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EFFECT OF THE AIR FLOW RATE OF BLOWER ON THE PERFORMANCE OF SOLAR STILL

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Abstract: Solar distillation is one of the important methods for water purification. This paper examines the performance of solar distillation system at different air flow rate. To increase the performance of distiller, artificial wind was created by fan and suitable wind speed was investigated to increase the amount of water distilled. The experiments were carried out in Elazığ climate conditions. In order to examine the effect of the wind speed on solar distillation system, two stills were manufactured with the size of 1000x1000 mm. One of them was the conventional still which was used as a reference. The other still was used to investigate experimentally the effect of the wind speed. Graphs were drawn for time-dependent changes in the amount of water distilled. It was found that that the productivity of the fan-still distiller was 14.7 % greater than that of a conventional still.
Keywords: solar still, distillation, blower

GÜNEŞ DAMITICININ PERFORMANSINA ÜFLEYİCİ HAVA DEBİSİNİN ETKİSİ

Özet: Güneş enerjili damıtma su arıtmada önemli yöntemlerden biridir. Bu çalışmada farklı hava hızlarında güneş damıtma sisteminin performansı incelenmiştir. Damıtıcının performanasını artırmak için, cam yüzeyine fan ilave edilmiş ve damıtılmış su miktarını artırmak için uygun hava hızı araştırılmıştır. Deneyler Elazığ iklim koşullarında gerçekleştirilmiştir. Güneş damıtma sistemi üzerinde rüzgar hızı etkisini incelemek için, 1000x1000mm ebatlarında iki damıtıcı üretilmiştir. Bunlardan biri, geleneksel damıtıcı olup referans olarak kullanılmış, diğeri ise rüzgar hızı etkisini deneysel olarak araştırmak için kullanılmıştır. Grafikler arıtılmış su miktarının zamana bağlı değişiklikler için çizildi. Fanlı damıtıcının üretkenliği geleneksel damıtıcıya göre % 14.7 daha fazla olduğu bulunmuştur.
Anahtar Kelimler: Güneş damıtıcısı,damıtma, fan

NOMENCLATURE

h	Heat transfer coefficient [W/m^{2}K]
α	Absorptivity,
Q	Heat transfer amount [W]
P	Partial vapour pressure [N/m^2]
m	Productivity [kg/m^{2}day]
V	Wind speed [m/s]
x_n	Uncertainty in the individual factors
w_R	Total uncertainty
w_n	Uncertainty in measurement or reading
R	Function of independent variables

Subscripts

A	Air
b	Blowing
c	Convective
d	Daylight
e	Evaporation
g	Glass cover
h	Hourly
w	Water
r	Radiation

INTRODUCTION

Due to its vital, economic and strategic importance, water has the potential of being the most widely debated issue of today and near future. As the world population increases, so does the need for usable water. However, in addition to the inequality in geographical distribution of water resources, there is another problem that it will not meet the water requirements of world population. For this reason, protection of existing water resources; finding the new water resources transporting and carrying out sustainable usage of water all emerge as essential issues. One of the most critical areas of water management is distillation of water in order to upgrade it to the desired quality level appropriate for its usage purpose. Desalination means to eliminate salt. In general, Desalination is called to processes aimed to obtain drinking, irrigation, usable water by removing minerals and other impurities. it has become important as a solution to the problem of declining water resources. (Ayav and Atagündüz 2007).

Such power sources as petroleum, natural gas, electricity etc. which will be used in distillation process are rather costly and cause environmental pollution. For this reason, renewable energy has to be used as power source during distillation process. For this purpose, several methods having various advantages and disadvantages to each other have been developed. One of these methods is distillation with solar energy. Operation principle of solar energy distillation systems is simple compared to other distillation systems and no intermediary procedures are needed when using these systems. Solar distillation is a natural process on earth. Solar energy heats the water in the seas and lakes; hot

water evaporates and returns to earth with rain water condensation. Basin-type solar distillation is the most common method used to obtain clean water those copies of these natural phenomena. (Aybar, at al, 2005). In this method, the solar radiation is used as a source of heat

energy. Thus, water evaporation is separated from foreign matter and then concentrating purified water is obtained. Basic energy in present methods is thermal energy. Turkey has a high potential for utilization of solar energy due to its geographical location. Therefore, establishment and operation of solar-energy distillation systems are more economic compared to other systems.

