BITLIS EREN UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY 9(1) (2019) 32–40

Available online at www.dergipark.gov.tr/beuscitech

Journal of Science and Technology

E-ISSN 2146-7706

Efficiency analysis of solar supported integrated water heating-distillation

Gülşah Çakmak [a] , Emin El [b,*] , Cengiz Yıldız [a]

[a] Fırat University, Department of Mechanical Engineering, TR-23000, Elazığ Turkey

[b] Bitlis Eren University, Vocational School of Technical Science, TR-13000, Bitlis Turkey

ARTICLE INFO

Article history:
Received 26 February 2019
Received in revised form 12 April 2019
Accepted 24 April 2019

Keywords:
Solar Still
Solar Heating
Energy Efficiency
Drinking Water

ABSTRACT

In the present study, a system that combines hot water collector and distiller for the purpose of increasing efficiency in solar water heating systems and simultaneously producing distilled water is designed. Obtained results are compared with conventional solar distiller developed under the same conditions. It has been determined that in the distiller system connected with hot water collector, daily distilled water amount is 7924 ml, 4610 ml of which is during daytime and 2790 ml of which is during night-time. This developed system produces fresh and hot water simultaneously. It has been observed that hot water temperature is at appropriate levels for local usage. In conventional basin type distiller, the total water amount produced during daytime and night-time were measured as 844 ml and 1545 ml, respectively. It has been determined that the total distilled water amount produced in one day in this system is 2389 ml. Efficiencies of conventional and integrated with hot water collector distiller systems continuously increase during the day and reach at 51.47% and 77.98% levels, respectively. Compared to conventional distiller, 70% more distilled water was obtained.

1. Introduction

Distillation is the process of separating the components in a liquid mixture by first evaporating and then cooling. With water vapour distillation, organic materials which are degenerated at boiling point and are unable to mix with water can be distilled at lower temperatures and such non-volatile abundant materials as resin or inorganic salts which can be found in the environment can be removed from the environment.

In every part of the world clean and pure water is an obligation for the lives of people. In several places of the world drinking water exists but is either salty or sour which makes it inconvenient for consumption by humans. For this reason, existing water resources need distillation. Usually the heat energy used for distillation is obtained from fossil fuels or conventional energy sources produced by electricity. Distillation with solar energy is still working at low inefficiency although its production is easy.

Several studies have been carried out to increase the efficiency of solar energy supported distillation systems. In his study, Deniz (2012) tried to increase the efficiency of distiller system using a vacuum-piped hot water collector in the distiller system. He also conducted mathematical modelling using experimental data and proved that obtained values were in harmony with experimental data. He found the highest system efficiency as 73% at 4 pm during daytime. After the sunset, 800-900 distilled water was obtained from the system.

Ali et al. (2015) used a solar energy distiller with conventional and pin wing suction plates and compared theoretically and empirically clean water distillation. Heat transfer energy balance equations are solved numerically and evaluated for active solar distillation elements. Results showed that the used wings increased daily production by 12 percent.

Sheeba et al. (2015) conducted a comparative study for solar supported distiller and joined-with-flat-plate-collector solar distiller under real environmental conditions. They tried both tap water and sea water in these studies. For the integrated system, they determined daily system efficiency as 20.4% and 23.6% for tap water and sea water, respectively. Values for production were determined as 20.8% and 24.1% respectively.

Ayoub et al. (2015) tried to increase system efficiency by making a simple change in conventional distillation system. For this purpose they added a slowly rotating drum inside the distiller which is constantly renewed and does create a thin layer of water so as to increase evaporation speed. The performance of this system was compared with the system without drum and a better performance was obtained in daily production with the new system with 200% increase on average. It was argued that this system generally solved slack water problem.

El-Naggar et al. (2016) reorganized the conventional solar distiller system and generated the system using the surface with wings and examined this system theoretically and experimentally. Energy balance equations were formulated and analytically solved for the organized distiller system. Appropriate computer programme was prepared for estimating and optimizing the thermal performance of the system. Experimental and theoretical results were compared and their conformity was proved. Daily production was obtained as 4.325 and 4.802 (kg/m2 d) for conventional and improved distiller systems respectively, and daily efficiency was obtained as 42.36% and 55.37% for the same systems respectively.

Taghvaei et al. (2015) experimentally examined the concurrent impacts of collection area and water depth on the performance of active solar power distillers. The results showed that for all solar power collection areas, decrease in water depth led to a reduction in production and efficiency of distilled water. At the same time, they found out that as solar collection area increased, so did water efficiency but their efficiencies decreased for all depths. As a result, they predicted that in the case of low sea water temperature and high collection area of active solar distillers, salty water boiled and it decreased the efficiency of active solar distillers.

El et al. (2017) attempted to increase the efficiency of solar-assisted distillation systems and simultaneously obtain distilled water. For this purpose, they designed 5 different solar energy systems. These are respectively; conventional distillation, conventional distillation coupled with natural convection water heating system, conventional distillation with tube heat exchanger supported natural convection water heating system, conventional distillation with plate heat exchanger supported natural convection water heating system , and conventional distillation with plate heat exchanger supported forced convection water heating system. According to the results obtained the amount of distilled water and efficiency of conventional solar still were 2389 ml and 51.47%, respectively. Maximum total amount of water and efficiency from natural convection systems were obtained from Type 4, and the values calculated were found as to be 5788 ml and 55.91%.

