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Prediction of Thermal Performance of Hot Water System with a Concentric Evacuated Tube Solar Collector using Axially Grooved Heat Pipe

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Abstract: - In the present study, a concentric evacuated tube solar collector with axially grooved heat pipe was investigated experimentally under the weather field conditions of Jinju, Korea. The collector was designed, constructed, and tested at transient conditions to study its performance for different cooling water mass flow rates as well as different inlet cooling water temperatures. Under different climate conditions of Jinju, the experimental results showed that the optimal mass flow rate is very close to the ASHRAE standard mass flow rate for testing conventional flat-plate solar collectors. So, the experimental results indicated that the mass flow rate has a significant effect on the collector efficiency. Subsequently, long term thermal performance of system can be predicted by using TRNSYS model under the weather condition for Jinju, Korea. The annual solar fraction is about 73% for all the hot water system of a house of four people in summer.

Key-Words: - Concentric Evacuated Tube, Grooved Wick, Heat Pipe, Solar Collector

1 Introduction

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. Domestic hot water is one of the essentials for a good standard of living. Solar thermal applications include domestic hot water production, solar cooking, space heating and air conditioning, solar drying, green house energy supply, industrial heat, etc.

In recent years the production volume of evacuated tubes has exploded, resulting in greatly lower manufacturing and material costs. The result is that evacuated tubes are now similar in price to flat plate, but with the insulating benefits of the evacuated tube, they are set to become the default choice for thermal solar applications worldwide.

ETC (evacuated tube collector) have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures than FPC. Like FPC, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give ETC an advantage over FPC in day-long performance.

ETC basically consist of a heat pipe inside a vacuum-sealed tube. Kind of ETC is what is called Dewar tubes. In this two concentric glass tubes are used and the space in between the tubes is evacuated (vacuum jacket). The advantage of this design is that it is made entirely of glass and it is not necessary to penetrate the glass envelope in order to extract heat from the tube thus leakage losses are not present and it is also less expensive than the single envelope system.

ETC use liquid–vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. A heat pipe is a highly efficient device for heat transfer. It consists of an evacuated closed tube filled with a suitable amount of a working fluid. Heat is transfer by the processes of a evaporation and condensation of the working fluid at lower section of the tube (evaporator section) and the upper section of the tube (condenser section), respectively. Therefore, heat is transferred in a latent form (high heat rate) over considerable distance and extremely small temperature drop between the evaporator section (heated region) and the condenser section (cooled region) of the heat pipe tube with a small degradation of energy.

This make the heat pipe tube more recommended to be used in solar system, mainly in solar collector. Moreover, using the heat pipe in solar collectors does not need moving parts or external pumping power, freezing of the working fluid inside the heat pipe is not destructive, and the unit acts as thermal diode preventing the reverse circulation problem in conventional solar collector. This self-limiting temperature control is a unique feature of the evacuated heat pipe collector.

The previous work on two-phase closed thermosyphon flat-plate solar collectors was directed towards studying their performance theoretically and experimentally or comparing them with conventional solar collectors [1,2].

This paper has been carried out to find the thermal efficiency and operating characteristics of solar collectors with grooved wick heat pipes using a glass concentric evacuated tube. And the aim of this work is to predict the thermal performance of a solar water heater with TRNSYS and validate the model by performing a number of simple experiments. Subsequently, the long-term system performance is predicted by using TRNSYS model under the weather condition for Jinju, Korea

2. EXPERIMENTAL METHODS

A schematic diagram of solar collectors with type of heat pipes using a glass concentric evacuated tube and photograph of the collector and storage tank used in this study under consideration are shown in Fig. 1 and Fig. 2, respectively. Heat transfer from the collector to the cooling water is performed by the process of evaporation of the working fluid of the heat pipe, which was water, in the evaporator section of the heat pipe and condensation of the vapor by realizing its latent heat to the cooling water through the tube cross flow heat exchanger that is manifold. The CETC consists of 7 tubes in which absorber fins were welded respectively. The condenser sections of the heat pipe were placed inside a manifold where the cooling water flow in cross direction on the condenser sections of the heat pipe as shown in Fig. 2. The basic characteristics and specifications of the different components of the collector and heat pipe are summarized in Table 1.