Solar desalination in recent years has been the focus of many researchers. There are ways to improve productivity of the solar still. Passive methods include the use of dye to increase the solar absorptivity, applying good insulation, lowering the water depth in the basin, and using reflective side walls. Active methods include the use of solar collector, the use of the condensers or applying vacuum inside the solar still to enhance the evaporation/condensation processes, and cooling the glass cover (Vashishtha, 2014). Malik et al., 1982 reviewed the work on passive solar distillation. Tiwari et al., 2003 carried out a study on the present status of research work on both passive and active solar distillation systems.

A detailed review of different studies on active solar distillation system over the years presented (Sampathkumar, at al, 2010). The effect of different water depths in the basin on the heat and mass transfer coefficients studied. They showed that the convective heat transfer coefficient between water and inner condensing cover depends significantly on the water depth in the basin (Tripathi and Tiwari 2005). Murugavel et al., were optimized the orientation and inclination to receive maximum radiation and lower the condensation loss in the single basin solar still. They used different materials in the basin along with water to improve the heat capacity, radiation absorption capacity and enhance the evaporation rate. They found that rubber is the best basin material to improve absorption, storage and evaporation effects (Murugavel at al, 2008).

Aybar modeled and simulated an inclined solar water distillation system, which generates distilled water and hot water at the same time. It showed that the simulation results were in good agreement with the experimental results (Aybar, 2006). Tanaka presented a theoretical analysis of a basin type solar still with internal and external reflectors (Tanaka, 2010). The results reported that the increase in the average daily amount of distillate throughout the year of a still with inclined external reflector with optimum inclination in addition to an internal reflector, compared to a conventional basin type still was predicted to be 29%, 43% or 67% when the glass cover inclination is 10°, 30° or 50° and the length of external reflector is half the still's length.

Wind speed is a parameter regarding influence on distillation. Many numerical and experimental studies on this subject have been made. El-Sebaii, 2000 has numerically shown that at higher wind speeds, both temperature difference and distillation output increase.

Zurigat and Abu-Arabi, 2004, examined the effect of wind speed on regenerative and conventional solar still. They showed that increase in wind speed increase the productivity of both regenerative and conventional solar still. Tellez at al, 2014 analyzed the effect of the air velocity on the water production, temperature distributions and efficiency in a modified double slope solar still. The other climatic parameters were minimized, placing a transparent wind tunnel on the solar still external cover. They demonstrated that develops the production and efficiency for the tested air velocities. El Sebaii, 2004

found the effect of wind speed on the daily productivity of the still. It showed that with minimum depth of water and high wind velocity, the productivity of still is increased.
The aim of our research has been to study the effect of wind speed on the productivity of a simple basin solar still. For this purpose, a conventional still and a fan-still were manufactured. In the fan-still was created artificial wind and investigated suitable wind speed. The conventional still was used as a reference. The fan-still was used for 4 different wind speed experiments. Graphs were drawn for time-dependent changes in the amount of water distilled.

EXPERIMENTAL SET-UP AND METHOD

In experimental study, a conventional still and a fan-still is used to distillation of water. The set-up designed for experimental study is given in Fig. 1.Both solar stills have 1 m^2 basin areas for comparison purposes, are made of 1.5 mm galvanized stainless-steel sheets. A glass sheet with a thickness of 4 mm is used as a glass cover for the still. The glass cover is inclined to an angle of 38° in order to make the dripping water run down on the system. The system glass cover angle considered for 38 N latitude of Elazığ in September. Conventional distillation unit used in experiments generally consists of distillation basin, distilled water tank, and a transparent cover.