El-Samadony et al. (2015) empirically investigated a changed graded solar distiller with internal and external reflector and external condenser. In this system they used a suction fun which draws water vapour. They compared the distiller they developed with conventional distiller system. As a result of this comparison, they showed that the efficiency n condenser and reflector distiller and only condenser distiller was 165% and 66% higher compared to conventional distiller, respectively.

Morad et al. (2015) conducted thermal analysis in order to estimate performance using external and internal heat transfer and energy support equations. On the basis of thermal analysis they designed active and passive solar distillers. In these designed systems they made necessary temperature measurements and examined the system performances according to water depth, and thickness of cooling and non-cooling glass covers. They obtained 24% higher efficiency in cooling active system compared to cooling passive system.

A. E. Kabeel et al. (2012) developed a solar distiller in which pure water production was increased by the solar PV powered turbulence system. They used the 18 W Solar PV panel for rapid evaporation of salt water. With this method they obtained higher daily yields than the traditional distillers. In their study, they stated that the first brine fed to the basin was at normal temperature and also the solar PV temperature increased gradually due to the atmospheric situation.

El et al. (2017) designed a new type of distiller with flat surface panel collector and vertical storage. The solar water heating system, which works as a closed system, has been tested under natural convection and forced convection at flow rates of 30 kg / h and 50 kg / h, making modifications to obtain distilled water. As a result of the experiments, the highest amount of distilled water was obtained from the natural convection system at 1.820 kg / day.

Rajaseenivasan et al. (2014) empirically investigated the performance of single-direction solar distiller with preheating of salty water using flat sheet collector organization. In this study traditional monoclinal solar distiller and monoclinal flat sheet collector distiller were produced with the same basin area. Collector distiller was produced similar to the conventional distiller and it was joined with horizontal flat sheet collector organization in the form of small sections in the basin. The gap designed between consecutive basins provides an expanded surface in the flat sheet collector which includes pre-heated salty water and increases the temperature in the basin. In the improved distillation system, 60% more distilled water was obtained compared to conventional distillation system.

In this study, forced circulation hot water collector, basin type distiller with plate heat exchanger and tank type distiller were integrated to create a new type of distiller system. Performance values of this system were examined experimentally. System tests designed in this study for this purpose were made as closed system at forced circulation at 50 kg/h flowrate, 38^{o} collector inclination and temperature, efficiency and distilled water amounts were determined and compared with conventional type distiller.

2. Materials and Method

The designed system basically consists of a forced circulation hot water collector, basin type distiller with plate heat exchanger and tank type distiller (Figure 1).

In the experimental study, tank and collector dimensions used in standard solar hot water systems were taken. The most commonly used measures in the literature for distillers were taken, and the slope of the transparent surface of the distiller was determined according to Elazığ conditions. Heat exchanger dimensions were determined by taking into consideration the usable space in the distiller to increase heat transfer.

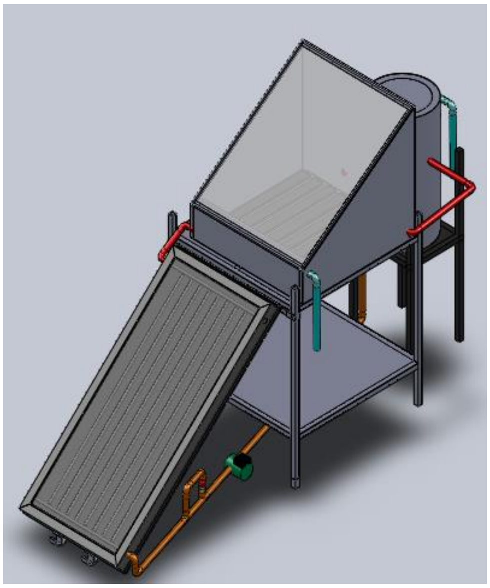

Figure 1. Distiller system

For experiments a 930x1930x87,5 mm sized flat surface solar power standard hot water collector with aluminum oval pipe, pallet black painted with 1.8 m^2 gross surface area and 1.6 m^2 net surface area was used (Figure 2).

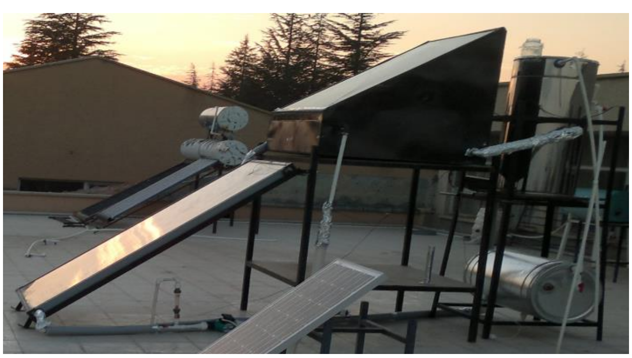

Figure 2. Photo of distiller system integrated with hot water collector

Basin-type distiller system used in the experiments usually consists of a distiller basin, distilled water collection container, transparent cover, insulation materials and heat converter placed into the distiller. The distillation basin is made of stainless sheet material at 1000x1000x250 mm size. Its bottom area is $1m^2$ and lid inclination is 38^0. Bottom and internal parts are painted with epoxy lining and black flat paint. The distiller is het insulated with 4 cm thick polyurethane material. In order to prevent the leakages from the lid, impermeability elements resistant to sun, heat and moisture were used.

