Journal of Engg. Research **Vol. 4 No. (4) December 2016** pp. 178-193

حلية المياه المالحة باستخدام الطاقة الشمسية المزدوج القائم بأعمال لا يزال

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الخلاصة

تحلية المياه المالحة هو نهج مناسب جدا لزيادة الطلب باطراد على المياه العذبة نتيجة للنمو السكاني غير المنضبط في البلدان النامية. واضعين نصب أعيننا على الاحتياجات المحلية للعائلات الصغيرة الذين يقيمون في المناطق النائية من البلاد وعدم توافر المياه العذبة، فقد تم في هذا البحث تطوير جهاز مصنع محليا يقوم بعمل مزدوج بالطاقة الشمسية لغرض تحلية المياة. ويتكون النظام من جامع لوحة مسطحة، وغرفة التبخر مجهزة بمبادل حراري مصنوع من أنابيب النحاس، لوحة فوتوفولتيك شمسية (Wp60)، سقف زجاجي وآلية لتدوير المياه. النظام المُصمم يعمل على حد سواء بنشاط وكذلك بشكل سلبي بسبب غطاء السقف الزجاجي وقاعدة لوحة سوداء. النتيجة تظهر أن إنتاج المياه العذبة وجدت لتكون 3.8 لتر / متر^{2} في 8 ساعات يوميا في الصيف عندما يتراوح متوسط الاشعاع الشمسي عادة ما بين 750 وات/ متر^{2} الى 800 وات/ متر^{2}. لوحظ أن كفاءة متوسط التحصيل اليومي لنظام تحلية المياه هي 38% عند معدل التدفق الكلي 0.0035 كجم / ثانية. كما تم إجراء اختبارات تحديد نوعية المياه الصالحة للشرب ومقارنتها مع المعايير الدولية. وتظهر النتيجة أن EC، ودرجة الحموضة، المواد الصلبة الذائبة، NA^{1+}، CA^{2+} والمغنيسيوم وجدت لتكون 0.15 DSM^{-1}، 6.1، 105 جزء في المليون، 0.47 ملغ / لتر، 0.65 ملغ / لتر و 0.54 ملغم / لتر على التوالي ومتوافقة مع المعايير الدولية. وبلغت التكلفة لكل لتر من الماء النقي 0.03 $ مما يدل على جدوى هذا النظام المقترح. وأظهرت النتيجة أن التصريف المزدوج للطاقة الشمسية لا يزال يمكن استخدامه لأغراض تحلية المياه تحت ظروف مناخية مواتية.

Desalination of brackish water using dual acting solar still

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ABSTRACT

Desalination of brackish water is a very suitable approach to augment the exponentially increasing fresh water demands due to uncontrolled population growth in developing countries. Keeping in view the local needs of small families residing in remote areas of the country and having no access to fresh water availability, therefore, this research has been carried out for the development of locally fabricated dual acting solar still for desalination purpose. The system consists of a flat plate collector, an evaporation chamber equipped with heat exchanger made of copper tube, 60 W_p solar photovoltaic (PV) panel, glass roof and water circulation mechanism. The designed system works both actively as well as passively due to glass roof cover and black base plate of evaporation chamber. The result shows that the fresh water production was found to be 3.8 l/m^2 in 8 hours a day in summer, when the average solar radiation usually ranges from 750 Wm^{-2} to 800 Wm^{-2}. The daily mean collection efficiency of the desalination system was observed to be 38% at mass flow rate of 0.0035 kg/sec. Drinking quality water tests have also been performed and compared with international standards. The result shows that EC, pH, TDS, Na^{1+}, Ca^{2+} and Mg was found to be 0.15 dsm^{-1}, 6.1, 105 ppm, 0.47 mg/l, 0.65 mg/l and 0.54 mg/l respectively and at par with international standards. The cost per liter of fresh water was $0.03, which indicates the feasibility of proposed system. The result showed that dual acting solar still can be used for desalination purposes under favorable climatic condition.

Keywords: Distillate; evaporation chamber; flat plate collector; solar still.

Nomenclature

PV	Photovoltaic
MSF	Multi stage flash
MED	Multi effect distillation
RO	Reverse osmosis
FPC	Flat plate collector
HEX	Heat exchanger
EC	Evaporation chamber
Q_i	Total available power
I	Total solar irradiance
A_c	Area of collector
Q_u	Useful energy
m	Mass flow rate
ΔT	Temperature difference
C_p	Specific heat of water
T	Time interval
η	Efficiency
C_t	Total cost of system
C_w	Cost of fresh water per liter
D	Amount of distillate per day

INTRODUCTION

Water is the basic necessity of life and the most important component of the biosphere. Water scarcity problem in the world is multifaceted and is increasing day by day. About three-fourth of the planet is covered by water, out of which around 97.5% is saline water. The remaining 3% comprises of glaciers, rivers, lakes and ground water etc. Only 0.007% of the available water is readily accessible for direct use. Fresh water supply issues are the burning issues of this era due to climate change, increasing population and water pollution caused by human activities. In developing regions like Africa, nearly 54% of population has no access to quality drinking water. Similar situation prevails in Asia, where 42% in Asia Pacific and 19% people in South Asia region have no access to fresh water supply. About 1.8 million deaths are reported annually due to problem of diseases produced from unsafe water supply, sanitation and hygiene (El-Dessouky & Ettouney, 2002).