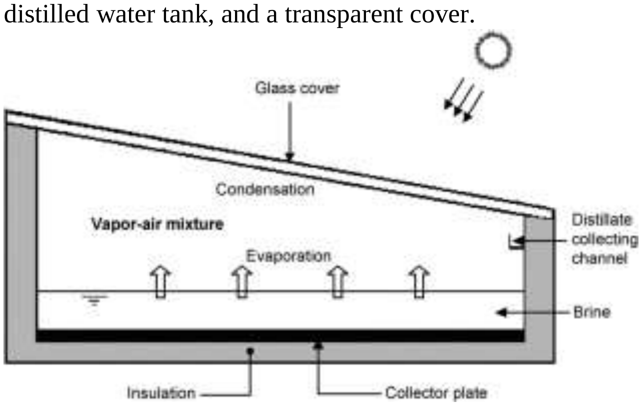

Figure 1 Convantional Distillation Unit (Nunez at al., 2008)

Transparent cover: prevents heat loss from upper part which transfer solar radiation also protects the absorber surface from external influences such as rain, hailing and dust remains. For this purpose, a single layer transparent cover glass of 4 mm thick is used in the system.

Distillation basin is made of stainless steel materials in size of 1000x1000x250 mm. The solar still basin is painted black to absorb maximum solar radiations. In order to obtain extra solar energy; system is oriented to the south. The bottom and sides of the basin are insulated to minimize heat losses by glass wool of 1 cm thickness. Base and interiors are painted with epoxy primer and black matte paint. The depth of water in the basin is maintained at 10 cm. The experiments are carried out four day between the hours of 9:00 am and 18:00 am through the 17th to 20th of September 2011, consecutively.

Inside the solar distillation system heat transfer occurs by convection, radiation and evaporation from the water surface to the inner surface of the glass cover. The solar radiations transmitted by the cover are absorbed by the absorber surface, in this way the water temperature and vapor pressure increases. The water in the system evaporates and the cover loses heat by evaporation, conduction, convection and radiation. The heat is then transferred by conduction through the glass cover.

The vaporized water is condensed along the cover material transferring the heat of condensation to the ambient air and flows down to the bottom of sloped cover and is collected in the water channel. The heat is then transferred by radiation and by forced convection from the glass cover to ambient air. The distilled water which is collected in channel fixed at the lower end of the glass cover flowed into the measuring cup.

Fresh water collection channel: It allows distilled water having flowed to the edges of the system because of the tilt in the cover after condensing to be taken out. It is made of stainless steel and mounted into the interior of the distillation pool. It is connected to the interior of the distiller to be 7 degree in angle, 50 mm in wide and 25 mm in high (Figure 2). Distilled water that condenses on the top cover of distiller flows to this channel to accumulate in a provided reservoir.

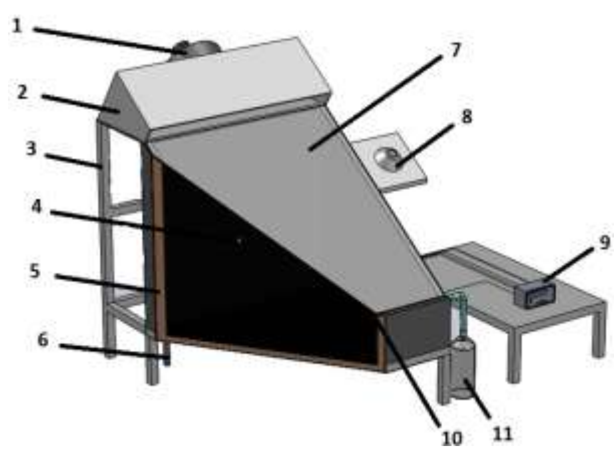

Figure 2 A schematic diagram of experimental set-up 1. Fan 2. Blowing channel 3. Stand 4.Charge hole 5. Insulation 6. Discharge hole 7. Glass cover 8. Pyranometer 9. Datalogger 10. Condensate channel 11. Measuring cup

The datalogger device which can measure at multi-point is used in the experiments. Temperatures are measured with T-type copper-constant (Cu-Co) thermocouples which can measure between -200 and +400 ^oC, at 0.1 K stability and with an error rate of ±0.1 %. During experiments a solar meter having a range of 0– 1000 W/m^2 solar intensity with an accuracy of 4–6 $\mu m/Wm^2$ is used. As shown in the cross-sectional, artificial wind is created by a fan and a blowing channel. The suitable wind speed is investigated. The distillation process is conducted at four different wind speeds, 1, 3, 5 and 7 m/s, respectively.

