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AN COMPARISON OF A NEW TYPE CONICAL SOLAR COLLECTOR WITH A FLAT-PLATE SOLAR COLLECTOR

ABSTRACT

In this study, a new type conical solar collector was designed and its performance was compared with of the plane collectors experimentally. The purpose of this study was to collect the sunlight perpendicular to the surface of the collector all day long and the sun's movement relative to the collector is tracked statically with no moving parts with this new design. Absorbing surface was produced from copper due to its high heat transfer coefficient. The surface of the copper was painted with mat black colour with a radiation coefficient of 0.96. The circulation pipes were also manufactured from copper and it was placed on the collector surface in helix. Circling the fluid all over the surface the circulation route was increased. The experiments were carried out in three different flow rates. The angle of the plane collector was chosen constant at 37°. The conical type solar collector was compared with conventional flat-plate collector. It was seen that the efficiency of the collector increased between 24% and 15% depending on three difference mass flow rates according to the flat plate collector.
Keywords: Conical Type, Solar Collector, Passive Water Heater.

KONİK TİP YENİ BİR GÜNEŞ KOLLEKTÖRÜNÜN DÜZLEMSEL GÜNEŞ KOLLEKTÖRÜYLE KARŞILAŞTIRMASI

ÖZET

Bu çalışmada, yeni bir tip güneş kollektörü tasarlanmış ve düzlem yüzey güneş kollektörü ile deneysel olarak karşılaştırılmıştır. Bu çalışmanın amacı; kollektörü hareket ettirmeksizin günün bütün zamanlarında güneş ışınımını kollektör yüzeyine dik gelecek şekilde toplamaktır. Toplayıcı yüzey, yüksek ısı transfer katsayısı özelliğinden dolayı bakır plakadan yapılmıştır. Bakır plaka yüzeyi yutma katsayısı 0.96 olan siyah mat boya ile boyanmıştır. Sirkülasyon boruları bakırdan yapılmıştır ve toplayıcı yüzeyine helisel olarak sarılmıştır. Böylece akışkanın yüzey üzerindeki yolu uzatılmıştır. Deneyler üç farklı akışkan debisinde yapılmıştır. Düzlem yüzey güneş kollektörü yatayla 37° olacak şekilde yerleştirilmiştir. Deneysel sonuçlarda, kütlesel debiye bağlı olarak konik tip güneş kolektörünün etkinliği düzlem yüzey güneş kolektörüne göre %15-24 arasında arttığı görülmüştür.
Anahtar Kelimeler: Konik Tip, Güneş Kollektörü,
Pasif Su Isıtıcı

1. INTRODUCTION (GİRİŞ)

Flat-plate collectors have an important place among applications of solar energy system. Main part of flat-plate collectors is black absorber surface. Because of this, several investigations are made on this subject in order to increase efficiency of the collector and outlet temperature of fluid. The aim of these investigations is to develop a more efficient absorber, to increase amount of energy obtained, to decrease the cost of energy provided from the sun, to storage the energy and to use it continuously. Solar collectors are classified into two groups according to fluid used. Water is usually used in liquid collectors and air, in gas collectors.

A new type of solar collector is developed and its short-term thermal performance is investigated [1]. The solar collector, which exhibited a net apertures area of 1,44 m^2, consisted of two adjoining sections one filled with water and the other with a phase change material with a melting and freezing range of about 45-50°C, i.e. paraffin wax in that study. It was seen that the instantaneous thermal efficiency values are between about 22% and 80%. This solar collector is much advantageous over the traditional solar hot water collectors in Turkey in terms of total system weight and weight and the cost in particular. In order to investigate variations in chemical composition across the drop size spectrum, a now multi-stage cloud collector is developed [2]. Limited field tests indicated that the CSU 5-stage works reasonably within field measurement uncertainty and its results are compared to those other cloud collectors. A solar plant for hot-water production is investigated by the dynamic simulation code (TRNSYS) [3]. A heat exchanger is considered between collector and storage tank. Pumps activated by photovoltaic panels circulated the fluid. The research revealed that the use of such a plant is clearly justifiable in situations where fossil fuel consumption is to be reduced.

