*Technology, 12(4), 259-266, (2009)*

**TECHNOLOGY**

# THE COMPARISON OF EFFICIENCIES BETWEEN TWO PHASED PROTECTED ZONE AND INDIRECT SOLAR WATER HEATERS

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**Abstract**

The solar water heaters becoming widely used in Turkey have been being limited to some regions due to some drawbacks such as; freezing conditions of cold regions, its occupation of large spaces and difficulties during installation. Besides, the loss of energy stored during the times of high solar radiation because of some external reasons is another disadvantage of solar water heaters. Using the two-phase (liquid-vapour) heat transfer system, which has recently found a variety of usage areas, these disadvantages can be eliminated. In this study, a solar heater with two-phase (liquid-vapour) was designed and constructed. This new system was tested comparatively with an identical classical natural circulatory solar water heater, which has the same characteristic dimensions. According to the test results, "Natural Circulatory System" has found to have a better performance by an average of 3 %, than the one with "Two-Phase System". However, considering the heat losses at night, due to having a protected area, the heat piped solar heater has been found to have a less heat loss by 29 % than the one with natural circulatory system. Two-phase solar heater with protected area, which was designed, manufactured and tested, would be preferred due to its simple construction, having an esthetical looking and easy installation.

**Keywords:** Solar water heater, Two phase, Efficiency.

## 1. Introduction

Due to the fast increase in the population of the World, also the need for the energy increases rapidly. Various studies have been made to meet this extra energy demand. Most of these studies were focused on alternative energy sources. Solar water heaters are one of the most popular ones of these sources due to relatively less installation cost, and because it can work for long times without any need for maintenance [1]. Yet the solar water heaters in use have some drawbacks such as: corrosion, freezing, and heat loss due to back-flow during the night time. To eliminate these drawbacks, two phase systems with vacuum tube were developed. There are many studies to improve and spread out the use of solar water heaters [2-5].

Dowing and Waldin (1980), have investigated the possibility of using freon gasses by comparing a two phase system using R11 with another solar collector using glycol-water mixture. They observed that the freon gasses evaporate easily and the efficiency of the system using R11 is better than that of the other one by 35%. Thus the two phase system increased the water temperature faster than the other system. R12, R113 and R114 were used in the experiments [6]. Samancı (2005) used R12 as the working fluid in a two phase solar heater which is designed and tested in Konya, and compared experimentally with a single phase solar water heater. Two phase system showed an efficiency of as high as 65.3% while the single phase system had an efficiency of 45.7% [7]. Esen et al. (2000) fabricated a two-phase thermosyphon solar collector with heat pipes and studied experimentally various phase-change fluids to evaluate the effect of insolation and mass of fluid on the collector performance. It was found that such a