The following assumptions in the experiments are adopted:

a. The water temperature inside the tank is assumed isothermal
b. The water density is unchanged throughout the experiments was adopted.
c. During the experiments the effect of air humidity environment are not considered.
d. The system was considered in steady-state conditions.
e. It has been recognized that there is no leakage from the corners of the glass cover
f. Dust and dirt on the collector are has been neglected.

On the basis of these assumptions the energy balance equations for the still components may be written as follows (Singh and Tiwari 1993);

Glass cover:

$\alpha_g I + Q_{rw} + Q_{cw} + Q_{ew} = Q_{rg} + Q_{cg}$

$$\alpha_g I + [(h_{rw}+h_{cw}+h_{ew})(T_w-T_g)] = [(h_{rg}+h_{cg})(T_g-T_a)] \quad (1)$$

Basin bottom plate (basin liner):

$$\alpha_p I = Q_{pw}+Q_p \quad (2)$$

Water mass:

$$\alpha_w I + Q_p = Q_w + Q_{ew}+Q_{cw}+Q_{rw} \quad (3)$$

The convection and evaporative heat transfer coefficient from the water surface to glass cover are calculated using the following equations (Shukla and Sorayan, 2005);

$$h_{cw}=0.884[(T_w-T_g)+(P_w-P_g)(T_w+273)/(268{,}9x10^3-P_w)]^{1/3} \quad (4)$$

$$h_{ew}= 16.273x10\text{-}3\ h_{cw}(P_w-P_g)/(T_w-T_g) \quad (5)$$

The wind heat transfer coefficient h_{cw} is calculated using the following Wattmuf et al., correlation (Wattmuf,at al 1977);

$$h_b = 2.8 + 3V;\ \text{for } V \leq 5 \text{ m/s}; \quad (6)$$

$$h_b = 6.15V^{0.8};\ \text{for } V > 5 \text{ m/s} \quad (7)$$

The hourly distilled water production (m_{ew}) of the still is calculated using the following equation:

$$m_{ew} = \frac{h_{ew}(T_w - T_g).3600}{L_w} \quad (8)$$

where L_w is the latent heat of vaporization of water and calculated using the following correlation proposed by Sharma and Mullick (Sharma and Mullick 1991);

$$L_w = 3044205.5-1670.1109\ T_w-1.14258\ T_w^2 \quad (9)$$

The daylight productivity m_{ewd} is calculated from;

$$m_{ewd} = \sum m_{ewh} \quad (10)$$

the efficiency of the system (η) is calculated from:

$$\eta = \frac{m_{ew}L}{I.A.3600} \quad (11)$$

EXPERIMENTAL UNCERTAINTY

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. During the experiments, the average uncertainties arisen from the measurement are classified as follows. Considering the relative uncertainties in the individual factors denoted by x_n, uncertainty estimation was made using the following equation (Holman, 1994):

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \ldots\ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \quad (12)$$

The total uncertainties of parameters that were calculated as below were presented in Table 1.

Table I. Total uncertainties of the parameters in the process

Parameter	Total uncertainties
total uncertainty of water temperature in the solar stil (oC)	± 0.173 °C
total uncertainty of vapour temperature in the solar still (oC)	± 0.173 °C
total uncertainty of glass surface temperature (oC)	± 0.173 °C
total uncertainty of environment temperature (oC)	± 0.173 °C
total uncertainty of measurement of air velociy	± 0.104 m/s
Total uncertainty in the amounts distilled water	± 0.212 gr
Total uncertainty in the amounts of water used	± 0.001 m
Total uncertainties in time measurement	± 0.1 min.

RESULTS AND DISCUSSION

This research article summarized a new solar still with blower which has been designed for and tested under the climatic conditions of Elazığ, Türkiye. The effect of cooling air flowing over the condensation surface was studied. Consequently, fan-generated wind was introduced and the effect of cover cooling using a fan close to the cover of the solar still units was investigated. In order to know the effect of air velocity on normal operating conditions in a conventional solar still, tests were carried out at the same time without the fan. The solar intensity, temperature and fan air velocity are considered to have an effect on the overall still productivity.