With the consideration of hydraulic dissipated energy, the influence of collector aspect ratio on the modified collector efficiency of sheet-and- tube solar water heaters is investigated theoretically [4]. As the collector area and the distance between tubes is fixed, the collector efficiency increased with increasing collector aspect ratio. However, based on the same hydraulic dissipated energy, decreasing the collector aspect ratio enhanced the performance of the collector. Comparison between theoretical and experimental analysis of an open type flat collector for tannery effluent treatment is presented [5]. Effect of the parameters such as insulation, wind speed, relative humidity, and mass flow rate and salt concentration on the evaporation rate of water in the effluent is studied. It is seen that the maximum deviation of the experimental performance is 10% in comparison with that of the theoretical analysis. An other study, the design and performance of a convex type of solar water heater is studied [6]. The main purpose of a convex solar collector is to accomplish static tracking for the sun radiation without additional cost. The research seen that the efficiency and the useful energy are considerably greater for the convex type collector than for the flat-plate collector under the same environmental and insulation conditions. An additional 45% energy gain is achieved from the convex type compared to the flat-plate collector. A survey of the orientations of domestic solar water heaters in Malaysia is showed a wide range of variations [7]. These collectors are installed on the roof, the slope being the same as the slope of the roof, with the result that the common slopes were 30° and 40°. It is observed that the most collectors in Malaysia are incorrectly installed and they are receiving 10-35% less radiation than a properly installed collector, while in some extreme cases, they are receiving as little as 50%. A study is carried out on the solar concrete collectors providing domestic hot water [8]. The comment concrete collectors are made up of thin comment concrete slabs with a network of aluminum pipes embedded over its surface. No glazing on the top of the cement collector solar collector or insulation at the back is used as in conventional solar water heaters. It is seen that hot water at moderate temperature (36°C to 58°C) can be obtained in the buildings during the daytime in winter by using rain-forced cement concrete slabs or by slightly modifying the roof structure and lying down a network of aluminum pipes over it which can offer a low cost passive solar water heating system in the building itself.

2. RESEARCH SIGNIFICATION (ÇALIŞMANIN ÖNEMİ)

In this study, the aim is to increase collector efficiency using passive method in water collectors. Two type of collectors, conventional flat plate and conical type having the same surface area (1,48 m^2), are tested under the same conditions. In conical type solar collector designed, almost all the beam solar radiation will have perpendicular incidence on the curved surface.

3. EXPERIMENTS (DENEYLER)

3.1. Experimental Set-Up (Deney Düzeneği)

The experimental apparatus used in this investigation is shown in Figure 1. Two types of solar collectors with the same projected area were compared with each other. These were a conventional type flat plate collector and a new type collector having conical surface area.

Figure 1. Layout of experimental set-up
(Şekil 1. Deney düzeneğinin görünüşü)

The conical type collector can be considered as a funnel inverted as shown in Figure 2. This collector consists of a copper absorber sheet with 1 mm thick and pipes with 12 mm diameter. The sheet was painted with mat black color having 0,96 absorption coefficient. The collector was covered by a single glass with 4 mm thick. Since conical glass with the desired dimensions was not provided prom the market, flat glass was into six trapezoids and joined as shown in Figure 1. Rubber sealing ribbons were employed beneath the glass covers and silicone rubber was used to seal the collector at the top. Joining points of the glass were carefully covered by joint seal and provided imperviousness. Solar radiation comes to Elazığ in Turkey with 37° angle at the summer mounts. For this reason, the conical collector was manufactured on a frame inclined at an angle of 37° with the horizontal. To minimize the heat losses from the bottom of the collector, glass wool having low heat conduction coefficient (k=0,038 W/m.K) and 50 mm thickness was employed for insulation in the collector underneath. The water tanks that were used to supply both conventional flat plate collector and the conical collector were manufactured. Two transparent hoses were assembled at the top of the tanks in order to observe and keep the water level constant. The outlet end of each tank was connected to a half-inch iron pipe with a calibrated valve. Pressure loss of each collector is different depending on the flow line and its construction. Therefore, the valves were calibrated separately for three different mass flow rates in the each collector.

