Development and Evaluation of Solar Still With an Internal Heater

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ABSTRACT

A basin type –inverted V- transparent polyethylene cover solar still with an internal heater having an effective base area of $2m^2$ has been constructed and operated in Al-Zubair semi arid zone. The unit was scheduled to provide fresh water from groundwater having average total dissolved salts of 5000 ppm. An experimental study was carried out to evaluate the effect of using an internal heater on the performance of the still. The effects of climatic and continuous day and night modes have been investigated and the effects of these conditions on the production rate of distillate have also been presented. The results showed that combining an internal heater with basin type solar still caused a much higher yield than that of the simple solar still.

تطوير وتقييم اداء مقطر شمسي ذو مسخن داخلي

الخلاصة

تم تصميم و تصنيع مقطر شمسي حوضي بمساحة امتصاص مقدارها 2 متـر مربـع مغطـاة بشـكل مخروطي برقائق البولي اثيلين الشفافة، زود بمسخن داخلي بسيط لدراسة كفاءته في تحلية مياه تحتـوي علـى معدل املاح ذائبة يقارب الـ 5000 جزء بالمليون مأخوذة من ابار منطقة خور الزبير الشـبه قاحلـة. درس تأثير كل من شدة الاشعاع الشمسي والظروف الجوية المحيطة وتأثير انماط التشغيل المستمر (لـيلا" و نهـارا")على كفاءة وانتاجية المقطر الشمسي . بينت النتائج تحسن ملحوظ في انتاجية الماء المتقطر باستخدام المقطر ذو المسخن الداخلي مقارنة مع تلك المستحصلة من المقطر الشمسي البسيط.

LIST OF SYMBOLS

Ag: Absorptivity of transparent cover for radiation.(-)
Aw: Absorptivity of water to radiation.(-)
Cga: Heat capacity of transparent cover ,($kJ/m^2.K$)
Cwb: Heat capacity of basin water,($kJ/m^2.K$)
Fst: Still efficiency, (-)
Lh: Latent heat of evaporation, ($kJ/hr.m^2$)
Pw: Vapor pressure of water at temperature of water surface,(N/m^2)
Pwg: Vapor pressure of water at temperature of transparent cover,(N/m^2)
Qb: Heat flux by conduction from still base, ($kJ/hr.m^2$)
Qc: Heat flux by convection,($kJ/hr.m^2$)
Qe: Heat flux by evaporation,($kJ/hr.m^2$)
Qga : Heat loss from transparent cover,($kJ/hr.m^2$)
Qi: Solar energy input to the still, ($kJ/hr.m^2$)
Qr: Heat flux by radiation ,($kJ/hr.m^2$)
Qs: Solar radiation intensity, ($kJ/hr.m^2$)

Qt: Total energy input,(kJ/hr.m^2)
Ta: Ambient temperature, (K)
Tb: Temperature of the still base, (K)
Tg: Temperature of transparent cover,(K)
Tw: Water temperature,(K)
T: Transmissivity of transparent cover for radiation.(-)
Y: Still productivity,(kg/hr.m^2.)

INTRODUCTION

Water is a vital commodity. For those who live next to a water network it is taken for granted. However for those who reside in remote areas a great deal of effort and money are spent to supply fresh water to those regions. Some of Al-Zubair semi-arid zones; southeast Iraq (30-35 ^{0}N , 47.5-48 ^{0}E) ; are characterized by high levels of solar radiation and a shortage of fresh water. These regions, nevertheless, often have underground reservoirs of either brackish or salt water that may be used. The depletion of underground water resources in some areas has resulted in a scarcity of clean drinking water constituting a health hazard. In some areas, people are accustomed to drink slightly brackish water, which causes irritation of the digestive tract and skin disease, especially in children (Abdul-Fattah 1986). In semi- arid and arid regions, where the population is scattered in small communities, the solar stills may be the ideal source of fresh water and conversely, these zones may be the ideal consumers for solar stills (Kudish 1986).

Historically, instances of the application of solar energy to fresh water production have been recorded throughout the world at various times .Active investigations have been carried out in many countries ,Chile, USA, Greece, Algeria, Tunisia, India, etc. All of these programs were directed towards the development of large-scale basin-type solar installations. An excellent summary of these efforts have been reported by Malik et al (1982). They have described the design and performance of various solar stills. On the other hand, solar distillators had been the subject of great numbers of researchers during the last two decades. Direction of research had involved the improvement of the various elements constituting the still (Kanbour & Matloob 1985), increasing the energy efficiencies of solar desalination processes by maximizing the utilization of solar energy (Bohner 1989), or association of the conventional desalination processes with renewable energies in general and solar energy in particular (Kehal 2001).