The radiation received from the sun provides energy necessary to evaporate the water from stills. Fig. 3 shows the daylight variations of the measured average solar intensities and ambient temperatures for four day. During experiments, solar intensities and ambient temperatures ranged from 200 to 900 W/m^2 and 26 to 32°C, respectively.

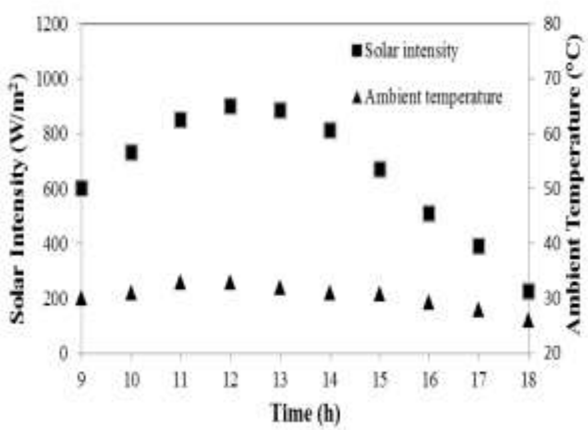

Figure 3 The daylight variations of solar intensities and ambient temperatures

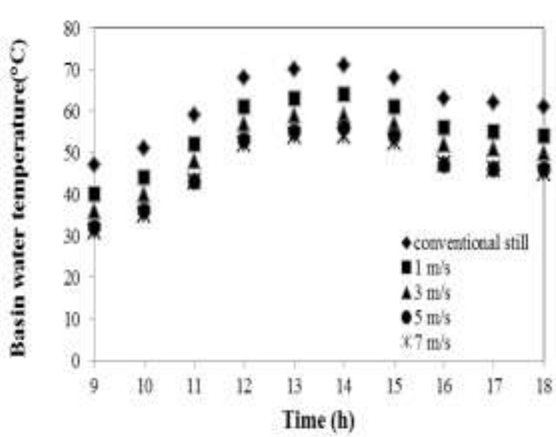

Figure 4 The daylight variations of basin water temperature depending on wind speeds

In the Fig. 4 and 5 are presented the basin water and glass cover temperature depending on wind speeds, respectively. As shown in the Figure 4, the basin water temperature decreases as wind speed increases. The basin water temperatures in the conventional still and fan-still with 7 m/s ranged from 47 to 71°C and 31 to 54°C, respectively.

Similarly, Figure 5 shows that the glass cover temperature decreases as wind speed increases. Increasing wind speed sweeping glass surface reduces glass temperature, naturally. Because of the decrease of glass temperature, the rate of heat transfer increases from the basin water to glass cover. Accordingly, the basin water temperature decreases. The glass cover temperatures in the conventional still and fan-still with 7 m/s ranged from 44 to 64°C and 28 to 44°C, respectively. The obtained temperature values in the fan-stills with 5 and 7 m/s wind speeds are very close.

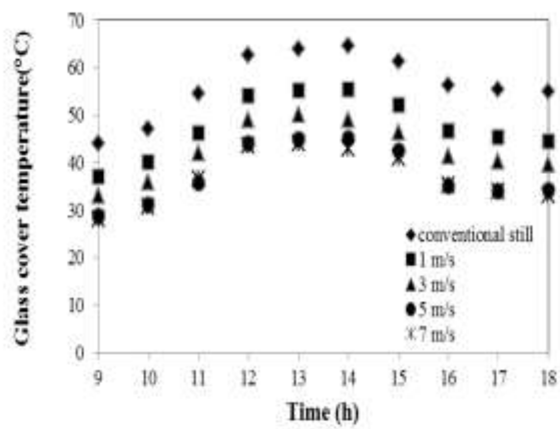

Figure 5 The daylight variations of glass cover temperatures depending on wind speeds

In the Fig.6 is presented temperature difference between basin water and glass cover for fan-still with four values of wind speed and conventional still. As shown in the figure, temperature difference increases as wind speed increases. The highest temperature differences are obtained in the fan-still with 5 and 7 m/s wind speed.

The comparison of the productivity of fresh water between the two types of stills for four wind speed is shown in Fig. 7. Fig. 7 shows experimentally obtained data, also. In general, the agreement between the measured data and the calculated data is within 2%.

