Journal of Engineering Science 04(1), 2013, 1-9

JES
an International Journal

WATER DESALINATION USING BASIN TYPE SOLAR STILL

Kh. Md. Shafiul Islam*, Shuvo Ramo Saha, Md. Abu Jafor and Md. Abu Raihan

Department of Civil Engineering, Khulna University of Engineering &Technology, Khulna-9203, Bangladesh

Received: 01 September 2012 Accepted: 18 October 2012

ABSTRACT

In this study, two types of Basin Type Solar Still (BSS): conventional (CBSS) and stepped (SBSS), were designed, constructed and field experiments have been carried out at KUET since January 2008 to evaluate the production performances of the stills. The average daily productions are found as 3.97, 2.97 and 2.43 lit/m^2-day (1.86, 1.60 and 0.38 lit/day) for the SBSS, CBSS and Tubular Solar Still (TSS), respectively. Whereas, the production costs of water from the stills are calculated as 0.20, 0.26 and 0.39 Tk./lit for the SBSS, CBSS and TSS, respectively. The construction costs are estimated as Tk. 1400, 1500 and 80 per still for the SBSS, CBSS and TSS, respectively. The production cost of water for the SBSS is found 30 and 95% lower than CBSS and TSS, respectively. It is concluded that the SBSS is the most cost effective than other type of stills considering the economic point of view. As the construction, operation and maintenance of SBSS are easier; it can be used for drinking and other purposes in remote, coastal and arid areas or in an emergency to meet the small scale fresh water demand.

Keyword: *Basin type solar still (BSS), Conventional basin type still (CBSS), Stepped basin type still (SBSS), Solar distillation.*

1. INTRODUCTION

The scarcity of fresh water is increasing day by day in arid and remote areas of Bangladesh. In south western region of Bangladesh, shallow aquifers contain arsenic, exceeding the allowable limit for Bangladesh standard (0.05 mg/l) and highly saline water exists in deep aquifers. Salinity and arsenic in water poses a serious problem for the development of appropriate water supply system in such region. In these areas desalination techniques could be applied to meet fresh water demand produced from brackish or saline water. Most desalination techniques such as reverse osmosis, electro-dialysis, multi-stage flash etc. consume a huge amount of external energy e.g. fossil fuel/electricity. Therefore, finding methods of using renewable energy to power the desalination process is desirable. Solar distillation is a simple desalination technique in which only solar energy is needed. A basin type solar still (BSS) is the most popular method of solar distillation compared with others due to its simplicity. It could be one of the viable options for providing drinking water for a single house or a small community in arid, remote and coastal regions.

For better understanding the production mechanism and improve the performance of solar still, many researchers (Chaibi, 2000; Clark, 1990; Cooper, 1969; Dunkle, 1961; Hongfei *et al.,* 2002; Malik *et al.,* 1982; Shawaqfeh and Farid, 1995; Islam *et al*., 2007 and 2012) have conducted experimental and theoretical studies on different types of solar still. On the other hand, uses of water from underground and surface water sources are not always desirable or possible because of the presence of large amount of salts especially in coastal areas. Excessive salinity causes various health hazard and diseases in coastal region. In these areas, basin type solar still (BSS) could be a suitable technique for supplying potable water. The method will serve the community with fresh water reducing the harmful effect. In this study, two basin types solar stills: conventional basin solar still (CBSS) and stepped basin solar still (SBSS), were designed, constructed and field experiments have been carried out at the Department of Civil Engineering of Khulna University of Engineering & Technology (KUET), Bangladesh to improve the production performance of the stills since January 2008.