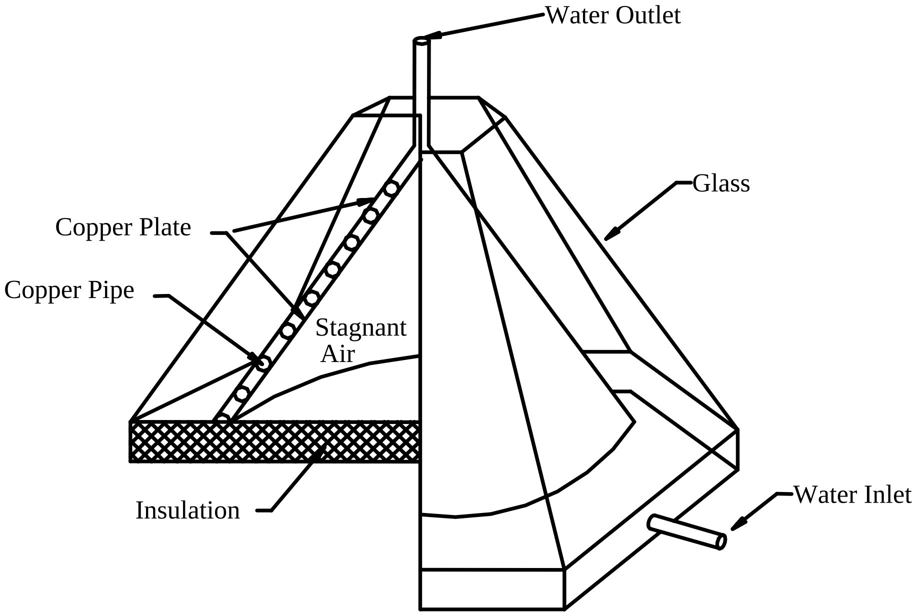

Figure 2. Cross section of the conical type solar collector
(Şekil 2. Konik tip güneş kollektörünün kesiti)

The flat plate collector was purchased from the local market. To make the surface area of absorbers and pipes in the each collector equal each other, 0,32 m^2 of the flat plate collector with (1x1,8 m) dimension was isolated by glass wool and prevented the water circulation by closing the outlet and inlet of one of the pipes.

3.2. Measurements (Ölçümler)

The experiments were carried out at the same time periods between 9.00 and 16.00 of the days for a variety of mass flow rates with $\dot{m}$=0,012 kg/s, $\dot{m}$=0,015 kg/s, $\dot{m}$=0,017 kg/s. The incident solar radiation was measured with a Kipp & Zonen (CM-3) piranometer. T type Copper-Constantan thermocouples with 0,5 mm were placed at four points in each collector as well as at the inlet and outlet ports of the water to measure by a multi-channel digital micro voltmeter for 60 min. periods.

In this study; errors are to come from sensitiveness of equipment and measurements. First; errors due to measurement of temperature; are sensitiveness of voltmeter is about ±0,1%°C, measurement error is ±0,2% and sensitiveness of Thermocouple is ± 0,1%°C. The sensitiveness was obtained from catalog of the instruments. Second is to come from measurement of flow rate. The sensitiveness of flow meter is about ±0,1% and error due to measurement is about ±0,1%. Totally errors for measurement of flow rate are about ±0,2%. The experimental results obtained have approximately 6% errors totally.

3.3. Analysis (Analiz)

The efficiency of solar heating systems extensively depends on the efficiency of the collectors. Test methods based on incident measures are applied to the all collector throughout both liquid and gas flows. In this method, mass flow rate of the fluid, the temperature of the collector inlet and outlet and the radiation intensity are measured simultaneously [9].

Thermal collector efficiency is defined as the ratio of useful energy and the incident solar radiation.

$$\eta = \frac{\text{Useful energy gain}}{\text{Total energy intercepted by the collector}} = \frac{Q}{I.A} \tag{1}$$

where I, is the incident solar radiation (W/m^2), A, area of the collector (m^2). The useful energy Q used in the calculation of collector efficiency can be estimated by using following equation;

$$Q = \dot{m}.C_p.(T_o - T_i) \tag{2}$$

where $\dot{m}$ is the mass flow rate (kg/s), C_p, specific heat of the water (J/kg.K), T_o and T_i, The outlet and inlet temperature (K) of the water, respectively.