Physical quantities measured are: cooling water temperatures in several axial sections along the manifold, cooling water temperatures at the inlet and outlet of the collector, cooling water flow rate, incidence solar irradiance and ambient air temperature. For temperature measurements, type T thermocouples are placed at several axial locations along the manifold as shown in Fig. 1. Another T-type thermocouple probe was used to measure the ambient air temperature. A flow-meter was used to measure the cooling water flow rate and a weather station connected to a data logger was used for the measurements of the solar irradiance incident on the tilted surface of the collector.

The solar water collector with type of heat pipe was installed and tested under the actual field conditions of Jinju, Korea. The experiments on the collector have been conducted during November 2004. The experiments were carried out at different cooling water flow rates 0.8, 1.2 and 2.0 kg/min.

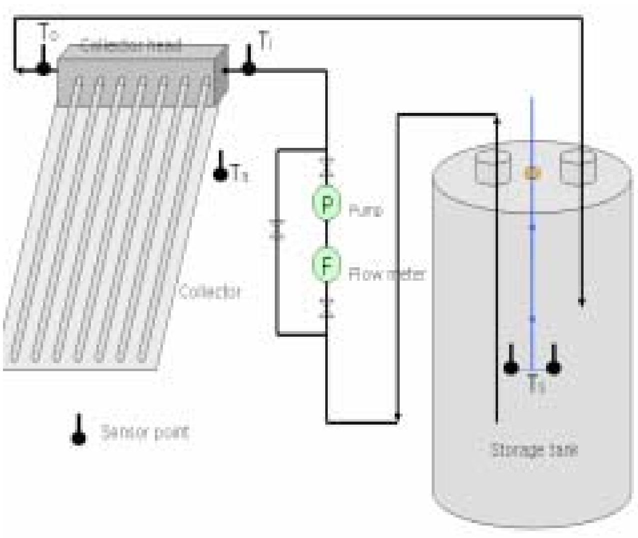


Fig. 1 Schematic diagram of solar collector system.

Fig. 2 Photograph of the solar collector system.

Table 1 Design summary of the solar collector.

Item	Specification	
Collector type	Concentric evacuated tube	O.D 47 [mm]
		I.D 37 [mm]
	Selective surface	Graded Al-N/Al
	Absorber area	0.735 m^2
	Collector tilting angle	35^o
Manifold volume	10 [kg]	
Storage tank volume	100 [kg]	
Heat pipe	Type	Grooved wick
		Number of the groove 30
		Groove width 0.4 [mm]
		Groove height 0.5 [mm]
	Material	Copper
	Working fluid	Water 9 [g]
	Pipe diameter	O.D 8.67 [mm]
		I.D 7.17 [mm]
	Length	Total length 1500 [mm]
		Evaporator length 1250 [mm]
		Condenser length 130 [mm]
		Adiabatic length 120 [mm]
Thermocouple	T-Type	

3. SIMULATION MODEL

Many computer software programs have been developed concerning the modeling and simulation of thermal systems. The most popular are WATSUN, TRNSYS and TSOL. As part of this study TRNSYS 14.2 is selected as the most appropriate because this program allows detailed analysis of all components of the system and it is widely accepted as giving accurate prediction of solar system performance. In the program all the system characteristics are required like the collector performance indicators of slope and intercept of the standard collector test, dimensions of all components and piping, hot water storage tank size, distance between the various components of the system and many others. The model was then simulated with weather data gathered at the location where the solar water heater under investigation is installed. These values were used in the TRNSYS program in order to predict the system performance.