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collector can be successfully used, especially during cold, cloudy and windy days [5]. The thermal efficiencies of a solar water heater with natural circulation and another solar water heater with a batch of heat pipes using ethanol, water, and R-11 as the working fluid were investigated by Alkaç (1996). This study showed that the heat piped solar water heater is more efficient than the natural circulation solar water heater system by 13% [3]. Similar study was carried out by Yılmaz (1988) who way assembled a batch of heat pipe and used ethanol as the working fluid. The performance value of the heat piped system was found 72% while the other 53%. It was alleged that heat piped solar water heaters can be preferred for the simplicity of their construction, ease of installation, and their aesthetical appearance [4]. Payakaruk et al. (2000) worked on inclined thermosyphon type solar collector. R-22, R-123, R-134a, ethanol and water were used in collectors as working fluid. Systems were filled by 50%, 80%, and 100%. Filling ratio and inclination angle have no significant effect on the heat transfer characteristics, however it was seen that the properties of the working fluid used in the experiment affected the heat transfer rate [8]. Mathioulakis and Belessiotis (2002) developed a new type of heat piped solar water heater using ethanol as the working fluid and investigated the energy behaviors of this new system. They reported the energy behavior of the system as high instantaneous efficiency up to 60% [9]. Pluta et al. (1995) designed a two-phase solar thermosyphon for use in a domestic hot water system and indicated that proper construction and choice of a suitable phasechange medium played an importance role in assuring the proper operating conditions of the phase-change thermosyphon [10]. Ghaddar et al. (1998) fabricated and tested an R-11 changed solar collector with an integrated condenser for secondary-cooling of the water flow. The forced circulation flow method use in his test demonstrated instantaneous system efficiency values varying from 20% to 60%, which was in the range of conventional water solar collectors [11]. Chun et al. (1999) experimentally studied a domestic solar hot water system using heat pipes. A number of systems with different configurations and working fluids were constructed and their performance measured to elicit the most feasible model considering the various limiting conditions present [12]. In other study, Rittidech and Wannapakne pointed that an experimental flat plate solar collector operating in conjunction with a closed-end oscillating heat-pipe (CEOHP) offers a reasonably efficient and cost effective alternative to conventional solar collector system that use heat pipes. R134a was used as the working fluid. An efficiency of approximately 62% was achieved, which correlates with the efficiency of the more expensive heat pipe system. As a result, the CEOHP system offers the additional benefits of corrosion free operation and absence of freezing during winter months [13].

In this study, a solar water heater was designed benefiting from the studies which employ heat pipe for the solar water heater systems. The system which is designed and made in this study is easy to produce and mount, is of high performance and low cost, resistant to freezing in winter, aesthetic, and free of circulation problems. It has low heat losses during night time, integrates with the roof making it a water-proof insulated area. The system was compared to the natural circulation system.

## 2. Theory

The thermal performance of a flat plate solar collector is defined as a linear performance characteristic, relating the rate of useful heat output per unit aperture area ($q_u$) and the solar radiation input ($I_c$) and the heat losses ($U_c$).

$$q_u = I_c.A_c.(\tau\alpha) - U_c.A_c.(T_c - T_a) \tag{1}$$

The instantaneous efficiency ($\eta$) of the collector is defined as the ratio of useful heat gain ($q_u$) delivered per unit area to the solar radiation intensity ($I_c$) multiplied by collector surface area ($A_c$).

$$\eta = \frac{q_u}{A_c.I_c} \tag{2}$$

The material of the collector, shape of the absorber, property of glass, and weather and test conditions affect the instantaneous efficiency of collector. These relations can be expressed as following equation,

$$\eta = F'.(\tau\alpha) - F'.U_L.(T_m - T_a), \quad (3)$$

where "$F'.(\tau\alpha)$", is the maximum collector efficiency when there is no heat loss from the collector or when $T_m$=$T_a$.

$$q_u = m.C_p.(T_s - T_b) \quad (4)$$

$$\eta = \frac{m.C_p.(T_s - T_b)}{A_c.I_c} \quad (5)$$

"$U_L$" is not always constant; it depends upon the collector operating temperature and the weather conditions. Since the heat loss coefficient "$U_L$" varies non-linearly with rise in collector temperature, the efficiency ($\eta$) should bend slightly downwards as the ratio of temperature difference to solar radiation increases (14, 15).

Results of the experiment, dated 19.May.2003, which two phase with protected zone solar water heating system with ethanol as the working fluid, are as follows;

I = 637 W/$m^2$
$T_b$ = 20 °C
$T_s$ = 39 °C
A = 0.5 $m^2$
$c_p$ = 4180 J/kg °C
m = 21 kg (1 liter of water assumed to be equal to 1 kg.),

If these values are used in Equation 5, efficiency can be found as;

$$\eta = \frac{\frac{21}{6.3600}.4180.(39-20)}{0,5.637} = 0,24$$

## 3. Experimental Setup and Application

### 3.1 Specifications of the Systems

Two systems, one of which is indirect system and the other is two phase with protected zone system, were constructed by using similar materials. Both systems have been designed with identical storage tank volume and collector surface area. In order to compare the efficiency of systems, technical specifications of both systems were given in Table1 and schematic representation of solar water heater with two phase was shown in Figure 1.