As shown in Fig.7, the daylight productivity of solar stills increases as wind speed increases. The highest daylight productivity is obtained in the fan-still with 5 and 7 m/s wind speed. The system productivity under fan-still with 7 m/s conditions is higher than conventional still productivity by 14.7 %. The results show that daylight productivity at higher speeds than 5 m/s does not change too much.

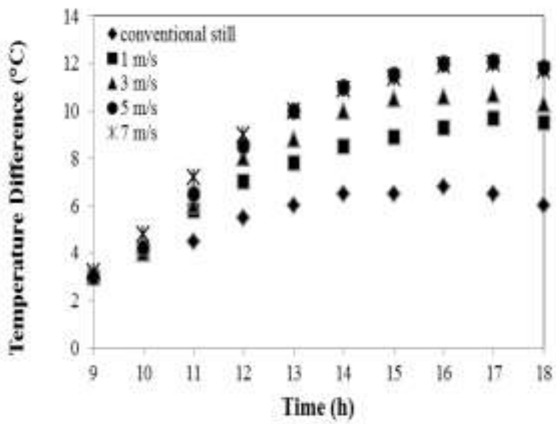

Figure 6 Water-glass temperature differences as a function of time for four different wind speeds

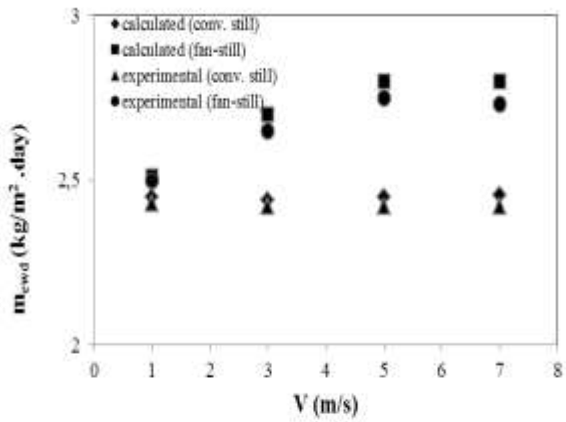

Figure 7 Variations of daylight productivity with wind speed

In the range of the considered velocities, the amount of distilled water obtained was increased due to an increment in the rate of condensation, reaching a maximum value, when the outer cover temperature is equal to the ambient and at the same time, the production decreases because the glass cover is colder than the ambient air.

The wind is one of the important atmospheric factors affecting the heat transfer from glass cover to ambient air and controlling the glass cover temperature. With increasing of the wind speed increases the heat transfer from glass cover to ambient air and raises the condensate rate between glass cover with basin water. Therefore, the still productivity increases. However, the speed must not exceed certain levels. Because, the wind speeds at high levels reduces the water temperature inside the cover and condensate quantity. So, the still efficient adversely affected. For the present design, the critical value of wind speed is obtained as 5 m/s.

In the reference study, El-Sebaii investigated the effect of wind speed V on the daily productivity of some active and passive solar stills on typical summer and winter days in Tanta. For the investigated single slope single basin still, the increase of daily productivity was found to be 13.4 and 12.9 % on 5 June and 26 December, respectively. The critical wind speed was found to be 10 and 8 m/s on 5 June and 12.9% on 26 December, respectively. In the study reported that the critical wind speed is independent on the still shape and the mode of operation (active or passive) but it shows some seasonal dependence. (El-Sebaii, 2004).

For the effect of wind, no strong correlation was found to exist for the wind on the yield of the solar still.

In the Fig. 7; the curve shown for obtained data are assume that a polynomial relationship exists between wind speed and productivity. Therefore, the calculated values of m_{ewd} are correlated using the Statistica software.

The following correlation has been obtained between m_{ewd} and V;

$$m_{ewd}=2.424+0.118V-0.009V^2 \qquad R^2=0.95 \qquad (13)$$

Figure 8 shows effect of the air flow rate. This shows that the efficiency was improved with increase of air flow rate. The daily yield of solar still with blower was found 50 % efficiency without air flow 80 % efficiency with air flow at a constant flow rate of 7 m/s. In summary, the solar still with air flow enhanced rate of condensation. Increasing the air velocity up to 7 m/s, the production of water was increased to a maximum value, where thermal equilibrium between the glass cover and the environment was achieved. For higher velocities, the temperature of the glass was lower than ambient, decreasing the water production and at the same time the maximum efficiency was obtained.