At steady state operation, the useful energy of conical type collector is equal to the difference between the absorbed solar energy and the thermal losses from the collector [6] and expressed by

$$Q = I.A_{proj}(\tau\alpha) - U_L.A_{act}.(T_s - T_a) \tag{3}$$

In this equation, T_a is outside temperature (K); T_s, the average collector plate temperature (K); A_{act}, the actual surface of the absorber (m^2); A_{proj}, projected surface area of the absorber surface (m^2); U_L is the overall heat loss coefficient (W/m^2.K); α is the transitivity of transparent cover and τ absorptivity of the absorber surface.

If the temperature of the absorber surface is equal to the inlet temperature of the water (ideal conditions), useful energy is:

$$Q_i = A.[I.(\tau\alpha) - U_L.(T_i - T_a)] \tag{4}$$

from equation (2) and equation (4);

$$F_r = \frac{Q}{Q_i} = \frac{\dot{m}.C_p.(T_o - T_i)}{A.[I.(\tau\alpha) - U_L.(T_i - T_a)]} \tag{5}$$

where F_r is heat removal factor or efficiency coefficient of the collector. Equation (5) is converted in a form of;

$$F_r = \frac{\dot{m}.C_p}{A.U_L}\left[1 - \exp\left(-\frac{A.U_L.F_V}{\dot{m}.C_p}\right)\right] \tag{6}$$

where F_v is efficiency factor of the absorber [9]. Therefore, energy gained can be calculated depending on ambient temperature and inlet temperature of the fluid as follows;

$$Q = A.F_R.(I.(\tau\alpha) - U_L(T_i - T_a)) \quad (7)$$

These parameters depend on the construction materials, flow conditions and design type of the collector.

4. RESULTS AND DISCUSSION (SONUÇ VE TARTIŞMA)

The most used collector type in the market in order to provide hot water is flat plate solar collector. Solar radiation falls perpendicularly or about perpendicularly to the absorber surface of flat plate collector in particular time of days because of its construction. This causes a decrease the efficient of collector. The experiment results are compared with flat plate collector having the same surface area and also tubeless convex solar collector designed by M-Au-Qudais et al. [6].

Instantaneous efficiency of both collectors and average radiation intensity belong to days of the experiment as a function of day times are given in Figure 8. Average radiation intensity ranging between 550 W/m^2 and 850 W/m^2 instantaneous efficiency of the conical collector is about 24% more than conventional flat plate collector for maximum mass flow rates ($\dot{m}$=0,017 kg/s). Instantaneous efficiency of the conical collector and flat plate collector for maximum mass flow rates in the midday is approximately 78% and 64%, respectively. Instantaneous efficiency of the conical collector is approximately 15% more than flat plate collector for minimum mass flow rates ($\dot{m}$=0,012kg/s).