2. METHODOLOGY

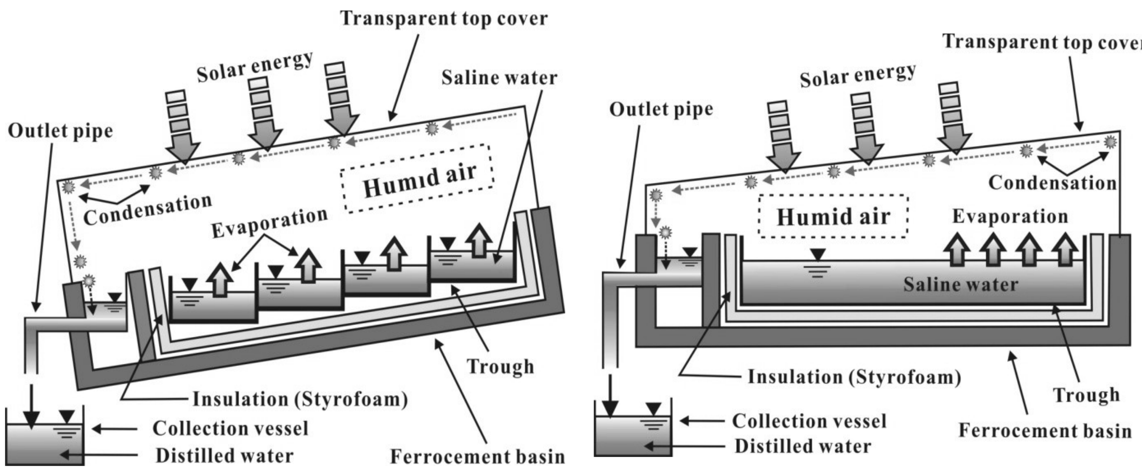
Two basin types solar still (conventional and stepped type), were designed and constructed using locally available materials. They consisted of rectangular ferrocement basin with a transparent glass cover on its top and all for sides and rectangular ferrocement trough(s) for storing saline water. Field experiments are conducted using the constructed stills. Daily distilled water production and hourly production of some typical days are recorded.

* Corresponding author : khmsislam@yahoo.com

Collected data was analyzed and correlations are proposed for daily output. Finally, the water production cost is estimated and conclusions are drawn.

3. PRODUCTION PRINCIPLE OF BASIN TYPE SOLAR STILL (BSS)

Production principle of BSS's is illustrated in Figure 1. The solar radiation, after transmission through a transparent glass cover, is mainly absorbed by saline water in the trough. The glass cover and trough absorb the remaining small amount of the solar energy. Thus the water in the trough is heated and then evaporation begins. Many types of heat transfer occur inside the glass and outside, e.g., evaporative heat transfer from the saline water to the humid air, condensative heat transfer from the humid air to the glass cover, convective heat transfer between the saline water and the humid air, the trough and the water, the trough and the humid air, the humid air and the cover and the glass cover and the atmosphere, radiative heat transfer between the water surface and the glass cover and the glass cover and the atmosphere. The evaporated water vapor is transferred to the humid air and then finally condensed on the top glass cover inner surface, releasing its latent heat of vaporization. The condensed water trickles down the bottom of the glass cover inner surface due to gravity and is stored in a collection bottle through a pipe provided at the lower end.



a) Stepped basin type still (SBSS) b) Conventional basin type still (CBSS)

Figure 1: Production principle of basin type still

4. MASS AND ENERGY BALANCE EQUATIONS

4.1 Assumptions

The mass and energy balance equations are made up on the following assumptions:

Heat and mass transfer in a BSS are formalized using the representative temperature of the saline water, humid air, trough and tubular cover and the relative humidity of the humid air.

Water vapor on the water surface is saturated.

There is no water vapor leakage across the still.

The absorption of the solar radiation in the humid air is negligibly small.

Figure 2 shows the mass and energy transfer of a BSS.

4.2 Mass Balance Equations

Saline Water in Trough:

The mass reduction of the saline water in a trough is prescribed by the evaporation from the saline water surface and the time rate of the mass reduction is written as:

$$\frac{dh_w}{dt} = -\frac{m_{evap}}{\rho_w} \tag{1}$$

where, h_w is the depth of water in trough (m), m_{evap} is the evaporation flux (kg/m^{2}s), ρ_w is the density of water (kg/m^3) and t is time (s).