Table 1. Technical Specifications of the Solar Water Heaters Used in the Experiments.

| Material Type | Two Phase System | Natural Circulation System |
|---|---|---|
| Working Fluid | Ethanol | Water |
| Storage Tank Volume | 21 Liter | 21 Liter |
| Diameters, Lengths and Materials of the Pipes Used in the System | 35 mm 0.55 meter Copper<br>12 mm 7.5 meter Copper | 12 mm 6.6 meter Copper<br>20 mm 1.1 meter Copper<br>30 mm 0.6 meter Copper<br>25 mm 4.0 meter Iron |
| Collector Area | 0.5 $m^2$ | 0.5 $m^2$ |
| Storage Tank Material | 0.2 mm Sheet Metal | 0.2 mm Sheet Metal |
| Collector Case | 10 mm Wood | 10 mm Wood |
| Case Insulation | Polystyrene Foam | Polystyrene Foam |
| Glass | 3 mm Window Glass | 3 mm Window Glass |
| Inclination | 18° | 41° |

The designed system is called as "phase protected area system" which means that the system has the same inclination with the roof surface and integrates with the roof material. Hot water tank is located inside the roof as to not prevent the circulation. "protected area" here refers to prevention of collectors and the tank from the outside effects (Wind, Dust, Cooling etc).

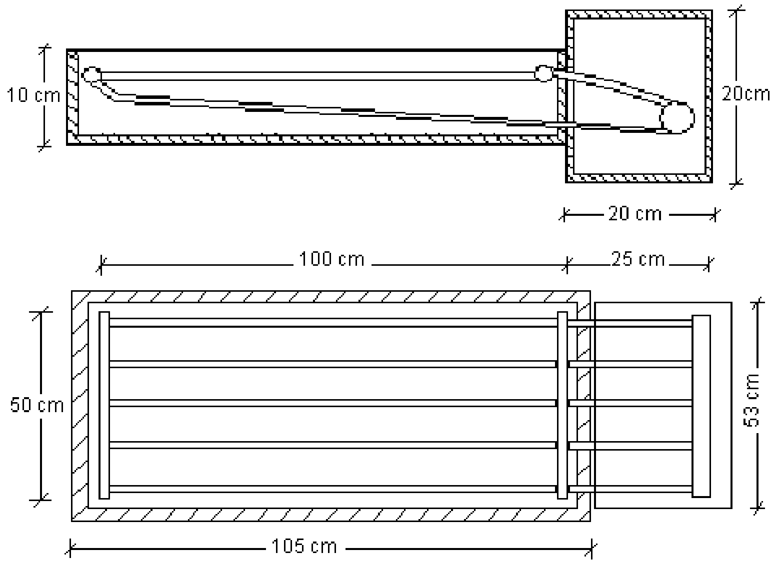


Figure 1. Schematic Diagram of Two Phase with Protected Zone Solar Water Heater.

Schematic diagram of the indirect solar water heater with natural circulation was shown in Figure 2. This system is widely used and is exposed to hard outside effects and that's why it was chosen to compare with the dual phase protected area solar water heater.

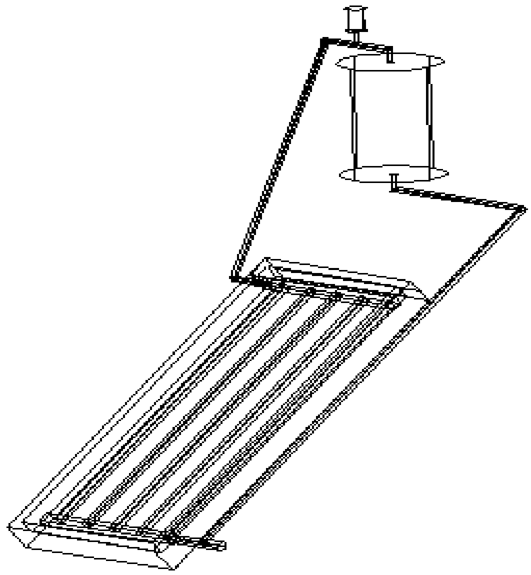

Figure 2. Schematic Diagram of The Indirect Solar Water Heater with Natural Circulation.