In order to increase the amount of distilled water produced in the distiller and the efficiency of the distiller, a plate heat exchanger which entirely made of copper, is at 900x900 mm size and completely painted with black flat paint was designed and placed inside the basin-type distiller (Figure 3).

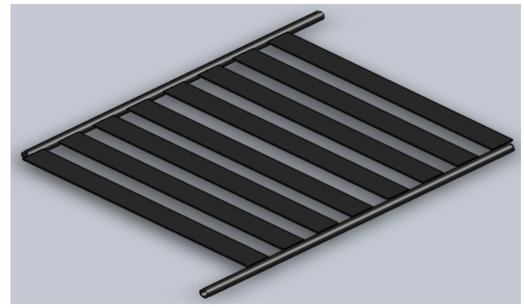

Figure 3. Developed plate heat exchanger

Cylindrical tank-type distiller was made of chromium-nickel material with 400 mm diameter, 1050 mm height and 0,8 mm thickness (Figure 4). The tank-type distiller was insulated with 400 mm thick polyurethane material. There are two serpentines inside the tank-type distiller.

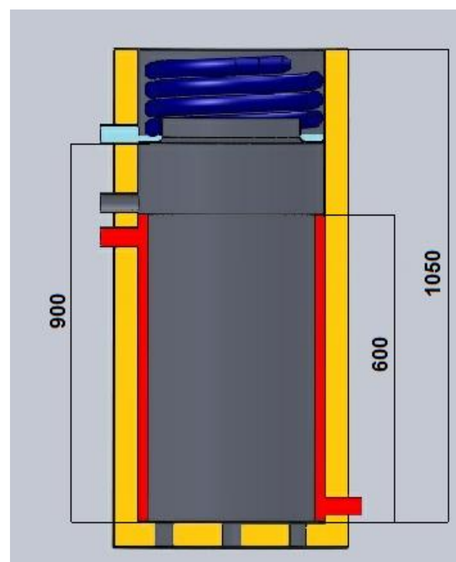

Figure 4. Dimensions of tank-type distiller (mm)

In this test mechanism which was designed as a forced convection closed system, water with 50 kg/h flow rate by using a pump was passed from surface-type hot water collector and its temperature is being increased and as the first step it is passed inside the plate heat exchanger inside the distiller. With this heat convertor which is improved by increasing its surface area, part of the heat is transferred to the water inside the distiller and the temperature of the water inside the distiller is increased. The fluid then flows to the hot water serpentine in the tank-type distiller where it transfers its heat to the cold city water and returns to the general collector.

The temperature of the city water inside basin-type distiller is increased by using solar energy and hot fluid coming from plenary collector. Evaporation increases with the temperature of the water in the distiller. The water vapor contacts the glass cover on top which is cooler and condensation occurs and it flows into the collection canal placed in the front part of the distiller basin. The distilled water accumulated inside collector canals is carried outside with the help of the slope given to the canal and is accumulated in the distilled water tank.

At the same time, in the upper serpentine of the tank-type water distiller in the system, there is cold water from the city network and hot water from the collector in the lower serpentine. After the water from the upper serpentine passes through the coil, it accumulates in the tank. The hot fluid coming from the collector and circulating through the lower serpent vaporizes the mains water accumulated in the tank by heating it. Evaporated water is condensed by contact with the cold upper serpentine and distilled water is obtained. The resulting distilled water is then transported to the distilled water tank with the piping (Fig. 5).

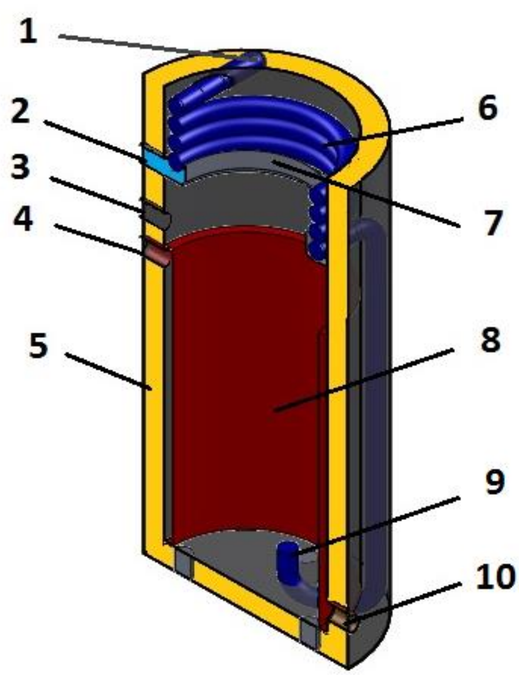

Figure 5. Distillation tank. (1. Tap water inlet 2. fresh water outlet, 3. Hot water exit, 4. Hot water inlet, 5. Glass wool, 6. Upper serpentine, 7. Fresh water collection pipe, 8. Lower serpentine, 9. Cold water inlet, 10. Hot water exit.)