In the case of brackish water, the uses of simple effect direct solar still would be convenient, this old application relying on a single basin still. This simple device is more cost effective and reliable for small capacities reaching tens liters a day. Such quantities would be suitable for small communities living in remote villages in arid and semi-arid zones generally without classical energy (Sadi & Kehal 2002). Furthermore, solar energy heats water to the pasteurization temperature to reduce the number of pathogens so that the water is safe to drink (Light & Watte 1996).

However, two important problems faced the application of solar energy in desalination. These are the low efficiency of energy conversion and the inefficient storage of energy. So most solar desalination processes are limited in capacity and work during certain hours in the day time. Many attempts had been made to improve the performance of solar stills (Malik et.al, 1982, Khalifa 1985), but little attention has been paid to the solar desalination in Iraq (Al-Asadi et al 2001). In order to increase the still daily productivity and to make it more efficient, an additional heat source is connected to the basin to supply the hot water during off-sunshine hours. This development make solar stills ideal for continuous fresh water production in remote arid zones when brackish water is plentiful but electricity is not available. In the present work a basin type –inverted V- solar still with a wick-type kerosene heater was constructed and operated in AI-Zubair semi-arid zone; and an investigation about its performance has been carried out.

THEORITICAL ASPECTS

The energy balance equations for the basin type solar still for several conditions can be expressed as follows (Khalifa 1985, Tiwari & Madhuri1987).

Solar input to the still may be evaluated by multiplying the solar radiation by the transmissivity of the still cover:

$$Qi = T\,Ag\,Qs \qquad (1)$$

Energy balance for basin water:

$$Qi = Qb + Cwb\,(Tb - Tw) \qquad (2)$$

Energy balance for glass cover:

$$Qe + Qc + Qr + Ag.Qs = Qga + Cga\,(Tg - Ta) \qquad (3)$$

Energy balances of the basin and cover assembly:

$$Ag.Qs + Qi = Qga + Qb + Cwb\,(Tw - Tg) + Cg\,(Tg - Ta) \qquad (4)$$

The predominant modes of heat transfer in a solar still are convection, evaporation and radiation, which could be approximated as that between two parallel planes (Khalifa 1985), using the following equations to describe these modes:

$$Qr = 18.371 * 10^{-8}\,(Tw^4 - Tg^4) \qquad (5)$$

$$Qc = 3.1824\,[(Tw - Tg) + (Pw - Pwg)Tw / (2.65 * 10^5 Pw)]^{0.3}(Tw - Tg) \qquad (6)$$

$$Qe = 16.276 * 10^{-3} * Qc\,(Pw - Pwg) / (Tw - Tg) \qquad (7)$$

The amount of distillate produced in the solar still depends primarily on the amount of the solar radiation available during the sunshine hours. In order to increase the daily yield further, basin water heating during the off-sunshine hours (night) is required. This is achieved by connecting an additional heat source to the basin of the solar still. The evaporative heat flux can be written as:

$$Qe = Y.Lh \qquad (8)$$

The ratio of the heat utilized for the evaporation of the water during the day to the total energy input to the still is known as the still efficiency:

$$Fst = Qe / Qt \qquad (9)$$

EXPERIMENTAL WORK

A schematic diagram of the cross section of the modified solar still designed and constructed locally is shown in Fig.1 This design includes a basin type –inverted V-polyethylene cover with a transparency of about 0.96. Polyethylene is used instead of glass for mainly cost, safety and ease of handling. The solar still having an effective base area of 1mx2m connected with a very simple wick type kerosene heater. It is worth mentioning that the internal heater consists simply of a number of kerosene burners wicks of cotton pieces installed on a horizontal galvanized plate, which need very little maintenance, if any. The wicks distributed along the lower surface of the basin and adjusted so that the basin water temperature does not exceed the boiling point. Water was supplied to the still via an adjustable float to provide and maintain the desired water level in the still.