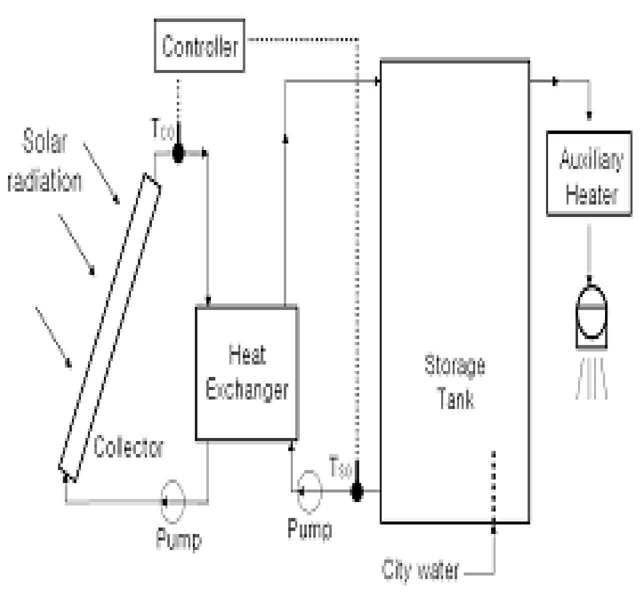


Fig. 3 Schematic diagram of solar collector system for simulation.

4. RESULTS AND DISCUSSION

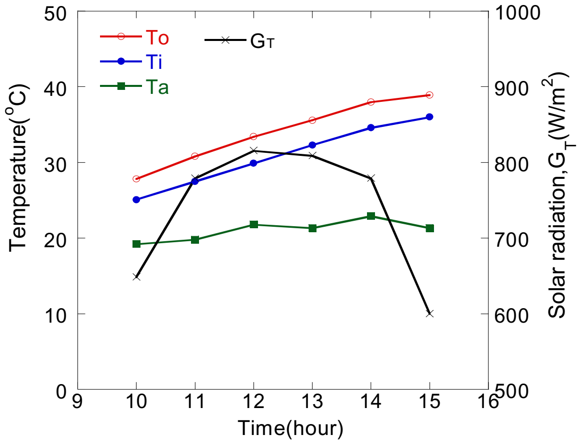
4.1 Experimental results

The useful energy collected from a collector can be obtained from the following formula.

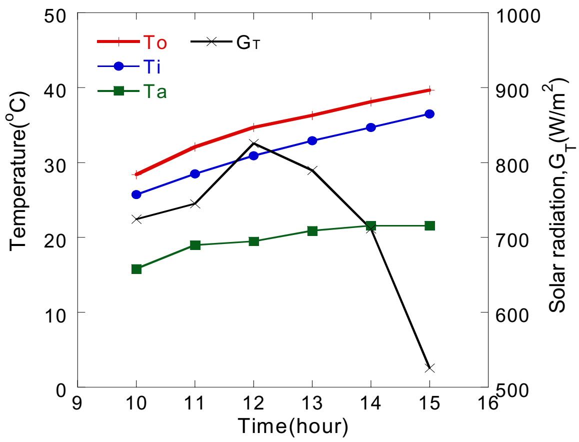
$$\eta = \frac{Q_u}{A_C G_T} = F_R(\tau\alpha) - F_R U_L \frac{T_i - T_a}{G_T} \quad (1)$$

Therefore, Eqs. (1) plot as a straight line on a graph of efficiency versus the heat loss parameter $(T_i - T_a)/G_T$ for collectors. The intercept (intersection of the line with the vertical efficiency axis) equals to $F_R(\tau\alpha)$ for the collectors. The slope of the line, i.e. the efficiency difference divided by the corresponding horizontal scale difference, equals to $-F_R U_L$. If experimental data on collector heat delivery at various temperatures and solar conditions are plotted, with efficiency as the vertical axis and ΔT/G as the horizontal axis, the best straight line through the data points correlates collector performance with solar and temperature conditions. The intersection of the line with the vertical axis is where the temperature of the fluid entering the collector equals the ambient temperature, and collector efficiency is at its maximum. At the intersection of the line with the horizontal axis, collector efficiency is zero. This condition corresponds to such a low radiation level, or to such a high temperature of the fluid into the collector, that heat losses equal solar absorption, and the collector delivers no useful heat. This condition, normally called stagnation, usually occurs when no fluid flows in the collector.