According to Global Water Intelligence report (2005), nearly 1.1-1.5 billion people worldwide do not have access to good quality drinking water. Pakistan is also facing scarcity of freshwater and has lowest fresh water availability in the region (below 1000

m^3 per capita annually). More than 35% of country's population does not have access to safe drinking water (WRI, 2003). The coastal areas of Pakistan have abundantly available sea water, but it cannot be used for drinking purpose. Therefore, desalination of sea water is necessary to augment the fresh water resources of the world. The major portion of fresh water is produced using conventional methods of desalination, which employ primary energy resources. These methods are highly expensive and energy intensive. Moreover, the environmental consequence of fossil fuel combustion is another arising issue of this era. It is worth mentioning here that most of the countries in the world have already stepped forward towards desalination, using renewable energy sources.

Desalination using solar energy is an attractive option for sustainability in fresh water availability by treating brackish water. Solar thermal desalination requires efficient method of evaporation and condensation at relatively low temperatures. In this regard, Pakistan is blessed with huge amount of solar irradiance, which offers an excellent opportunity to utilize this energy for desalination process. Many theoretical and experimental studies have been carried out for the design, development, operation and maintenance of different types of desalination systems. Conventional methods of water desalination based on multi stage flash distillation (MSF), multi effect distillation (MED), and reverse osmosis (RO) has been investigated by Kalogirous (2005). The authors suggested that desalination process uses high-energy and require heavy investment and infrastructure. The newly established desalination technologies revolve around the treatment of brackish/saline water utilizing renewable energy sources.

Qiblawey & Banat (2008) studied different forms of desalination using direct or indirect solar energy. Direct desalination systems produce distillate using solar energy, i.e. fresh water produced directly in solar collector whereas indirect system combines orthodox desalination methods in which heat is generated using solar collectors. Joseph *et al.* (2005) designed and fabricated a solar desalination system coupled with 1 m^2 flat plate collector to get a yield of 4.25 $l/m^2/d$ when the average beam radiation was found to vary from 400 Wm^{-2} to 900 Wm^{-2}. It was found that the cost of fresh water production using this system was three times less than the conventional method of desalination. A small sized solar desalination system with multi-stage evaporation processes has been designed and fabricated by Liu *et al*. (2014). The experimental result shows that the fresh water yield of the system can reach as high as 1.25 kg/h/ m^2 in the autumn, when solar radiation usually ranges from 700 Wm^{-2} to 800 Wm^{-2}. A pioneering design of a multi-stage flash distillation system was investigated by Maroo & Goswami (2009). The system has its individuality in a sense that it uses the natural forces of atmospheric pressure and gravity for generation of vacuum. The pilot setup for investigation of two stage-flash distillation was developed, in which source water heated using vapor's heat was approaching the evaporator in two stages. The experimental yield of distillate was found to be 5.54 kg in 7.83 hours while the system with two stages produced 8.66 kg in 7.7 hours, with an average efficiency of 48 and 75% respectively, when 1 m^2 of collector area was used.

Chafidz *et al.* (2014) developed a hybrid solar-driven desalination system with membrane distillation for operation in remote arid areas of Kingdom of Saudi Arabia (KSA), comprising of photovoltaic and flat plate collectors as energy sources. The results showed that the use of heat pump significantly increase the output of distilled water from 34.8 to 67.8 liters with an average hourly production of 5.98 and 11.24 l/h respectively. It was concluded that the production of distillate significantly depends upon the initial amount of feed water and system produced 34.8, 22.2 and 21.6 liters of distillate with 69, 96.6 and 134.4 liters of feed water respectively. Wang *et al.* (2012) carried out brackish water desalination by both free and forced convection approach using a photovoltaic driven humidification-dehumidification process. A bench scale apparatus was made to clean the sodium chloride contaminated water. The results showed that under ideal conditions, higher yields were produced using forced convection method compared with free convection method. The maximum yield of fresh water was found to be 8.73 kg/m^2/d using forced convection at an evaporative temperature of 64.3 °C.

Solar thermal desalination could be done either by active (indirect) heating or passive (direct) heating. Using direct methods required large areas and have relatively low productivity as compared to indirect methods (Qiblawey & Banat 2008). The literature cited clearly states that traditionally, desalination system developed in other parts of the world may work either passively or actively. In contrast to literature reviewed, this study was focused on designing a small scale system, that works both actively and passively to achieve maximum efficiency for specific operating condition. The dual acting system comprised of flat plate collector (FPC) for active heating. For passive heating, the cover of the solar still was made transparent to allow maximum radiation to pass through. The thickness of glass cover affects the amount of absorbance and transmittance of incoming radiation. Tiwari & Shah (2011) investigated the effect of glass covers with different thickness on passive single slope single basin solar still. Three identical sized solar stills having glass thickness of 4 mm, 8 mm and 12 mm have been used in the experiments. The results showed that the distillate output was found greater for 4 mm thick glass cover as compared with 8 and 12 mm thickness glass. The prime objective of the study was the indigenization of the thermal desalination technology, that eventually facilitates the local community development in the country. The designed system was operated under different conditions to check its overall performance and it was concluded that the system exhibits excellent performance in accumulating solar energy, heat utilization and water evaporation. The system's daily water productivity rate was also observed to be higher as compared to other solar still.