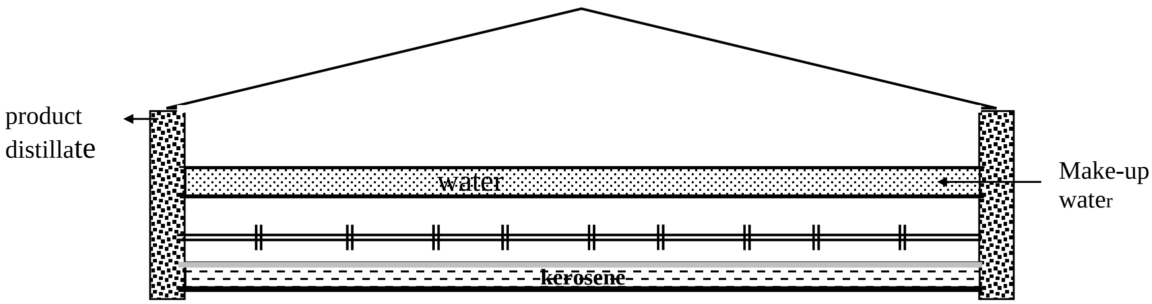

Fig. 1 schematic diagram of a basin – type solar still with internal heater

Productivity, and temperature of the water, cover and ambient were measured hourly during the continuous day and night operation. Wind velocity and solar radiation were continuously measured by a pyronmeter provided with an integrator.

RESULTS AND DISCUSSION

Basrah is considered one of the richest cities of the world in solar energy potential, it receives an average of solar energy radiation ranging between 7 kW/m^2.day in winter to 14 kW/m^2.day in summer for sunny days (Al-Asadi et al 2003). In order to have a graphical presentation of the experimental and analytical results, calculations for hot day (2/7/2002) and cold day (10/1/2003) have been carried out. In fact, a number of reading where taken over an extended period of time lasting over through almost one year, extending from July 2002 to February 2003. These readings have given similar behaviors, that is the main reason for not showing all these figures. Fig. 2 shows the variation of solar intensity along the day hours at the experiment site.

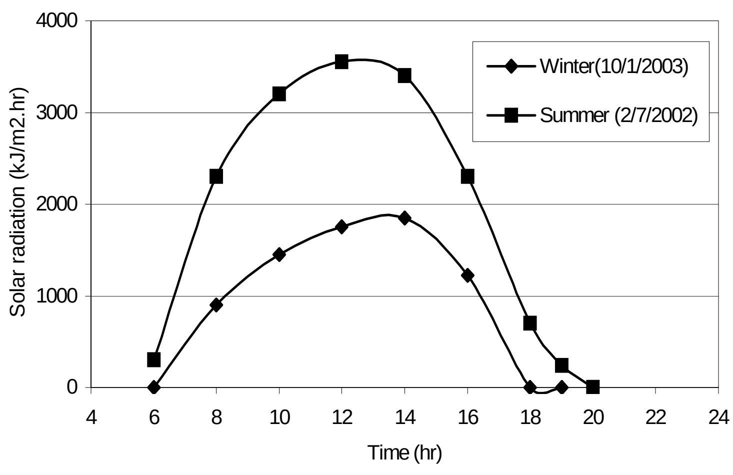

Fig. 2 Hourly variation of solar intensity at the city of Basrah

The hourly variation of ambient air temperature, cover temperature and water temperature in the basin during the continuous 24 hour operation, using a heater at the off-sunshine operation (Tw2), and water temperature in the basin without heater at the sunshine operation (Tw1) are shown in Figs. 3 and 4 .In addition to the main advantage of operating the unit efficiently during the night; the initial hot water temperature in the basin during the starting of the sunshine time operation remains high. Hence, an efficient evaporation process was continued and the yield increases in proportion to the increase in the initial water temperature.

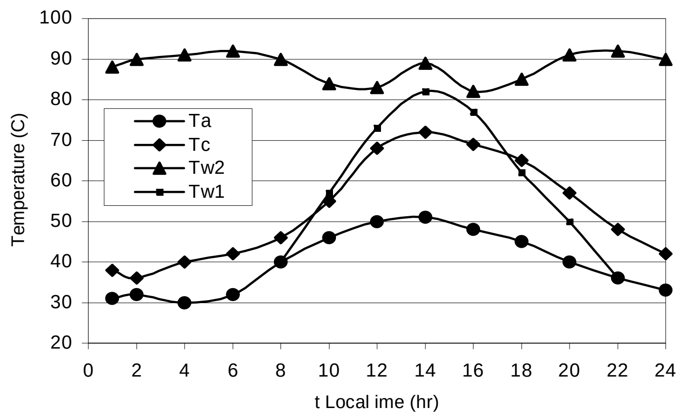

Fig. 3 The hourly variation of the system components temperature (2/7/2002).