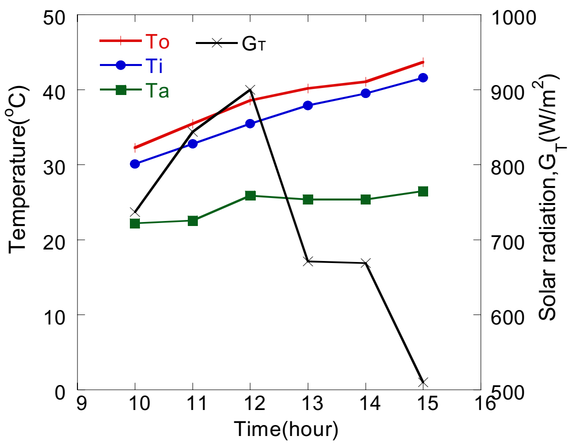
For an understanding of the performance evaluation of the collector, Fig. 4 gives the instantaneous variation of the ambient temperature, the inlet and outlet cooling water temperatures and the experimental measured global solar radiation intensity along the standard local time of the day for four different cooling water flow rates. As shown in the figure, as expected, for the same solar intensity the cooling water temperature rise increases with the decrease of the cooling water flow rate. Fig.5 shows the temperatures that difference between inlet and outlet at manifold with mass flow rate. Fig. 6 shows the comparison between the instantaneous collector efficiency for three different cooling water masses



(a)m=0.8kg/min



(b)m=1.2 kg/min



(c)m=2.0 kg/min

Fig. 4 Variation of temperature and solar radiation with flow rate for a typical sunny day.

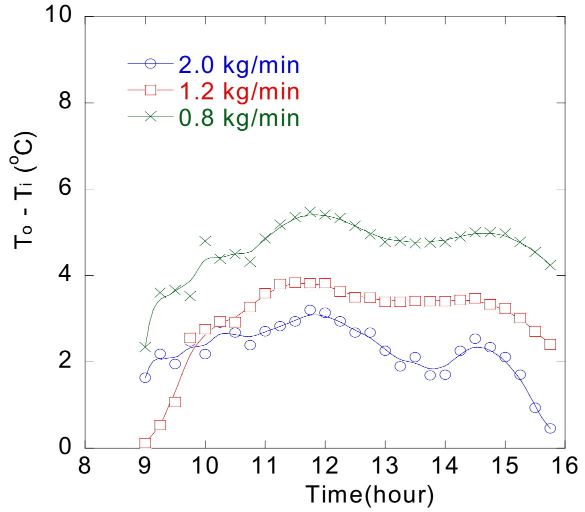


Fig. 5 Temperature difference between collector head inlet and outlet with mass flow rate.

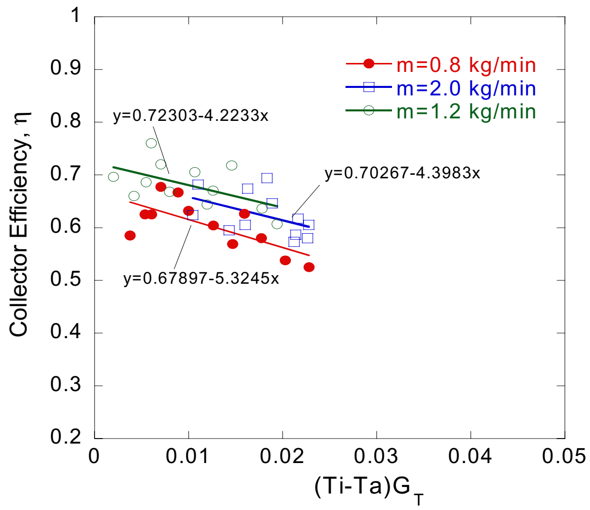


Fig. 6 The thermal efficiency of collector with type of heat pipe.