MATERIAL AND METHODS

This research work involves the development and performance evaluation of indigenous dual acting solar still. The performance of any experimental system or machine depends on the feasibility and precision of its design. The preliminary design of the desalination system has been carried out using SolidWorks software. The system mainly comprises of two units namely evaporation chamber and 1 m^2 flat plate collector (FPC). The complete development of dual acting solar still has been carried out using locally available low cost materials and manufacturing facilities in the workshop of the Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad - Pakistan. The materials used for the development of solar still have been selected based on their physical and mechanical properties. The schematics of the dual acting solar still desalination system is shown in Figure 1.

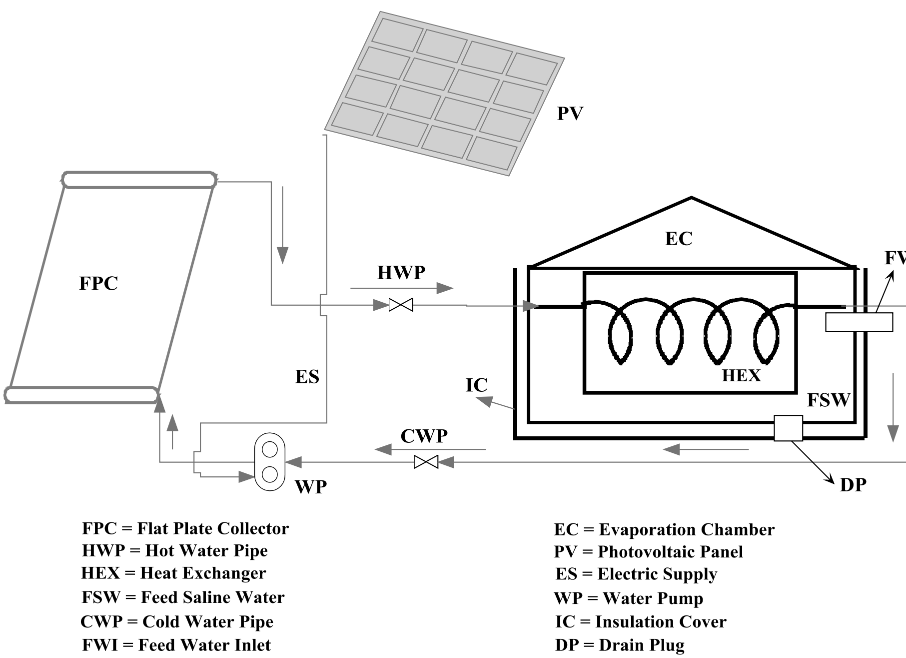

Fig. 1. Schematics of dual acting solar still desalination system

A 16 gauge galvanized iron (GI) sheet having thermal conductivity as 73 $Wm^{-1}K^{-1}$ with thickness and specific weight as 1.6 mm and 11.9137 kg/m^2 respectively was used as core material for the development of 1 m^2 evaporation chamber. The inner base of the evaporation chamber is painted black to increase its absorptivity. This eventually increases the overall efficiency of the system as the feed water temperature increased by passive heating. A 5 mm Soda-lime-Silica glass is used for making pyramidal roof of the evaporation chamber. It has low thermal resistance (500–600 °C). The low thermal resistance of glass helps in promoting rate of condensation inside of glass, as most of the heat releases to atmosphere. Copper tube with 5 mm diameter and 0.5 mm thickness having thermal conductivity of 385 $Wm^{-1}K^{-1}$ was used to develop heat exchanger (HEX) for the active heating of the feed water. The total length of the copper tube in the evaporation chamber (EC) is 731 cm. To minimize the thermal losses from the EC, the sheets of thermocol having 2.5 cm thickness and 2 kg/m^3 density are used to insulate the EC. Aluminum channel having specific weight of 2.7 g/cm^2, size of 2×3 cm and channel thickness of 0.5 mm has been used as distillate collection channel. A 1 m^2 solar FPC is the essential part of the solar still desalination system. It has thin aluminum sheet painted with black matte paint for efficient absorption of the solar radiation. A PV operated 12V DC water pump is used for the continuous circulation of heated water in the FPC and HEX of the EC in a closed loop. A small sized thermal storage tank is connected between FPC and HEX of the EC for thermal energy storage. This thermal energy is used in case of low or scarce radiation.