Water Vapor in Humid Air:
The mass balance of water vapor in a BSS is prescribed by the evaporation from the saline water surface and the condensation on the inner cover surface and the time rate of the mass of water vapor can be expressed as the difference between the evaporation and the condensation, i.e,

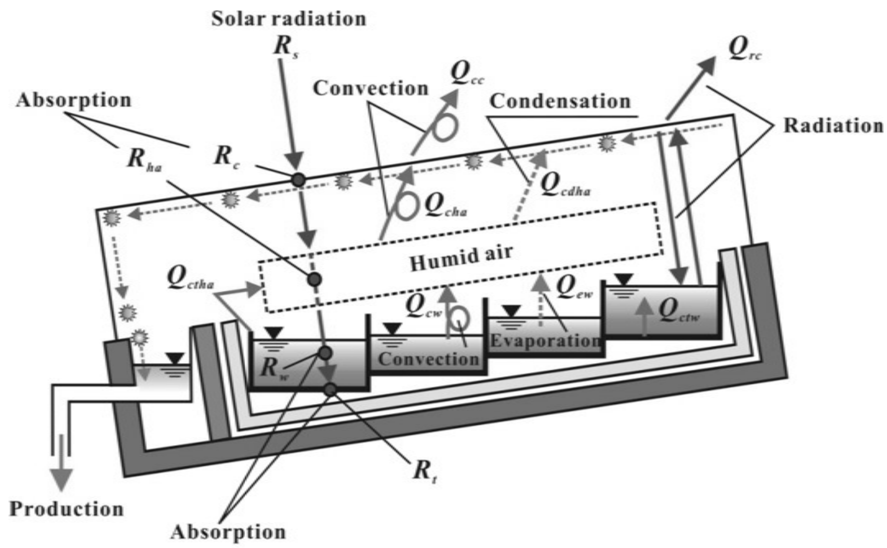


Figure 2: Mass and energy transfer of a basin type solar still

$$V_{ha}\frac{\partial \rho_{vha}}{\partial t} = A_w m_{evap} - A_c m_{cond} \tag{2}$$

where, V_{ha} is the volume of humid air (m^3), ρ_{vha} is the vapor density of the humid air (kg/m^3), A_c is the top condensation cover surface area (m^2), and m_{cond} is the condensation flux (kg/m^{2}s). m_{evap} and m_{cond} may be calculated from the following equations, respectively:

$$m_{evap} = h_{ew}(\rho_{vw} - \rho_{vha}) \tag{3}$$

$$m_{cond} = h_{cdha}(\rho_{vha} - \rho_{vc}) \tag{4}$$

where, h_{ew} is the evaporative mass transfer coefficient (m/s), h_{cdha} is the condensative mass transfer coefficient (m/s), ρ_{vw} is the vapor density on the saline water surface (kg/m^3) and ρ_{vc} is the vapor density on the condensation cover (kg/m^3).

4. 3 Energy Balance Equations

The energy balance equations of the BSS may be expressed according to the mass and energy transfer shown in Figure 2.

Saline water: $$(\rho C)_w \frac{\partial (V_w T_w)}{\partial t} = R_w + Q_{ctw} - Q_{ew} - Q_{cw} - Q_{rw} \tag{5}$$

Trough: $$(\rho CV)_t \frac{\partial T_t}{\partial t} = R_t - Q_{ctw} - Q_{ctha} \tag{6}$$

Humid air: $$(\rho CV)_{ha} \frac{\partial T_{ha}}{\partial t} = R_{ha} + Q_{ew} + Q_{cw} + Q_{ctha} - Q_{cha} - Q_{cdha} \tag{7}$$

Top cover: $$(\rho CV)_c \frac{\partial (T_c)}{\partial t} = R_c + Q_{cha} + Q_{cdha} + Q_{rw} - Q_{cc} - Q_{rc} \tag{8}$$

where,
$Q_{cc} \quad = \quad h_{cc}\,(T_c - T_a)\,A_c$

$$Q_{cdha} = Lh_{cdha} (\rho_{vha}-\rho_{vc}) A_c$$
$$Q_{cha} = h_{cha} (T_{ha}-T_c) A_c$$
$$Q_{ctha} = h_{ctha} (T_t-T_{ha}) A_{tha}$$
$$Q_{ctw} = h_{ctw}(T_t-T_w) A_{tw}$$
$$Q_{cw} = h_{cw} (T_w-T_{ha}) A_w$$
$$Q_{ew} = Lh_{ew} (\rho_{vw}-\rho_{vha}) A_w$$
$$Q_{rc} = h_{rc} (T_c-T_a) A_c$$
$$Q_{rw} = h_{rw} (T_w-T_c) A_w$$