In the experiments Kipp and Zonen brand (CC12) pyranometer was used to measure the level of radiation. The pyranometer used was placed in accordance with the collector and distillation inclination angles and measurements were taken every half an hour.

Hioki brand 8402-20 model datalogger with automatic thermocouple recognition was used to measure temperatures. In the experiments, temperature measurements were made at the determined points for each distiller such as condenser glass internal surface and glass external surface temperatures, bottom temperatures of four walls, water temperature, vapor temperature, and tank temperature. Rotameter used to determine the flow rate of the fluid can work at high temperatures and make measurement in 0-200 lt/h interval.

While measuring a parameter, the total error calculation can be made as in (1) taking into consideration constant errors, random errors and manufacturing errors. In the study conducted in recent years, Kline and McClintock uncertainty analysis method (Holman, J.P. (1971)), which are widely preferred by researchers, were used in the determination of error rates. The error rates of the magnitudes causing errors are given in Table 1.

Table 1. Total errors in distillation tests

Magnitudes Causing Errors	Total Error
Total temperature measurement error at collector input	± 0.173 °C
Total temperature measurement error at collector output	± 0.173 °C
Total water temperature measurement error	± 0.173 °C
Total tank water temperature measurement error	± 0.173 °C
Total temperature value reading periodic error	± 0.1 min
Total radiation measurement periodical error	± 0.1 min
Total periodic error in fresh water measurement	± 4.062 ml
Total periodic error in flow rate measurement	± 0.86 kg/h

The efficiency equation in the pumped system is as follows;

$$\eta = \frac{m_{ew} L}{IA3600 + Wp.\Delta t} \quad (1)$$

where

η is efficiency,

m_{ew} is the amount of distilled water (ml),

L is water’s heat of vaporization (J/g),

I is total solar energy (W/m^2)

A is heat transfer area (m^2)

W_p is consumed electric power (W)

3. Analysis of Results

System experiments were made as a closed system at 50 kg/h flowrate and 38^o collector inclination. Radiation values for the day when the experiment was made are transferred to the graph in Figure 6. As can be seen from the graph, the highest radiation value was measured as 740 W/m^2.

In conventional distiller system and distiller system integrated with hot water collectors, the bottom temperature (Tb), water temperatures (Tw), vapor temperature (Tv), internal surface of glass (Tig), and outer surface of glass (Tog), tank type distiller water temperature (Td) are shown in this order in Figure 6 and Figure 7.