Experimental procedure

The water need to be purified is added into the evaporation chamber through an inlet provided at the side of the EC. The FPC is attached to the EC through a heat exchanger. The FPC is connected to increase the evaporation rate of the solar still desalination system. The collector has been oriented to north-south direction to get maximum daily solar radiation throughout the year. The mass flow inside the collector tubes and the heat exchanger of the EC is maintained using multi speed water pump and speed regulator. This water after heating in the collector is passed through the HEX in the EC, where heat is exchanged with feed water to convert it into vapors. The pyramidal glass roof collects the vapors and condenses them by losing their latent heat to the atmosphere. The angle of the pyramidal glass roof is adjusted to maximize the interception of the radiation. The gradient of glass is provided for the efficient removal of distillate from the EC. Distillate is then temporarily collected into the aluminum channels attached inside the four sides of the EC. The gradient of the aluminum channel is adjusted, so that its flow is naturally designed towards outside of the EC to store into a storage tank. Due to continuous desalination process, the concentration of salts gradually increases in the EC, resulting in slow feed water evaporation. Therefore, flushing system is required at regular intervals to ensure efficient system operation. There are about seven main experimental parameters viz. solar radiation, collector inlet and outlet temperature, tilt angle, mass flow rater, chamber outlet temperature and water temperature inside the desalination chamber, having direct influence on the productivity and efficiency of the desalination system. The system was operated at a fixed tilt angle of 32 °N, which was the best suited angle for the experimental site. The mass flow rate was varied using a flow regulator attached to the pump. Due to change in mass flow rate and solar radiation, all other parameters vary accordingly. There are also some other climatic factors like wind speed, direction and relative humidity that slightly affect the production rate of the system but their effect is low and can be neglected.

The efficiency of the solar still has been calculated using following procedure. The total power available on the collector can be calculated using Equation 1.

$$Q_i = I \times A_c \tag{1}$$

Where; Q_i is total power available on the surface of the collector in W, I is the total solar irradiance in W m^{-2} and A_c is the area of collector in m^2.

The total power produced by collector is the rate of heat extraction by fluid passing through the collector and can be calculated using Equation 2.

$$Q_u = \frac{m c_p \Delta T}{t} \tag{2}$$

Where; Q_u is the useful energy per unit time produced by the collector in W, m is the mass of fluid flowing in kg, ΔT is the temperature difference in K, c_p is the specific heat of water taken as 4187 $Jkg^{-1}K^{-1}$, and t is the time interval in seconds.

The collector efficiency (η) is the ratio of the useful energy produced (Q_u) to the total incident energy on the collector (Q_i) over a specific period of time and can be calculated using Equation 3.

$$\eta = \frac{Q_u}{Q_i} \times 100 \tag{3}$$

Where; η is the efficiency in %, Q_i is the total incident solar energy per unit time on collector in Wh and Q_u is the useful energy per unit time produced by the collector in Wh.

The total cost of the system was estimated using Equation 4 considering both fixed and operational cost in order to calculate the specific cost of distillate using Equation 4 and 5.

$$C_t = \text{Fixed cost} + \text{Operational cost} \tag{4}$$

$$C_W = \frac{C_t}{D} \tag{5}$$

Where; C_t is the total cost of the system in \$, C_w is the cost of fresh water per liter in \$ and D is the amount of distillate produced per day in liters.

The instruments used during the performance evaluation of solar desalination system include K-type thermocouples and thermometers to measure the inlet and outlet temperatures of collector and evaporation chamber. Pyranometer is used to record daily solar radiation. A graduated cylinder is used to measure the hourly and cumulative distillate production. The quality tests of feed water and distillate have also been carried out using WQC-20A water quality analyzer, pH meter, EC meter etc. available in the laboratories of the Department of Structures and Environmental Engineering laboratories of the University to determine the total dissolved solids (TDS), electrical conductivity (EC), pH, Ca, Na and Mg.

RESULTS AND DISCUSSION

The performance evaluation of newly developed solar still desalination system has also been carried out under local climatic conditions to test its suitability for desalination purpose. The data has been collected continuously in order to evaluate the different parameters affecting the distillate production. The data has been collected on hourly basis starting from 9:00 am to 4:00 pm Pakistan standard time (PST). The sample data collected on May 14, 2015 about incident energy, collector inlet and outlet temperatures, evaporation chamber temperature and distillate production is shown in Table 1. The table shows that the rate of distillate production increases rapidly from 10:00 am to 12:00 pm and gradually decreases afterward.