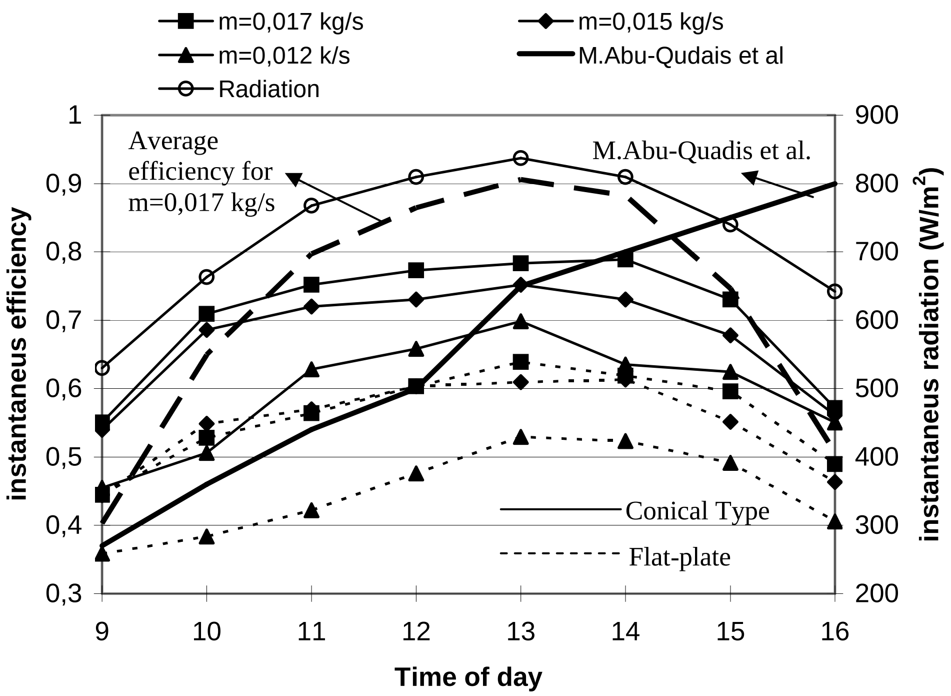

Figure 3. Change of collector efficiency and instantaneous radiation with day times for each collector
(Şekil 3. Her bir kollektör için kollektör etkinliği ve anlık ışınımın günün zamanına gore değişimi)

It is seen that maximum efficiency of the flat plate collector is obtained between 12 am and 14 pm from Figure 3. However, maximum efficiency or near to maximum efficiency occurs between 11 am and 15 pm in the conical collector. In other words, maximum efficiency is obtained for a long time period from conical collector. This state can be attributed to the collection of energy more efficiently in the early and later times of day due to the low angle of incidence with a high percentage of solar radiation perpendicular of the conical collector plate. Small increases of the conical collector efficiency between 13 pm and 14 pm must have became due to the solar radiation intensity depending on the orbit of the sun.

Useful energy gained by unit area of both collectors as a function of day times is given in Figure 4. It is seen that the amount of useful energy gained by the conical collector and flat plate collector is approximately 655 W/m^2 and 535 W/m^2, respectively. It was clearly seen from Figure 4, the conical surface collector gains approximately 100-110 W/m^2 of solar energy more than flat plate collector. Energy gained by both collectors is the lowest level at the morning and increases at solar noontime, while just right after that, depending on solar radiation intensity.

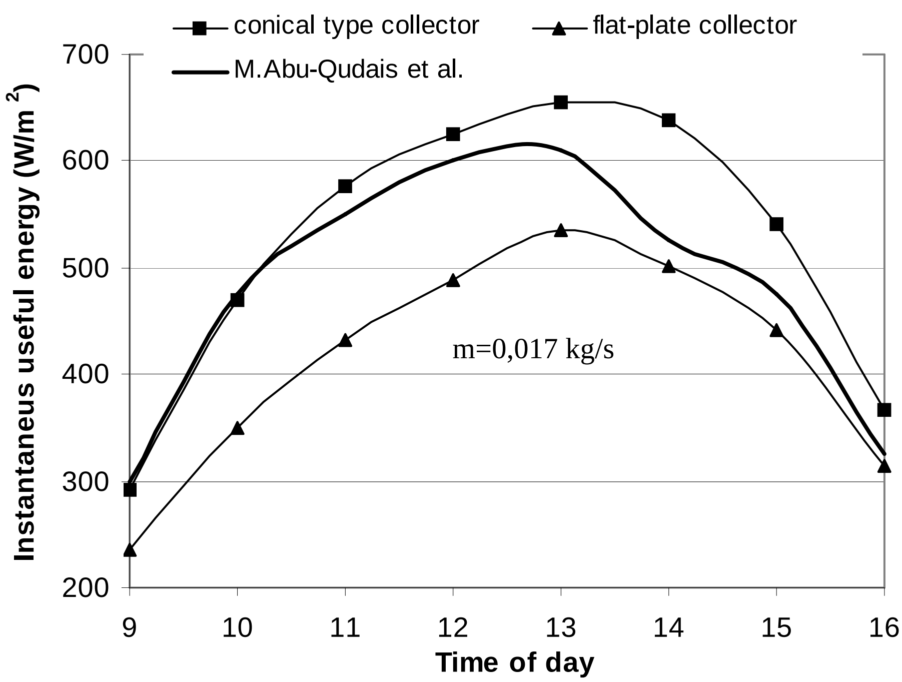

Figure 4. Change of useful energy gained with day times for each collector in $\dot{m}$=0,017 kg/s
(Şekil 4. Her bir kollektör için enerji kazancının günün zamanına gore değişimi)