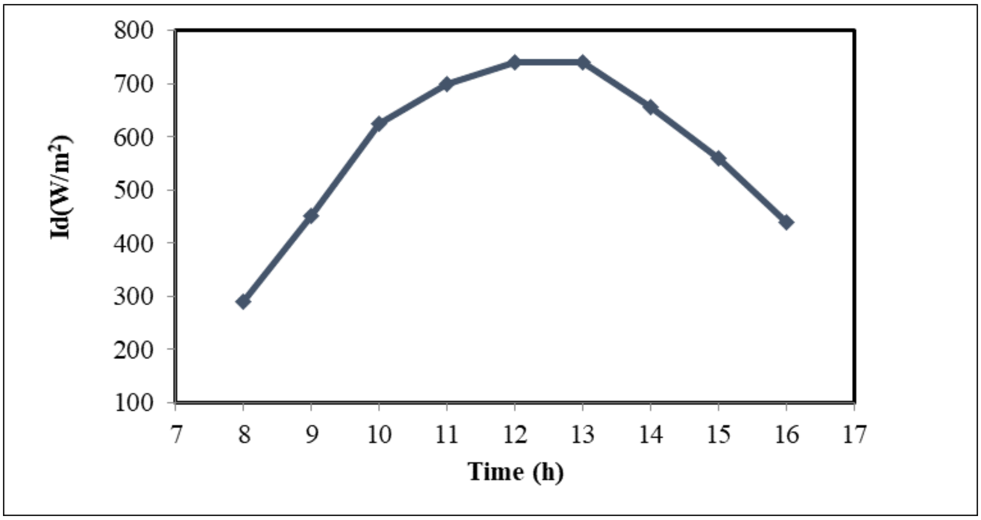

Figure 6. Solar **r**adiation values

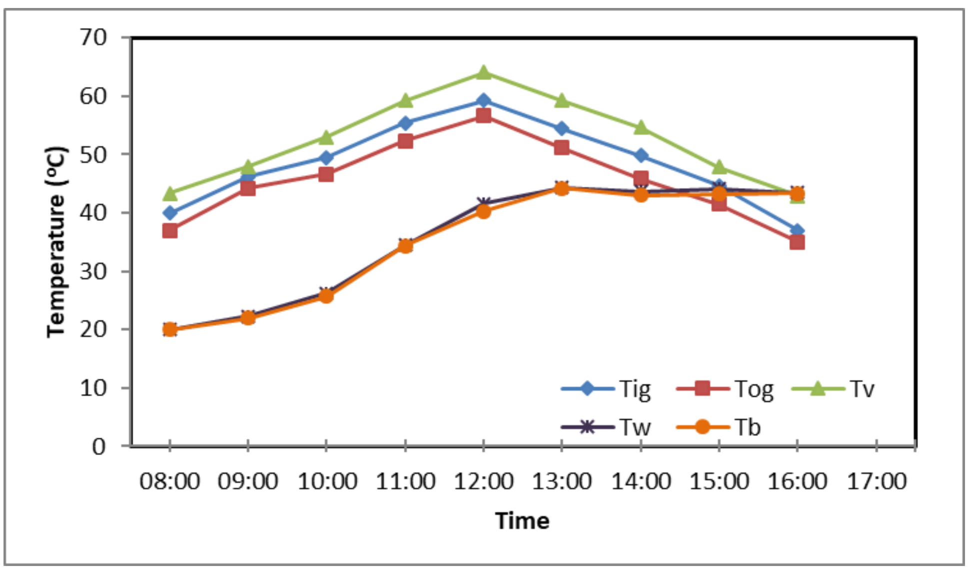

Figure 7. Temperature changes in conventional basin-type distiller

As can be seen in Figure 7, glass temperatures show increase until 12.00 hrs. and then decrease. At 12.00 when glass temperatures are highest, internal surface temperature and external surface temperature of the glass was measured as 59.3 ºC and 56.6 ºC. Bottom and water temperatures are continuously rising during the day and vapor temperature increases until 12.00 after when it decreases. Vapor temperature was measured as 64.1ºC at 12.00 when it was the highest. Measurements showed that bottom temperature and water temperature were close to each other.

As can be seen in Figure 8, glass temperatures show increase until 13.00 after when they begin to fall. At 13.00 when the glass temperatures are the highest, internal and external surface temperatures of the glass were measured as 74.7 ºC and 71.5 ºC, respectively. Bottom and water temperatures increase until 14.00 during the day whereas vapor temperature increase until 13.00 after when they begin to decrease. Vapor temperature was measured as 87.0 ºC at 13.00 when it was the highest.

Figure 9 shows the amount of water produced in hourly intervals as "m" and total amount of water produced as "mt" for the conventional basin-type distiller. The measurements showed that the distilled water increased continuously until 15.00 and then decreased. As a result of hourly measurements, the highest water production was measured as 210 ml between 14.00 and 15.00 hrs. At the end of the day 844 ml distilled water was produced.

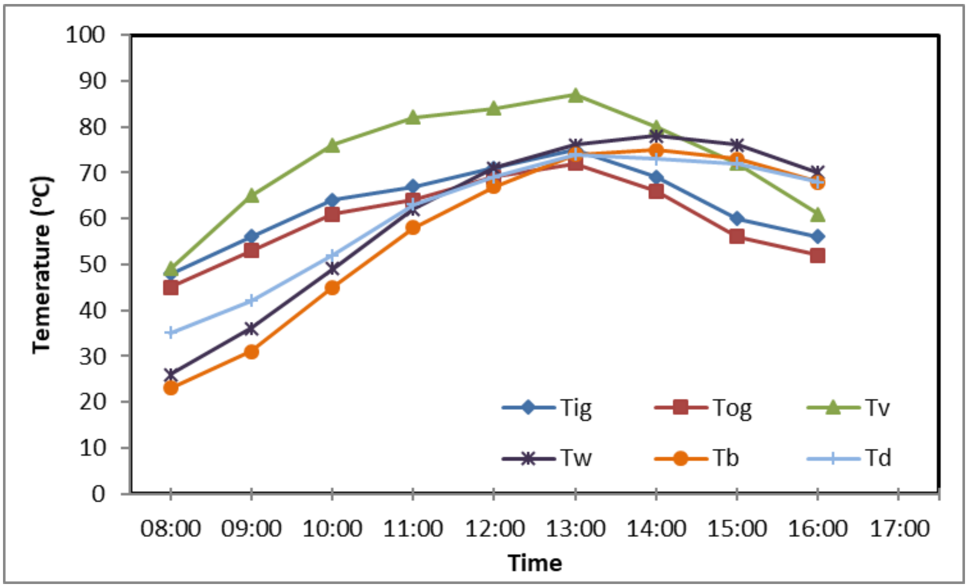

Figure 8. Change of temperatures in solar supported integrated water heating-distillation system with time