### 3.2 Experiments

Two phase system was first vacuumed and then filled with 30% ethanol by volume. To form the protected area of the system, collectors of the system were installed to a prototype roof with 18° of inclination following the regulation of Karabuk municipality number 759/34, which is related to the roofs of the buildings. On the other hand, indirect heated planar solar collector is installed with 41° of inclination which is the latitude of Karabuk region.

Two solar water heaters were tested at the same conditions for seven days from 14.November.2002 to 17.November.2002 and from 17.May.2003 to 19.May.2003. Experiments were started by filling up the storage tanks at nine o'clock on the first day, and continued by hourly measurements until 15:00. At the following days storage tanks of the systems were emptied and refilled with fresh water at nine o'clock and the measurement were recorded hourly until 15:00. During the experiments global insolation on absorber ($I_c$), storage tank water temperatures of both system ($T_b$, $T_s$) and ambient temperature ($T_a$) were measured.

Temperature measurements were taken with calibrated Fe-Const. thermocouples connected to a multichannel digital readout with accuracy of 0.1 °C. The solar radiation intensity on solar collector surfaces was measured with Solar-130 type pyranometer digital readout, which has an accuracy of 1.5%. Measurements were taken at intervals of one hour during the effective sunshine period of 09:00 a.m. to 15:00 p.m.

## 4. Result and Discussion

Two solar water heaters were tested at the same conditions for seven days in November and May mounts. The results of these studies are show in Fig. 3-7. The following points can be noted: Fig. 3 and Fig. 4 shows the daily changes of the ambient conditions for both experiments. Values of ambient temperature ($T_a$) and solar energy irradiation (I) are shown.

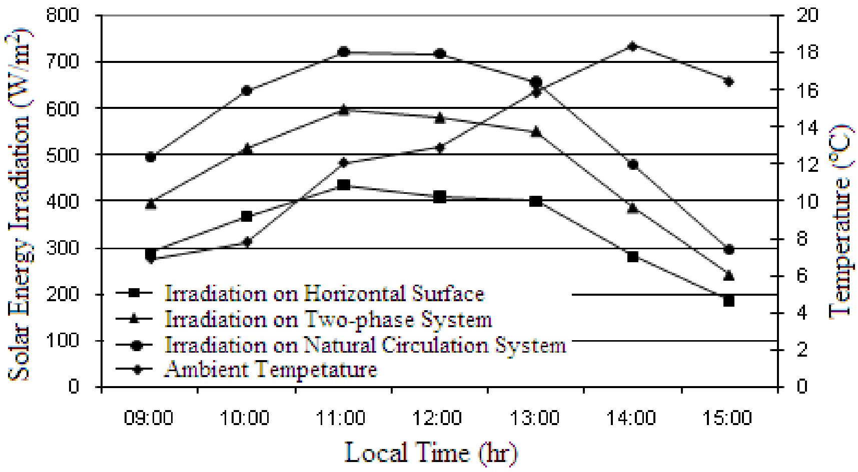


**Fig. 3.** The Daily Changes of the Ambient Conditions in November 2002.

In Fig. 3 and 4, two phase system have low solar irradiation according to indirect solar water heater in November. However, solar irradiation value approximate to two systems in May.