Table 1. Average hourly data recorded for different variables on May 14, 2015 (Tilt angle: 32^{o}N)

Time (hr)	Total Radiation (W/m^2)	Collector Inlet Temp (^{o}C)	Collector Outlet Temp. (^{o}C)	Evaporation Chamber Outlet Temp. (^{o}C)	Inner Glass Wall Temp. (^{o}C)	Base Plate Temp. of Evap. Chamber (^{o}C)	Hourly Distillate Production (Liters)
9:00	769.8	31	55	38	41	48	0.2
10:00	795.8	42	62	48	46	55	0.26
11:00	830.4	45	75	49	48	56	0.38
12:00	839.05	47	78	53	57	64	0.51
13:00	821.75	50	77	56	60	66	0.55
14:00	761.2	54	68	61	63	70	0.59
15:00	757.4	55	63	62	61	68	0.58
16:00	510.35	54	56	60	58	63	0.55

The hourly solar irradiance and ambient temperature on May 13 and May 14, 2015 is shown in Figure 2. The solar irradiance and ambient temperature is slightly higher on May 14. The average ambient temperature on May 13 and May 14 was measured to be 40.75 and 41.75 ^{o}C while average solar irradiance as 760.72 and 782.01 Wm^{-2} respectively. It is also depicted from the figure that the ambient temperature increases uniformly upto 3:00 pm and then decreases afterwards while the solar irradiance starts decreasing after 01:00 pm.

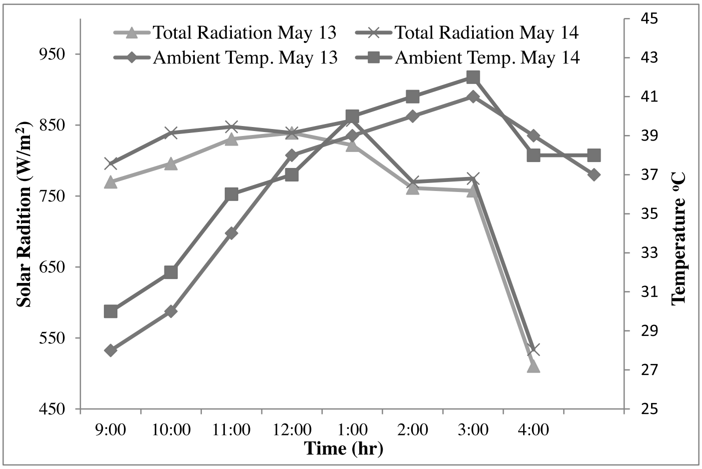

Fig. 2. Hourly ambient temperature and solar irradiance

The daily collector outlet temperature on May 13, 14 and 15 is shown in Figure 3. The figure shows that the collector outlet temperature was higher on May 14 as compared with May 13 and May 15. The maximum collector outlet temperature was found to be 82 °C at 01:00 pm on May 14, while on May 13 and May 15 it was 78 °C at 12:00 pm and 79 °C at 11:00 am respectively. It is due to the fact that the solar irradiance and ambient temperature was higher on May 14. It is also important to mention that the mass flow rate on May 14 was also higher as compared to other days. The average collector outlet temperature on May 13, 14 and 15 was found to be 66.75, 71.5 and 68.75 °C respectively.

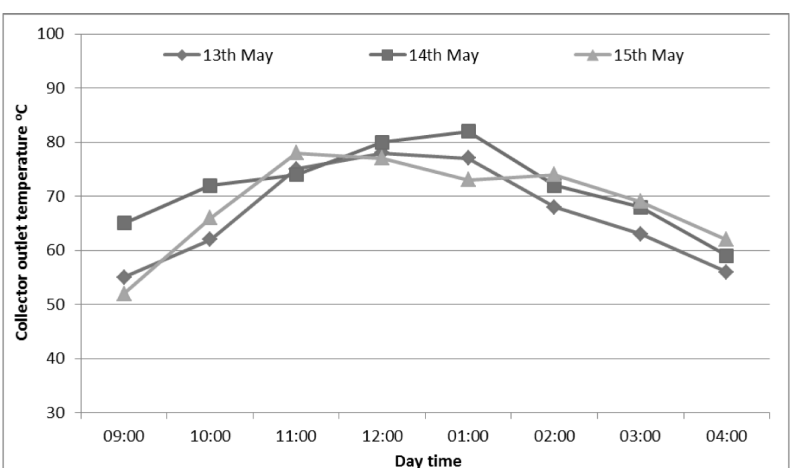

Fig. 3. FPC outlet temperatures on three consecutive days

The relationship between outlet temperature of collector and evaporation chamber and heat utilized from heat exchanger is shown in Figure 4. The data observed on May 14 is presented because system's productivity was found maximum on that particular day. The difference between collector outlet temperature and chamber outlet temperature at a single point gives the heat value exploited by feed water in the evaporation chamber. The figure shows that the heat recovered is higher at the start of the experiment and found to be maximum at 10:00 am. It is due to the fact that the temperature difference between collector outlet temperature and feed water temperature was high at the start of day as temperature of water in evaporation chamber is low and collector outlet temperature was high. The heat energy utilized by feed water in the evaporation chamber decreases continuously throughout the day and found to be negligible at 03:30 pm, when both the collector and evaporation chamber intersect each other at equilibrium state. The evaporation chamber temperature increases rapidly from 11:00 am to 01:00 pm and becomes nearly constant because of high solar radiation at noon.