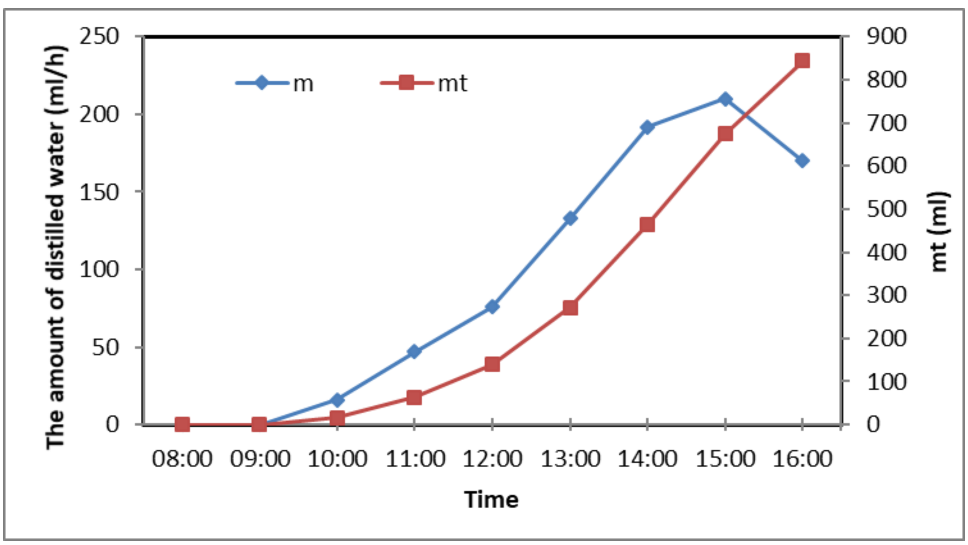

Figure 9. Hourly and total amount of water produced for conventional basin-type distiller

In figure 10, the hourly and total produced distilled water amounts in the distiller system integrated with hot water collectors are shown. Accordingly, distilled water amount increases until 14.00 during the day after when it drops. The amount of water obtained during the day reached the highest value of 918 ml at 14.00 hours.

Figure 11 shows the amount of distilled water obtained from the tank type distiller and basin type distiller used in the integrated water heating-distillation system. In this graph, it is seen that the amount of fresh water produced in the basin type distiller is much higher than the water produced in the distillation tank. In the integrated system, 14.00—15.00 is the time interval when the production is the highest. According to figure 11, at 14.00, the distilled water amounts produced in distillers which constitute the integrated system was 698 ml in basin-type distiller and 220 ml in tank-type distiller. At 15.00, the amount was 734 ml and 180 ml for basin-type distiller and tank-type distiller, respectively.

For conventional basin-type distiller, total amount of water produced during day and night is shown in figure 12. Accordingly, the total distilled water produced daytime was and night time was measured as 844 ml and 1545 ml, respectively. In this system, the total distilled water was determined as 2389 ml in one day.

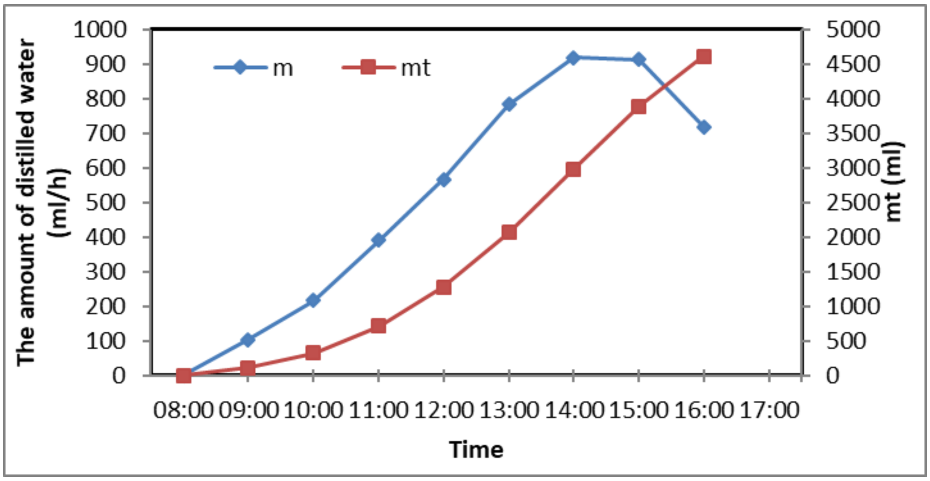

Figure 10. Amount of hourly and total produced distilled water in solar supported integrated water heating-distillation system

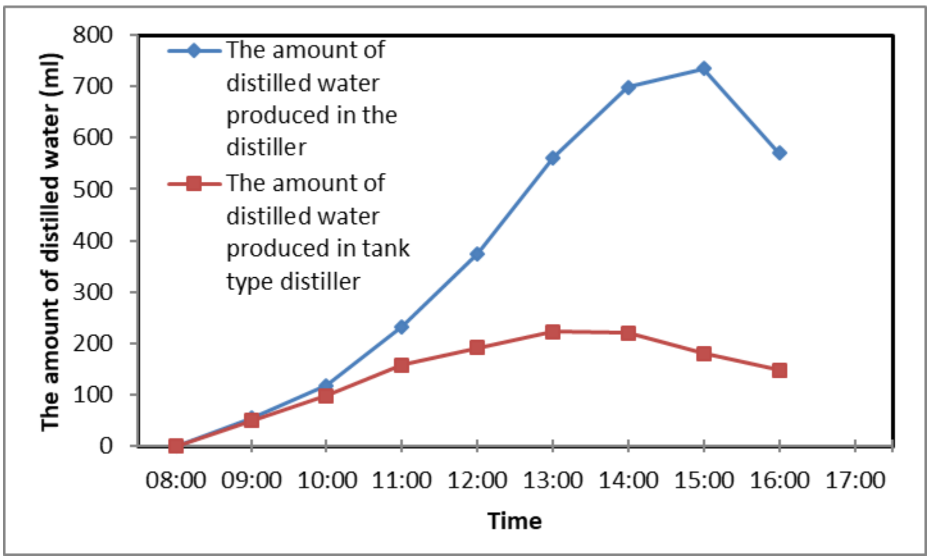

Figure 11. Amounts of basin-type and tank-type distiller produced in solar supported integrated water heating-distillation system