in which,

A	:	area	(m^2)
A_{tha}	:	contact surface area between trough and humid air	(m^2)
A_{tw}	:	contact surface area between trough and water	(m^2)
C	:	specific heat capacity	(J/kg ^oC)
h_{cc}	:	convective heat transfer coefficient between cover and atmosphere	($W/m^2\ ^oC$)
h_{cdha}	:	condensative mass transfer coefficient from humid air to tubular cover	(m/s)
h_{cha}	:	convective heat transfer coefficient between humid air and tubular cover	($W/m^2\ ^oC$)
h_{ctha}	:	convective heat transfer coefficient between trough and humid air	($W/m^2\ ^oC$)
h_{ctw}	:	convective heat transfer coefficient between trough and water	($W/m^2\ ^oC$)
h_{cw}	:	convective heat transfer coefficient between water surface and humid air	($W/m^2\ ^oC$)
h_{ew}	:	evaporative mass transfer coefficient from water surface to humid air	(m/s)
h_{rc}	:	radiative heat transfer coefficient between tubular cover and atmosphere	($W/m^2\ ^oC$)
h_{rw}	:	radiative heat transfer coefficient between water surface and tubular cover	($W/m^2\ ^oC$)
L	:	latent heat of vaporization	(J/kg)
Q_{cc}	:	convective heat transferred between tubular cover and atmosphere	(J/s)
Q_{cdha}	:	condensative heat transferred from humid air to tubular cover	(J/s)
Q_{cha}	:	convective heat transferred between humid air and tubular cover	(J/s)
Q_{ctha}	:	convective heat transferred between trough and humid air	(J/s)
Q_{ctw}	:	convective heat transferred between trough and water	(J/s)
Q_{cw}	:	convective heat transferred between water surface and humid air	(J/s)
Q_{ew}	:	evaporative heat transferred from water surface and humid air	(J/s)
Q_{rc}	:	radiative heat transferred between tubular cover and atmosphere	(J/s)
Q_{rw}	:	radiative heat transferred between water surface and tubular cover	(J/s)
T	:	temperature	(^oC)
V	:	volume	(m^3)
ρ	:	density	(kg/m^3)

The subscripts *a*, *c*, *ha*, *t* and *w* denote atmosphere, cover, humid air, trough and saline water, respectively. For details of mass and energy balances of a still reader are referred to Islam *et al.* (2007).

5. DESIGN, CONSTRUCTION AND FIELD EXPERIMENT

5.1 Design and Construction of Basin Type Solar Stills

Two basin type solar still, conventional type treated as CBSS and stepped type treated as SBSS, were designed and constructed using locally available materials. Both stills are 100cm long, 70cm wide, 10cm deep and made of 2.5cm thick ferro-cement materials. All four sides and the top of basins are covered with 4mm thickness trasparent glass. The inclination of the top glasses is 10° with horizontal. The height of glasses in all four sides of the SBSS and the minimum height of glass downward side of the top glass cover of the CBSS are 6cm. A rectangular trough 90cm long, 60cm wide, 5cm deep and made of 2.5cm thick ferro-cement materials is placed inside the main basin for the CBSS. The trough for the SBSS is comprised of four sets of stepped rectangular tray of 90cm long, 13cm wide and 5cm deep. Inside surface and bottom of the main basin are insulated by styrofoam (known as cork sheet) of thickness 2.5cm to prevent the heat losses from inside the still. The distillated water is collected into a bottle everyday approximately two hours after the sunset. The distilled water collection bottle is put in insulation box in order to collect the amount of distilled water from the still accurately.

Figure 4: Photograph of field experiment carried out at KUET from 2008 to 2011.