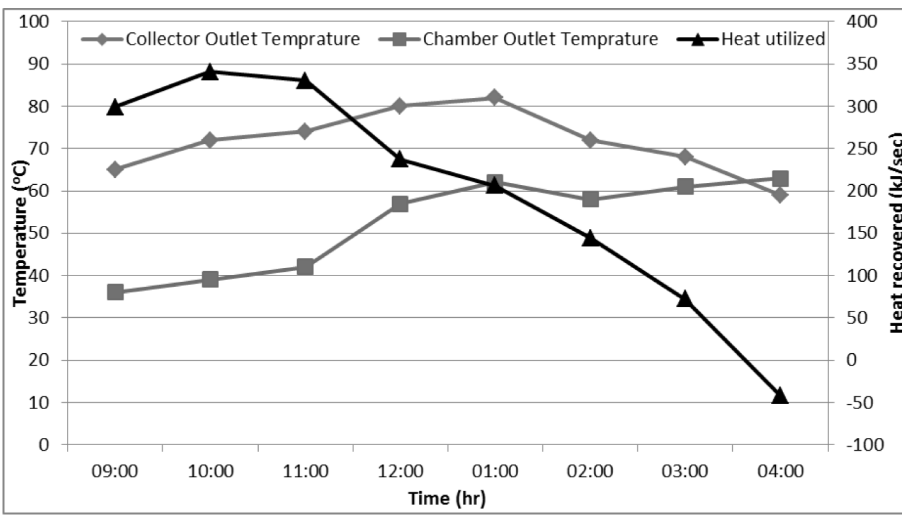

Fig. 4. FPC outlet temperature, EC outlet temperature and heat utilized

The maximum FPC outlet temperature was found at 01:00 pm and it decreases due to lower solar irradiance. It can also be observed from the figure that the rise in EC temperature is lower during start of the experiment from 9:00 am to 11:00 am as compared with 11:00 am to 01:00 pm. It is due to the fact that at the start of the day, there persist a greater temperature difference (Δt) between collector and evaporation chamber outlet temperatures and consequently decreases at the end of the day. The maximum heat energy recovered (340.47 kJ/kg) was found during start of the experiment and reduces to -41.27 kJ/kg indicating the reverse heat flow in the evaporation chamber. At this stage, the system is not viable to run actively.

Figure 5 represents the behavior of glass and base plate temperature of the evaporation chamber and heat dissipated to the environment measured using infrared gun temperature sensor. The figure depicts that both glass and base temperature on 14th May have similar trend throughout the day. The maximum glass and base temperature was measured to be 70 and 63 ºC respectively at 02:00 pm. The maximum temperature gain was found between 01:00 and 03:00 pm. It is due to the fact that the ambient temperature and solar radiation are maximum at noon. The average difference between glass and base temperature was found to be 6 ºC with the fact that the base temperature is higher due to its painted black surface. The system was operated at different days and similar trends for glass and base plate temperature were observed.

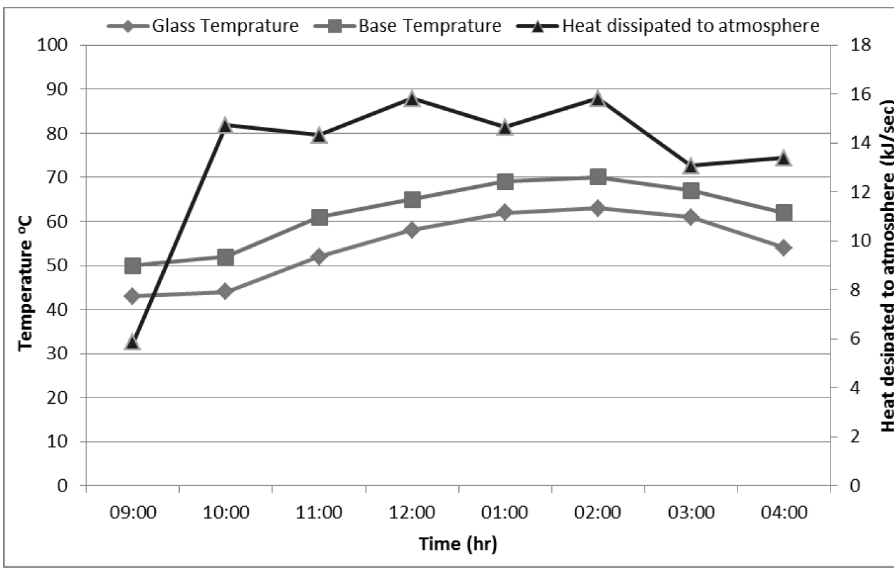

Fig. 5. Glass temperature, base temperature and heat dissipated to the atmosphere

The maximum amount of heat dissipated to the environment was found between 09:00 am to 10:00 pm, as the ambient temperature is quite low in the early hours and becomes nearly constant between 10:00 am to 02:00 pm and then decreases. As temperature difference between the parts of the system and surroundings increases, the heat starts dissipating from glass and base of the system. The hourly distillate production on May 13, 14 and 15 is shown in Figure 6. It is depicted from the figure that the distillate production rapidly increases in the early hours of the day and almost becomes constant during mid-day and then decreases at the end of the day. The main reason behind the low productivity rate in the early hours is due to the fact that significant time required to heat the water in the evaporation chamber.