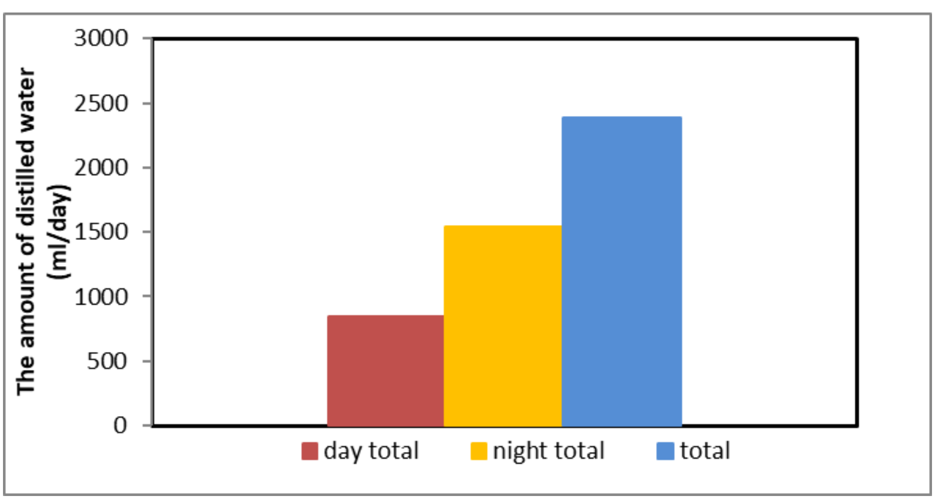

Figure 12. Daytime, night-time and total amount of water produced for conventional basin-type distiller

Figure 13 shows the amounts of day, night and total distilled water. Accordingly, during the day and night, 4610 ml and 2790 ml distilled water were produced in the system respectively and a total of 7924 ml distilled water was obtained. The collector cools off throughout the night and night production occurs. This heat caused by storage effect.

Efficiency values of distiller system are given in Figure 14. Accordingly, system efficiency is continuously increasing throughout the day. The highest values for the conventional distillation and solar supported integrated water heating-distillation system are 51.47% and 77.98%, respectively.

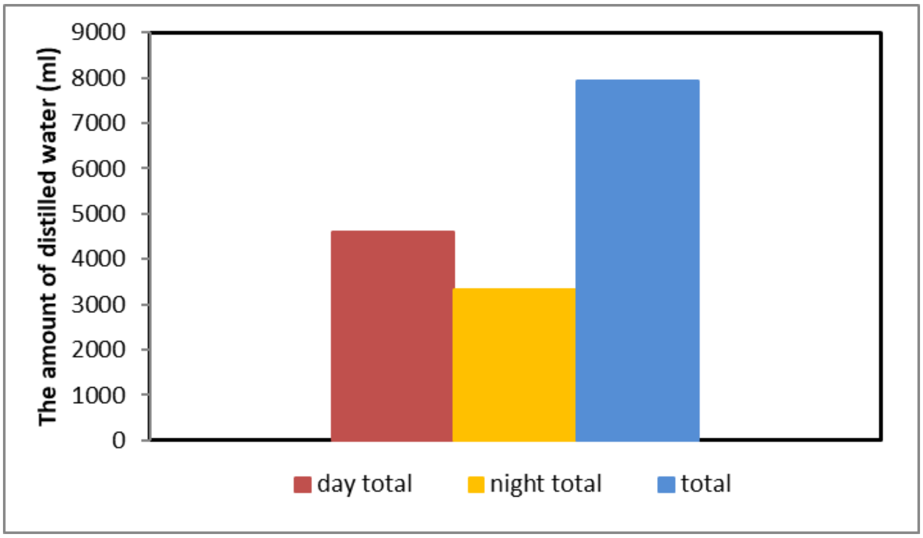

Figure 13. Daytime, night-time and total amount of water produced solar supported integrated water heating-distillation system

