids and the force of gravity; warmer water like air tends to rise, displacing cooler water, which goes to the bottom of container. These systems appear in many engineering applications, including solar heating and cooling systems, central heating systems, solar water heating and also geothermal power production and cooling of nuclear reactions.

The advantage of natural circulation systems are its simplicity, lower cost, high mechanical reliability (no moving parts, no electronic component), and low operating cost with minimal maintenance. Solar power systems can be a less expensive way to develop power on remote property.

The hot water demand is in the early morning and at nights where at these times there is no radiation. Demand is critical during the June, July and November which is the radiation low. It is important to know how the system performs during these months. It is also necessary to install auxiliary electric heater in the system to reduce this mismatch.

Most of the families in Malaysia are using hot water in evening and nights. A survey among 62 families (Seri Petaling, K.L) was done in March, 2004 to understand when and why they are using hot water. Most of the families answered that they are