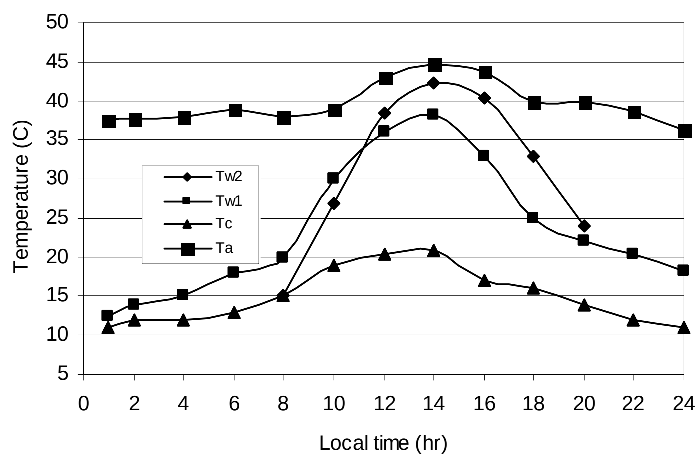

Fig.4 The hourly variation of system component temperatures (10/1/2003)

Energy balance over the still suggests that part of the solar input is used for the sensible heating of the water in the still. The remaining part is lost through convection and radiation from the still, which includes the recovered heat of evaporation of water via its condensation on the glass cover. The amounts of solar input to the still during the sunshine hours of a summer day (i.e 6 a.m – 8 p.m) ,the heat associated with the evaporation of water ,and the heat losses from the still components were calculated from the experimental measurements using equations 1-8. The results were plotted on Fig.5, while the same energy terms resulted from winter day measurements were shown in Fig. 6. In both figures, the area enclosed by the input heat and the heat losses represents the sensible heat effect. Prior to the time 1400 hour sensible heating occurs then followed by cooling. The sensible heat stored in the morning is utilized later for evaporation. This is in agreement with the previous experimental observations and theoretical simulations of Farid and Hamad (1991). During the off-sunshine operation the same trend has been achieved with a little increase in heat losses due the decrease in ambient night temperatures which enhance the heat transfer phenomena between system components and the surrounding.

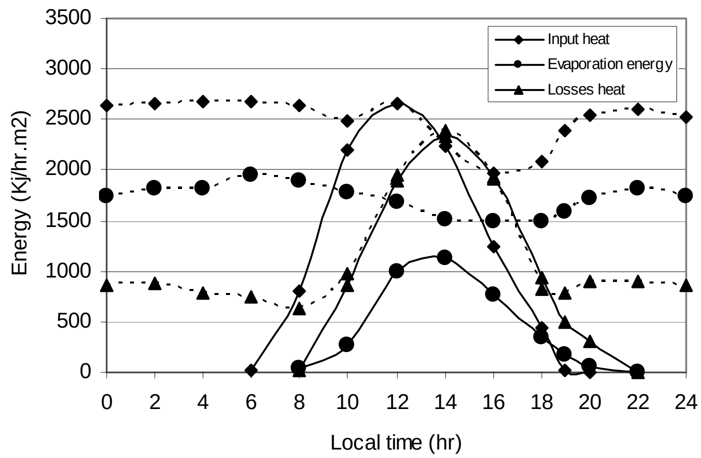

Fig. 5 Thermal performance of the still (19/7/2002)
(solid line=without heater ; dashed line= with heater)

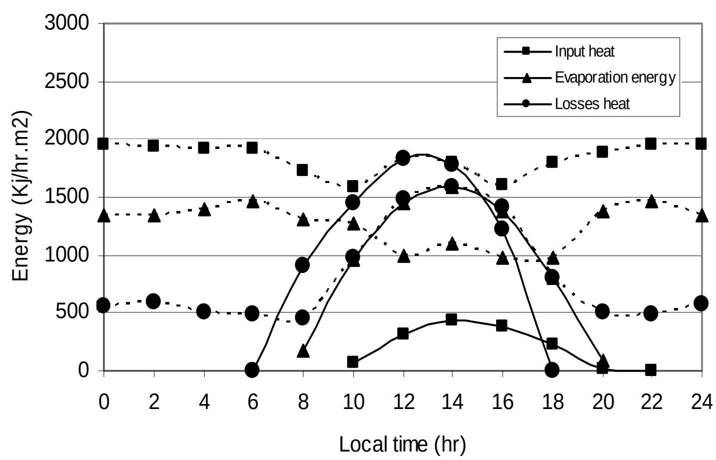

Fig. 6 Thermal performance of the still (16/1/2003)
(solid line =without heater ; dashed line=with heater)

Fig. 7 shows the effect of wind velocity on the still efficiency calculated using equation 9
for different climatic conditions. There is a significant decrease in efficiency with the increase of
wind velocity. Therefore, it has been suggested that the still must be placed in areas with the lowest wind velocity (Farid & Hamad 1991). Although the increasing of wind velocity decreases the cover temperature, the net effect of the heat loss by convection will increase since the increasing of wind velocity decreases the ambient temperature, which means more losses of heat from the still to the environment.