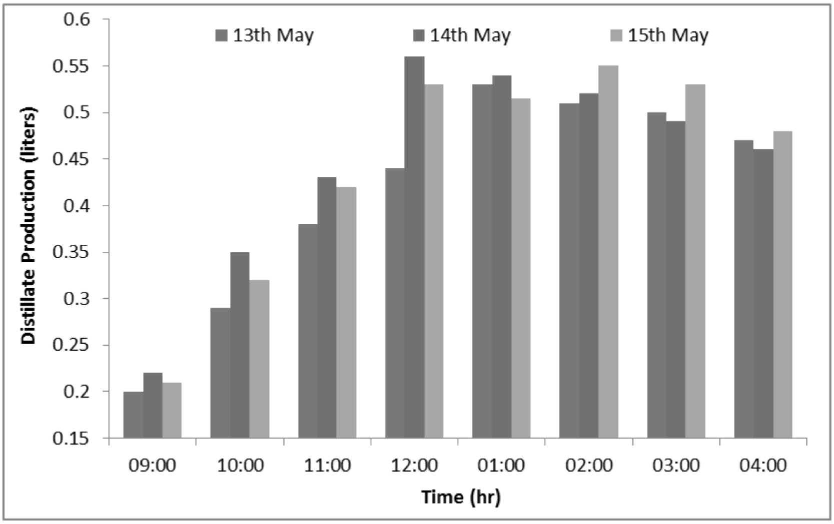

Fig. 6. Hourly distillate production

The maximum distillate production for all the days was found between 12:00 to 02:00 pm. It is obvious that at the end of the day, the solar radiation decreases, while the distillate production is quite higher as compared with start of the day. It is due to the fact that at the end of the day, the system works passively due to the heat stored in the evaporation chamber.

The cumulative distillate productivity for all the days is shown in Figure 7. The figure shows that the distillate production on May 14 and 15 is quite similar, while it is slightly lower on May 13. The cumulative distillate production on May 13, 14 and 15 was found to be 3.32, 3.80 and 3.65 liters respectively. The result shows that the system has a capacity to produce 3.8 l/m^2 in 8 hours a day during summer when the average solar radiation usually ranges from 750 to 800 Wm^{-2}. The quantity of water required per person per day is variable and it depends on physical health, age, activity and environmental conditions. The British Dietetic Association (BDA) recommends 1.8 liters water per day for an adult. The typical household in rural areas of Pakistan has an average of 6.5 persons but one-fourth of all households have less than four members (Greenhalgh, 2001). The combination of two to three units of proposed system could be sufficient to fulfill the drinking requirement of small household. The system can also be designed on larger scale by increasing either the area of FPC or EC or both. The active (indirect) heating of water requires less area and have higher production rate as compared to direct (passive) heating (Qiblawey & Banat, 2008). In case of larger system, the utilization of land covered area could be optimized by increasing the FPC surface area only while keeping the same EC surface area. The EC surface area can also be increased, but it will be less advantageous for a given increment. It was inferred that the cost was found to be $0.03 per liter of fresh water considering both fixed and operational cost. The cost per liter of fresh water could be lower, if the radiation is higher due to the fact that radiation is a key factor and it directly affects the productivity of the system.