Instantaneous efficiency with three mass flow rates for both collectors as a function of operation point parameter as well as performance curve is given in Figure 5. There is a reverse relationship between instantaneous efficiency and operation point parameter. Besides, this figure gives us an opinion concerning overall heat transfer coefficient. Although the slope of conical type solar collector is almost identical to that of the flat plate collector, operation point parameter for conical type solar collector and flat plate collector changes with 0,045<θ<0,080 and 0,055<θ<0,11, respectively.

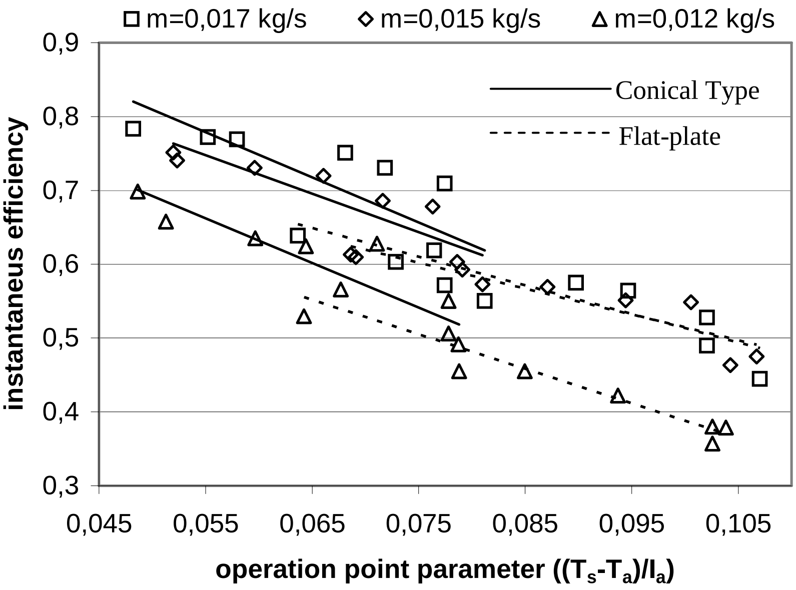

Figure 5. Change of instantaneous efficiency with operation point parameter for each collector
(Şekil 5. her bir kollektör için anlık verinin çalışma noktası parametresine gore değişimi)

The reduction in the overall heat transfer coefficient due to the lower plate temperature for the conical type solar collector compensates for the increase of its area over the flat plate for heat loss [6]. Likewise, the efficiency slope for both collectors decreases same depending on the mass flow rates. This state may be considered as a consequence of increasing of effects of molecular absorption and free convection currents from the base plate. Instantaneous efficiency of the conical type solar collector is approximately 35% more than the flat plate collector for maximum mass flow rate.

Average temperature of the conical type solar collector surface changes with 80°C and 82°C depending on the radiation intensity and the mass flow rates, as shown in Figure 6. These temperatures are average values determined at four difference points (the east, the west, the south and the north) of the collector surface. There is a reverse relationship between the water outlet temperature and mass flow rates. The water outlet temperature is approximately 66°C and 60,5 for $\dot{m}$=0,012 kg/s and 0,017 kg/s, respectively. Heat removal factor of the absorber depends on the mass flow rate and geometer of the absorber. It is proportional with the mass flow rate of the fluid and reverse proportional with the heat conductive coefficient [9]. However, this increases and decreases are insignificant in practice. As shown in Figure 6, the heat removal factor increases considerably and changes between 0,61 and 0,79 depending on the mass flow rates in the conical type solar collector. The mass flow rate is an important parameter on the collector efficiency. When the mass flow rate was increased from

0,012 kg/s to 0,015 kg/s, the conical type solar collector efficiency increased approximately 13% and from 0,012 kg/s to 0,017 kg/s, the efficiency increased 18%.