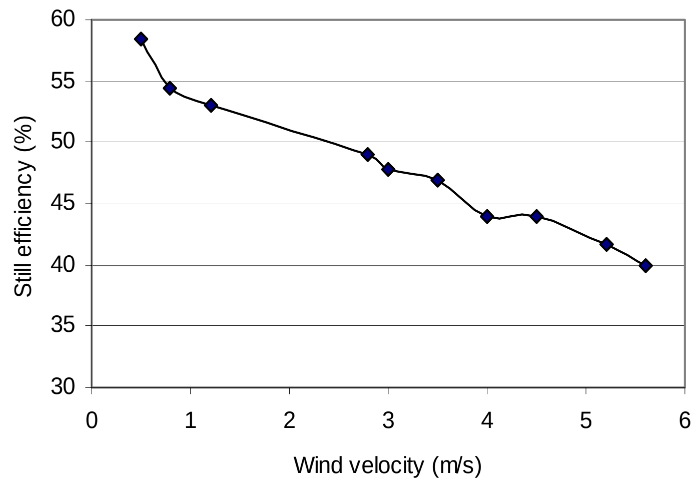

Fig. 7 Effect of wind velocity on still efficiency

The comparison of daily productivity of two different operation modes is presented in Figs. 8 and 9.Figure 8 presents the measurements for a summer day while figure 9 is for the winter day. As far as hourly productivity is concerned, the daily (24 hour) fresh water yield of the present work shows a superior improvement over that of the simple solar still, because the temperature between the basin water and the polyethylene cover has always been kept large.

The first dip in the curve shown in fig. (8) is mainly due to the fact that the burners are switch off during the morning period, while the second dip shown the beginning of lighting the wicks of the burners after the sunset.

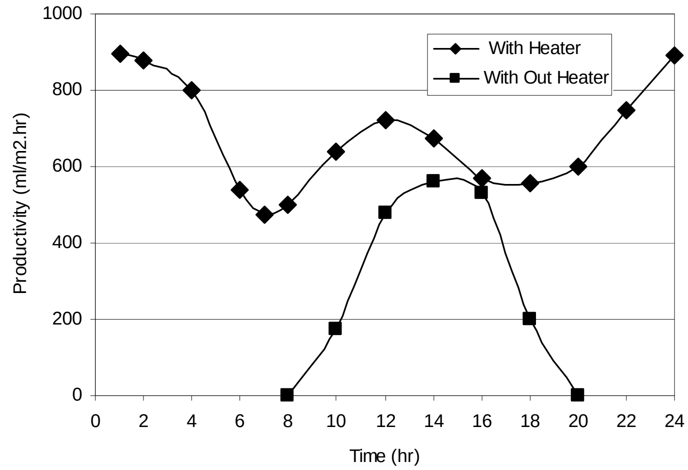

Fig. 8 Hourly production rate (2/7/2002).

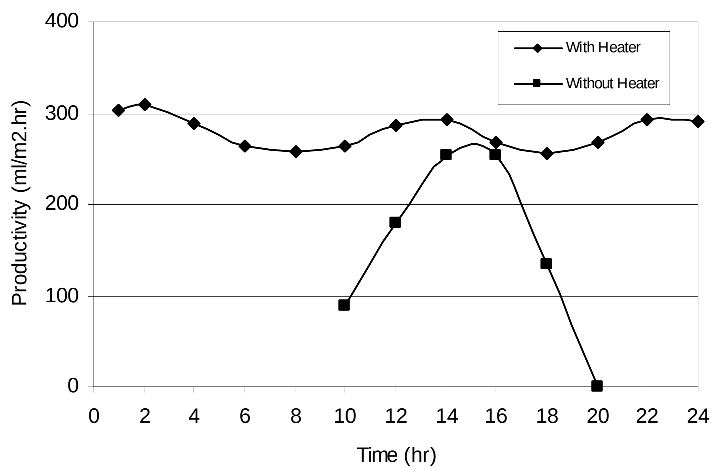

Fig. 9 Hourly production rate (10/1/2003)

CONCLUSIONS

On the basis of the results of this study, the following conclusions have been reached. Simple solar stills suffer the complete dependability on solar energy. This point showed that the heater assisted solar still is a good alternative for continuous fresh water production especially for small capacities. The simple operation of the present system which requires no high technology parts is acceptable and appropriate to the social structure in rural regions for producing potable water. The productivity and efficiency of the basin were increased by adding an internal heater. The still must be placed in areas with the lowest wind velocity since the wind velocity is an important parameter for basin –type solar stills.

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