flow rates and at the conditions shown Fig. 6 shows the comparison of the efficiency curve of the present design with solar collector at the ASHRAE standard mass flow rate of the present study**.**

4.2 Simulation results

The variation of the annual solar contribution is depicted in Fig. 7. In this figure, , the solar fraction, is defined as the ratio of the useful solar energy supplied to the system to the energy needed to heat the water if no solar energy is used. In other words, f is a measure of the fractional energy savings relative to that used

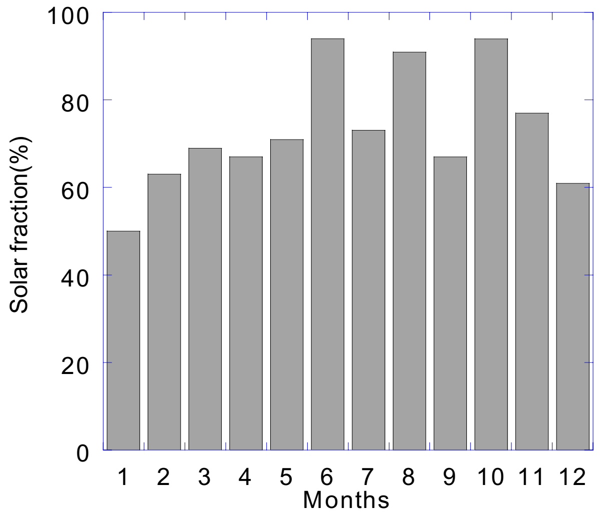


Fig. 7 Predicted monthly and yearly solar contribution of the solar water system.

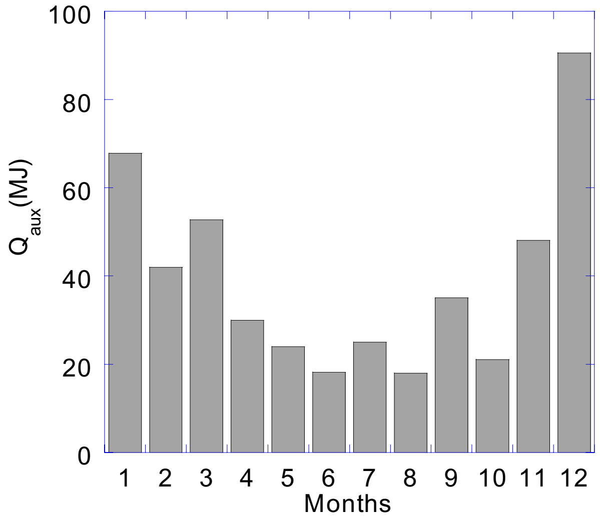


Fig. 8 Predicted monthly auxiliary energy needed by the system.

for a conventional system. It can be calculated from the following relationship:

$$f = \frac{Q_{LOAD} - Q_{AUX}}{Q_{AUX}} \quad (2)$$

Fig. 7 implies that the solar fraction is lower during the winter months and higher, reaching 100%, during the summer months. The annual solar fraction is determined to be 73%. Fig. 8 shows the auxiliary energy needed per month. The maximum auxiliary energy consumption is in January and December.

During the summer months the heat requirements are fully met by solar, hence a little auxiliary is needed.

5. CONCLUSIONS

In this work, the thermal performance for concentric evacuated tube solar collector with axially grooved heat pipe has been investigated experimentally and the results from this work can be summarized as follows:

(1) The thermal efficiency of collector is highest at flow rate of 1.2 kg/min in the range of experimental operation. It is shown that, at 1.2 kg/min, the intercept is about 0.72 and the slope 4.22.

(2)Simulation results for solar system show that annual solar fraction of system is determined to be 73% for domestic hot water system.

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