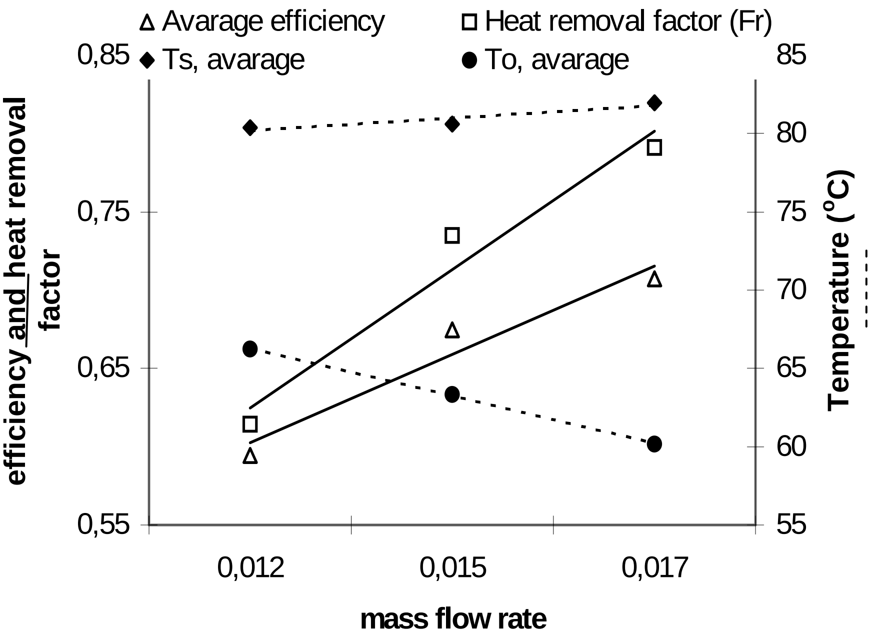

Figure 6. Change of average efficiency, heat removal factor, surface temperature of the collector and outlet temperature of water with mass flow rates
(Şekil 6. Kollektör anlık etkinliğinin, ısı faktörünün, kollektör yüzey sıcaklığının ve suyun çıkış sıcaklığının kütlesel debiye gore değişimi)

The instantaneous efficiency and the magnitude of useful heat obtained by M.Abu-Quadis et al. are given in figures 3 and 4, respectively. This study and our study are geometrically similar. Both collectors track the sun statically without additional cost. Average instantaneous efficiency of the tubeless convex type solar collector as a function of the times of day is given in Figure 3. Although, instantaneous efficiency of the convex type solar collector is the lowest at the morning and increases up to 16 pm. continuously because of the thermal energy stored in the collector, the instantaneous efficiency curve of conical type solar collector is identical with radiation intensity curve. Even though instantaneous useful energy obtained in the tubeless convex type collector is less than the conical type collector, as shown in Figure 4, the convex type collector efficiency rises to 90%. This may be due to same effects such as, heat gain factor of the collector, efficiency factor and heat storage capacity of the absorber. However, the average efficiency of the conical type solar collector rises more rapidly than efficiency of the convex type solar collector and it keeps maximum efficiency for a long period of daytime than both convex type solar collector and flat plate collector.

5. CONCLUSION (SONUÇ)

The thermal performance of the conical type designed and flat plate type solar water heater have been analyzed and compared at various mass flow rates. It was seen that the collector efficiency was increased using passive method without additional energy. The efficiency of the conical type solar collector is always higher than that of the flat plate solar collector.

NOMENCLATURE (SEMBOLLER)

A : Area (m^2)
A_{proj}: Projected surface area (m^2)
Cp : Specific heat of water (j/kgK)
Fr : Feat removal factor
Fv : Efficiency factor of the absorber
I : Incident solar radiation (W/m^2)
T : Temperature (K)
Q : useful energy (W)
U_L : Overall heat loss coefficient
$\dot{m}$: Mass flow rate (kg/s)
α : Transivity of transparent cover
τ : Absorvitiy
η : Efficiency

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