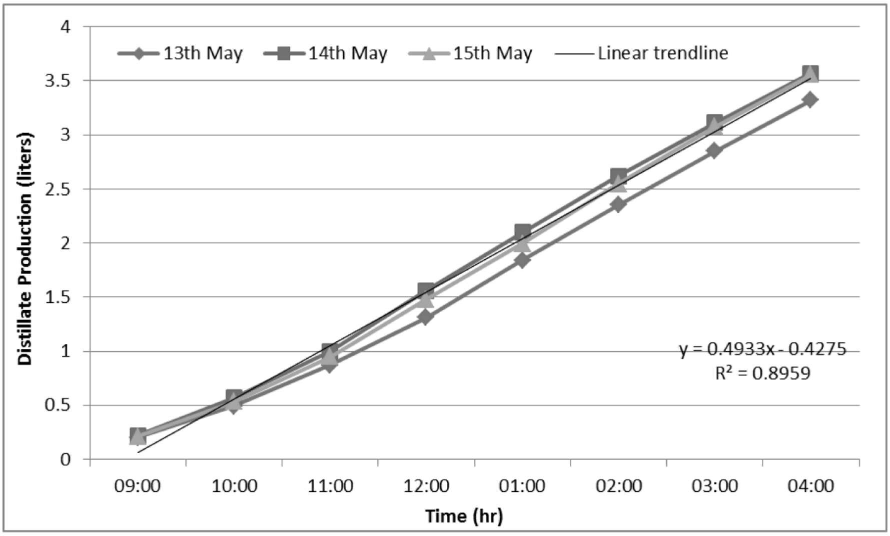

Fig. 7. Cumulative distillate production

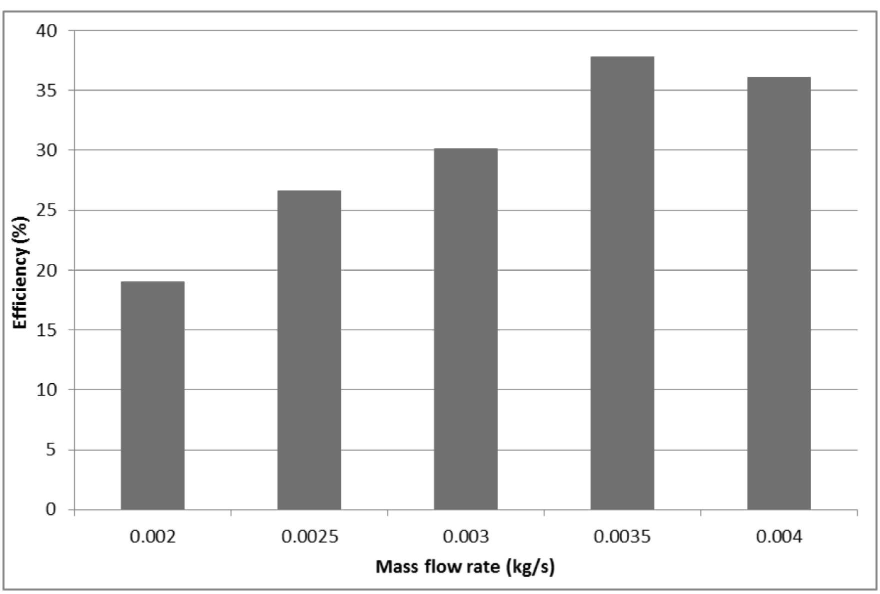

Fig. 8. Efficiency of the desalination system

Figure 8 shows the relationship between efficiency and mass flow rates of the system for five consecutive days. The figure shows that the efficiency of the system has direct relation with the mass flow rate. Low efficiency of the desalination system is associated with low mass flow rates and it is due to the fact that heat energy is significantly lost through the collector, when low mass flow rates are employed. The maximum rate of increase in efficiency is observed, when flow rate changes from 0.0030 to 0.0035 kg/s. At mass flow rate of 0.0040 kg/s, the efficiency of the system slightly decreases, as water flowing through the system does not achieve high temperature required for vapors formation. The maximum efficiency of the desalination system obtained was found to be 38%, when mass flow rate of 0.0035 kg/s was employed and the maximum FPC outlet temperature of 78 ^{o}C.

Water quality analysis

To evaluate the quality of the distillate produced from the solar still, water quality tests have been performed for samples of brackish feed water and output distillate from the system. The water quality tests have been performed in three different laboratories viz. water quality laboratory and environmental engineering laboratory at Faculty of Agricultural Engineering and Technology and Ayub Agricultural Research Institute Faisalabad. The water quality test results have also been compared with international standards. The water samples have been stored for 15 days and re-tested to validate its suitability for drinking applications. Table 2 shows the results of water quality analysis before and after desalination of brackish water. The results show that the TDS of the brackish water is reduced greatly from 1250 to 105 ppm, which fulfills drinking water quality standards as defined by World Health Organization (WHO). The results for other water quality parameters were also found satisfactory.

Table 2. Water quality analysis of brackish water before and after desalination process

Parameters	Before Desalination	After Desalination
TDS	1250	105
pH	6.92	6.1
EC	3.8	0.15
Ca	6.6	0.65
Mg	3.65	0.54
Na	27	0.47

CONCLUSION

Pakistan is facing severe water scarcity challenges and has lowest fresh water availability per capita in the region. Conventional methods of desalination are energy intensive processes in case of primary energy supply and are not economical in Pakistan. A dual acting (active and passive) solar still is developed and tested under local climatic conditions, while keeping in view the local needs of small households in remote areas of the country. The system comprises of a flat plate collector, evaporation chamber equipped with heat exchanger, 60 W_p solar PV panel and water pump for continuous circulation of hot water. The desalination system also works passively as the glass cover allow the radiation to pass through and the inner surface of the evaporation chamber is painted black, which increases the inside temperature of the chamber. The performance evaluation and water quality test has also been performed. The result shows that the fresh water production was found to be 3.8 l/m^2 in 8 hours a day, when the average solar radiation usually ranges from 750 to 800 Wm^{-2} with mean daily collection efficiency of 38%, which is an advanced value among related researches at mass flow rate of 0.0035 kg/s. The water flow rate has also direct relation on distillate production. The water quality tests show that EC, pH, TDS, Na^{1+}, Ca^{2+} and Mg was found to be 0.15 dsm^{-1}, 6.1, 105 ppm, 0.47, 0.65 and 0.54 respectively and are at par with International standards. The cost per liter of fresh water was calculated to be $0.03 which indicates the feasibility of this proposed system in the production of fresh water. It is concluded from the above results that the dual acting solar still can effectively be employed for desalination purposes especially in remote areas.

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Submitted: 24/08/2015
Revised: 11/02/2016
Accepted: 25/05/2016