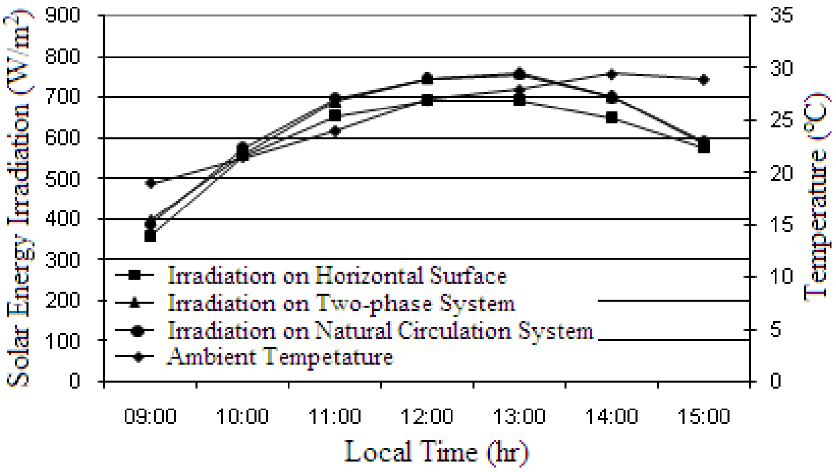


Figure 4. The Daily Changes of the Ambient Conditions in May 2003.

Figures 5 and 6 give the relationship between the ambient temperature and the tank water temperatures of the systems for November and May respectively. The result indicates that as the ambient temperature increases the water temperature in storage tank increases.

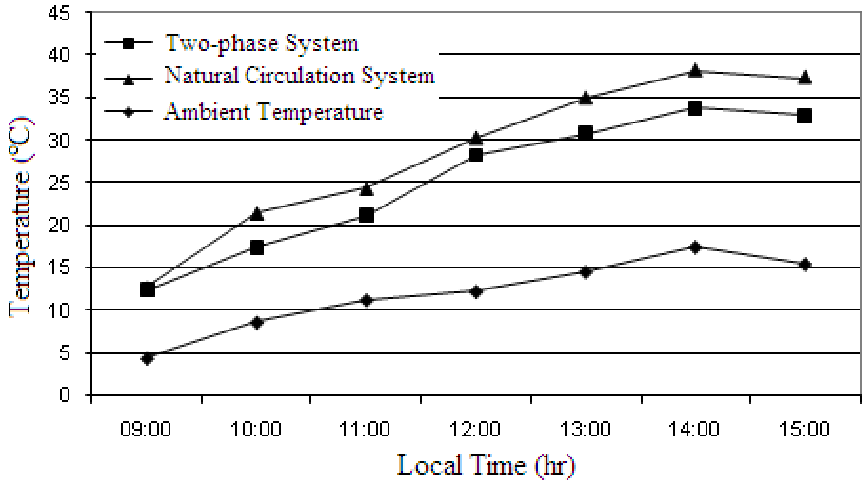


Figure 5. Water Temperature in Storage Tank Versus Ambient Temperature in November, 2002.

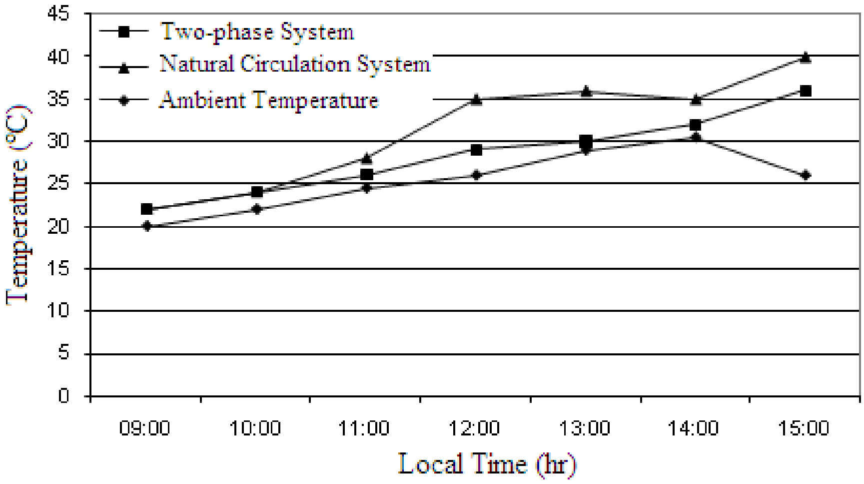


Figure 6. Water Temperature in Storage Tank Versus Ambient Temperature in May, 2003.