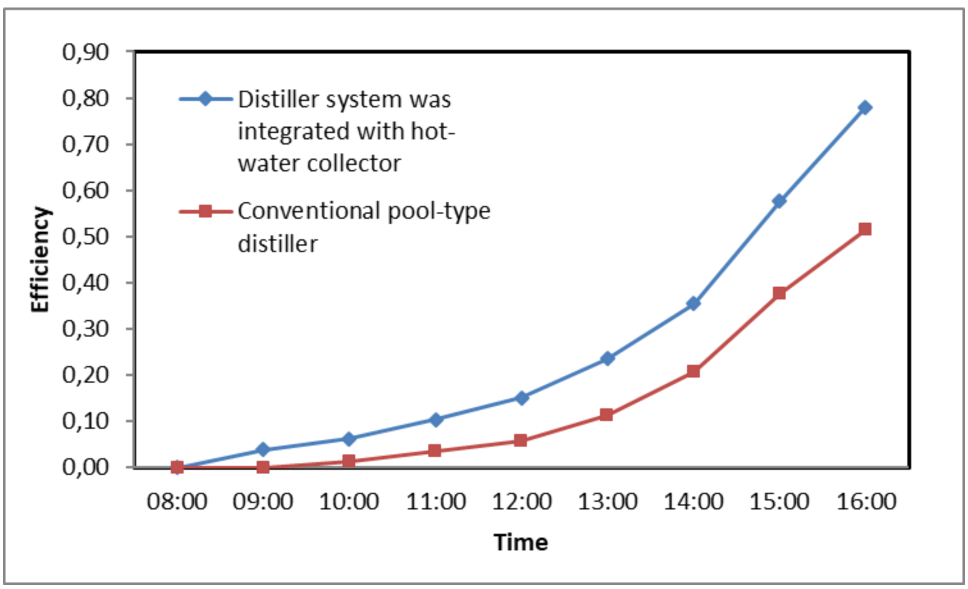

Figure 14. Efficiencies of solar supported integrated water heating-distillation system and conventional basin type

4. Conclusions

Using energy sources such as oil, natural gas, electricity in hot water and distillation systems lead to high costs and environmental pollution. For this reason, it must be ensured that renewable energies are used and popularized in these systems as energy source. In this study, a solar supported integrated water heating-distillation system was designed and water yield and system efficiency was determined experimentally. The results were compared with conventional basin type distillate data.

As a result of experimental study, it was found out that daily distilled water amount in distiller system integrated with hot water collectors was 4610 ml, 2790 ml and 7924 ml for daytime, night time and the entire day, respectively. Efficiency of distiller system integrated with hot water collectors increased during the day and reached 77.98% at the end of the day. Compared to conventional distiller, 70% more distilled water was obtained.

In this study, a distillation system integrated with the standard solar hot water system is designed. The added distillation system includes both conventional basin type and tank type distillers. As a result, the system provides hot water in a house, while at the same time it is obtained in clean water. Here, more clean water is obtained than conventional distillation systems, while the water temperature required for local use is provided.

Acknowledgements

This study was funded within Fırat University Scientific Projects Coordination Unit, Project No: MF.11.10 and Republic of Turkey Ministry of Industry and Technology, Project No: 00894.STZ.2011-1

References

A.E. Kabeel, Mofreh H. Hamed, Z.M. Omara,(2012). Augmentation of the basin type solar still using photovoltaic powered turbulence system, Desalin. Water Treat. 48 (1–3) 182–190.

Ali, C., Rabhi, K., Nciri, R., Nasri, F., & Attyaoui, S.(2015). Theoretical and experimental analysis of pin fins absorber solar still, Desalination and Water Treatment, 56,1705–1711.

Ayoub, G.M., Al-Hindi, M., & Malaeb, L. (2015). A solar still desalination system with enhanced Productivity, Desalination and Water Treatment, 53, 3179–3186.

Deniz, E. (2012). An Experimental and Theoretical Analysis of a Vacuum Tube Solar Collector-assisted Solar Distillation System, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,34,17,1637-1645.

El E., Çakmak G., Yıldız C., Efficiency analysis of tank-type water distillation system integrated with hot water collector, Therm. Sci. Eng. Prog. 3 (2017) 24–30, http:// dx.doi.org/10.1016/j.tsep.2017.05.012.

El E., Çakmak G., Arguhan Z., Yıldız C., 2015, Experimental Investigation Of Solar Stills Integrated With Solar Water Heating Collectors, J. of Thermal Science and Technology, 35, 145-152.

El-Naggar, M., El-Sebaii, A.A., Ramadan, M.R.I., & Aboul-Enein, S. (2016). Experimental and theoretical performance of finned-single effect solar still, Desalination and Water Treatment, 57, 17151–17166.

El-Samadony, Y. A. F., Abdullah, A. S., & Omara, Z. M. (2015). Experimental Study of Stepped Solar Still Integrated with Reflectors and External Condenser, Experimental Heat Transfer, 28:392–404.

Holman, J.P. (1971). Experimental Methods for Engineers, McGrawHill Book Company, 37-52.

Morad, M.M., El-Maghawry, H.A.M., Wasfy, K.I. (2015).Improving the double slope solar still performance by using flat-plate solar collector and cooling glass cover, Desalination, 373, 1–9.

Rajaseenivasan, T., Nelson Raja , P., Srithar, K. (2014). An experimental investigation on a solar still with an integrated flat plate collector, Desalination, 347, 131–137.

Sheeba, K. N., Prakash. P., & Jaisankar, S. (2015). Performance Evaluation of a Flat Plate Collector Coupled Solar Still System, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 37,291–298.

Taghvaei, H., Taghvaei, H., Jafarpur, K., Feilizadeh, M., Estahbanati, M.R.K.(2015). Experimental investigation of the effect of solar collecting area on the performance of active solar stills with different brine depths, Desalination 358, 76–83.