The increments of efficiency and production were obtained by increasing the air velocity up to the value limit of 7 m/s. The velocity of 5 m/s was considered to be the optimum. According to the results, the air velocity has a reduced effect on the still thermal performance and water production, and the efficiency increases up to 80% when the air velocity increases up to a maximum value of 5 m/s and in that a higher speed is not changing very much.

It is clear from the present experimental and theoretical results that the fan close to the cover of the solar still have a great effect on temperatures of the still elements,and the fan-generated wind improves efficiency and productivity

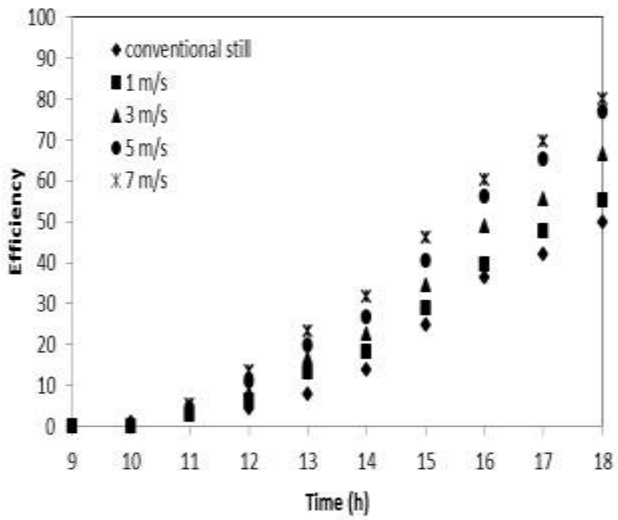

Figure 8 Variations of efficiency with wind speed

CONCLUSION

Solar energy is the best alternative heating energy source. It is inexhaustible, clean and available in almost all parts of the world. Solar stills have potential to provide cheaper distilled water and to reduce the consumption of conventional energy. The purpose of this study has been to evaluate effect of wind speed on the productivity of a simple basin solar still. Therefore, a single basin fan-solar still was fabricated and tested. The system was tested with four wind speed as 1, 3, 5 and 7 m/s. The effects of the wind speed were observed. The experimental study shows that for similar values of solar irradiance within the range of velocities from 1 to 7 m/s, the efficiency increase up to a maximum value of 80%.

From the obtained results, it is concluded that the maximum allowable system productivity is ranged between 2.44 and 2.8 kg/m^{2}day for conventional still and fan-still with 5 m/s in September. So the system productivity under fan-still with 5 m/s conditions is higher than conventional still productivity by 14.7 %.

Single basin solar still is a very simple solar device used for converting available brackish or waste water into potable water. This device can be fabricated easily with locally available materials. For this reason, research and development on solar distillation should be encouraged and carried out.

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ÖZGEÇMİŞ

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Doç. Dr. Zeki ARGUNHAN 1966 yılında Batman'ın Sason ilçesinde doğdu. 1981 yılında Sason Lisesinden birincilikle mezun oldu. 1987 yılında O.D.T.Ü. Gaziantep Kampüsü Mühendislik Fakültesi, Makina Bölümünden mezun oldu. Aynı yıl T.C. Karayolları 9. Bölge Müdürlüğünde Makina Teknik Elemanı olarakişe başladı. T.C.K. 9. Bölge Müdürlüğü bünyesinde çeşitli kademelerde görev yaptıktan sonra 1995 Mayısında D.Ü. Batman Meslek Yüksek Okuluna Öğretim Görevlisi olarak geçiş yaptı. Harran Üniversitesi'nden 1998 yılında Yüksek Lisansı, Fırat Üniversitesi'nden 2003 yılının nisan ayında doktora öğrenimini tamamladı. 2005 yılında Yardımcı Doçent, 2012yılında Doçent oldu. Halen Batman Üniversitesi Mühendislik – Mimarlık Fakültesi Makine Mühendisliği Bölümünde öğretim üyesi olarak çalışmaktadır.