Figure 7 gives the collector efficiencies by date. Natural circulation system is more efficient in May while the efficiencies of both system are close to each other in November. If the horizontal distance between the collector and the hot water tank in the roof can be increased to obtain the desired vertical height geometry, the system would be expected to operate more efficient.

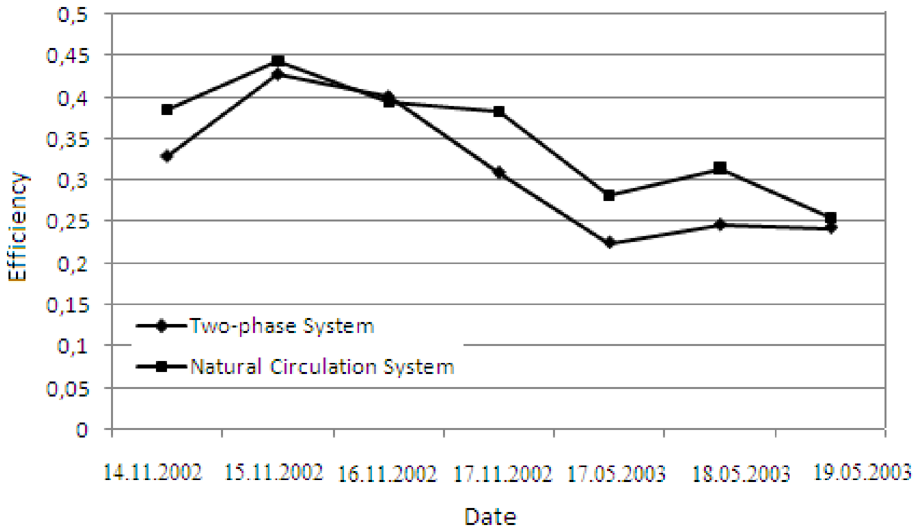


Figure 7. Collector Efficiency Versus Date.

Measurements showed that the designed system takes ideal solar radiation in summer season and is disadvantageous in other times of the year. In the study, heat losses from the system during the night time is measured. Heat losses from the two phase were estimated as 158 kcal in November and 147 kcal in May respectively which is less than natural circulation system by 28.5%. From the aesthetic and ease of assembly point of view, two phase protected zone solar water heater is much more better than the natural circulation system. According to the experimental results, protected zone solar water heaters would be more beneficial in cold regions and especially in winter due to its less heat losses.

## 5. Conclusion

In this study, a solar heater with two-phase was designed and constructed. This new system was tested comparatively with an identical classical natural circulatory solar water heater, which has the same characteristic dimensions. According to the test results, “Natural Circulatory System” has found to have a better performance by an average of 3 %, than the one with “Two-Phase System”. However, considering the heat losses at night, due to having a protected area, the heat piped solar heater has been found to have a less heat loss by 29 % than the one with natural circulatory system. Other advantages of the system include simple construction, having an esthetical looking, easy installation corrosion free operation and elimination of winter icing problems..

## Nomenclature

$q_u$ : Useful Heat Gain (W)
$A_c$ : Area of Absorber ($m^2$)
$I_c$ : Daily Average Global Insolation on Absorber ($W/m^2$)
$C_p$ : Specific Heat of the Working Fluid (kJ/kg °C)
m : Fluid Flow Rate (kg/s)
F : Collector Efficiency Factor
$\alpha$ : Absorbtance of Collector Plate (0.9–0.95)
$\tau$ : Transmittance of Glazing (0.75–0.9)
$U_c$ : Overall Heat Loss Coefficient ($W/m^2$ °C)
$\eta$ : Efficiency
$T_c$ : Average Absorber Plate Temperature (°C)

$T_a$ : Ambient Temperature (°C)
$T_b$ : Initial Water Temperature of The Experiment (°C)
$T_m$ : Temperature of (°C)
$T_s$ : The Water Temperature at The of Experiment (°C)
$\Delta t$ : Temperature Difference (°C)
$Q_s$ : Heat (W)

**References**

1. Yılmaz, S., Deniz, E., "Isı Borulu Güneş Enerjili Su Isıtma Sistemlerinde Soğutucu Akışkan R-22 Kullanımının Deneysel Olarak İncelenmesi", Cilt:8, Sayı:4, Sayfa: 349-356, 2005. (In Turkish)
2. Deniz, E., "Çift Fazı Korunmuş Bölgeli Güneşli Su Isıtıcı ile Endirekt Isıtmalı Güneşli Su Isıtıcı Vermlerinin Karşılaştırılması", Yüksek Lisans Tezi, Zong. Karaelmas Ünv., Fen Bilimleri Enstitüsü, 2003. (In Turkish)
3. Alkaç, Ö., "Isı Borusu Prensibinin Güneşli Su Isıtıcılarına Uygulanması", Yüksek Lisans Tezi, Z. Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, Zonguldak, 1996. (In Turkish)
4. Yılmaz, S., "Güneş Enerjili Isı Borusuyla Sıcak Su Üretimi", Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Ankara, 1988. (In Turkish)
5. Esen M., Yüksel T., "Isı Borulu Güneş Enerjili Termosifon Düzlemsel Kolektörün Performansı", Fırat Üniversitesi Makine Eğitimi Bölümü, 23119 Elazığ, F.Ü. Fen ve Müh. Bilimleri Dergisi 12(2), 201-207, 2000 (In Turkish)
6. Dowing, R. C., Waldin, V. H., "Phase-Change Heat Transfer in Solar Hot Water Heating Using R-11 and R-114", Ashrae Transactions, pp. 848–856, 1980.
7. Samancı, Ahmet, "Çift Fazlı ve Klasik Tek Fazlı Güneş Enerjili Su Isıtma Sistemlerinin Deneysel İncelenmesi", Tesisat Dergisi, Sayı 119, sayfa 134–139, 2005. (In Turkish)
8. T. Payakaruk, P. Terdtoon, S. Ritthidech, "Correlations to Predict Heat Transfer Characteristics of an Inclined Closed Two-phase Thermosyphon at Normal Operating Conditions", Applied Therm. Eng. 20, 781-790, 2000.
9. E. Mathioulakis, V. Belessiotis, "A New Heat-pipe Type Solar Domestic Hot Water System", Solar Energy 72, 13-20, 2002.
10. Pluta, Z., Pomierny, W., "The Theoretical and Experimental Investigation of the Phase-Change Solar Thermosyphon", Renewable Energy, 6:317-321, 1995.
11. Ghaddar, N., Nasr, Y., "Experimental Study of a Refrigerant Charged Solar Collector", International Journal of Energy Research, 22:625-638,1998.
12. Chun, W; Kang, Y.H., Kwak, H.Y., Lee Y.S., "An Experimental Study of the Untilization of Heat Pipes for Solar Water Heaters", Applied Thermal Engineering, 19:807-817, 1999.
13. S. Rittidech, S. Wannapakne, "Experimental Study of the Performance of a Solar Collector by Closed-End Oscillating Heat-Pipe (CEOHP)", Applied Thermal Engineering 27, 1978-1985, 2007.
14. J.A. Duffie, W.A. Beckman, "Solar Engineering of Thermal Processes", 2nd ed., John Wiley & Sons, Inc., New York, October, 1991.
15. A.A. Karaghouli, W.E. Alnaser, "Experimental Study on Thermosyphon Solar Water Heater in Bahrain", Renewable Energy 24, 389-396, 2001.