In 2010, the basin was stepped and comprised of 86cm long, 66cm wide and 22cm deep as ferro-cement basin, which is covered with glass as a top cover only. The still had rectangular small basin 74cm long, 51cm wide and 5cm deep, which contained four black rectangular troughs of 70cm long, 10.5 cm wide and 5cm deep for storing saline water. In 2008, the basin was stepped and composed of rectangular basin and three sets of rectangular trough for storing saline water. The rectangular basin was 60cm long, 45cm wide and 8cm deep and made of

2.5cm thickness Ferro-cement materials. The trough was made of 0.25mm thick GI sheet 53cm long, 13cm wide, 4cm deep and painted black. Only the top of basin is covered with 4mm thickness transparent glass and no sides were covered by glasses.

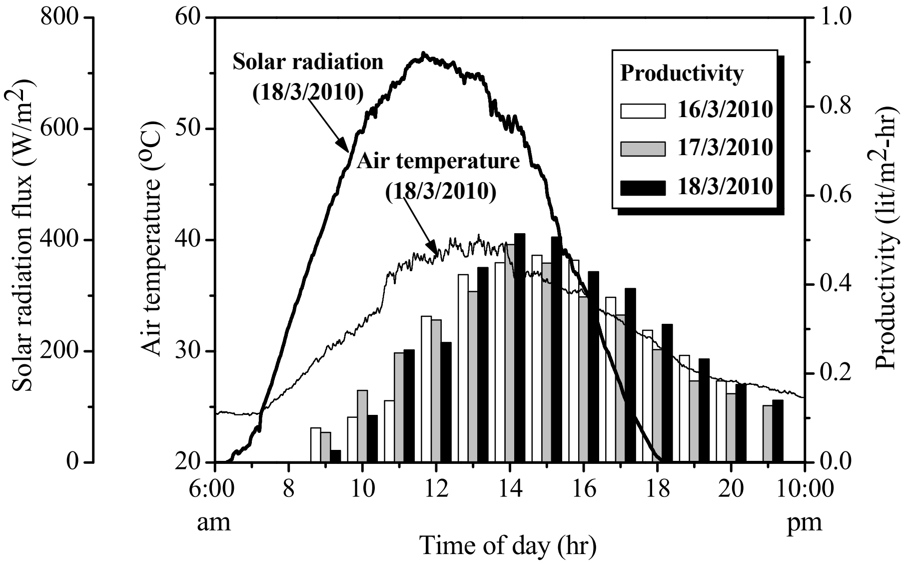


Figure 5: Observed diurnal variations of ambient air temperature, radiation flux and hourly production for the stepped BSS at KUET, Khulna from March 16 to 18 of 2010.

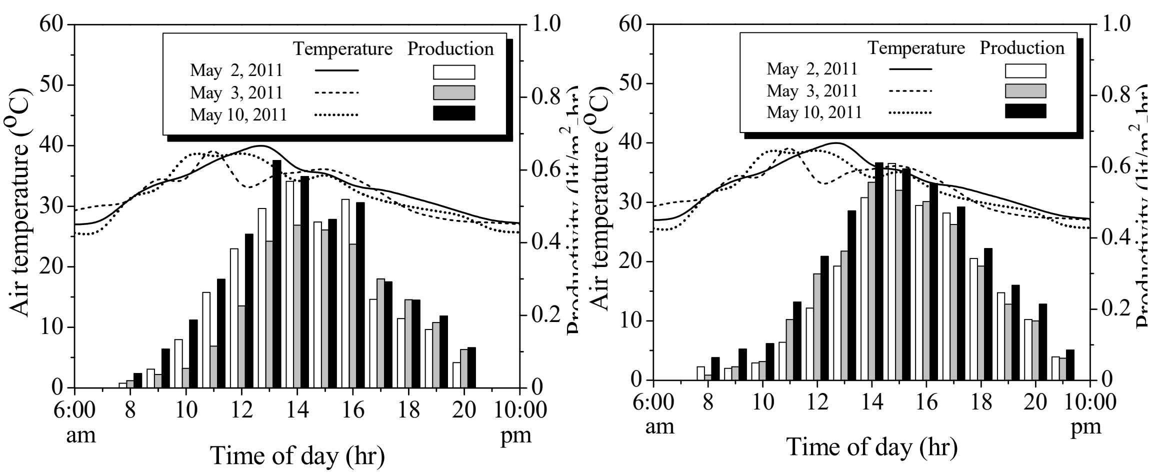


Figure 6: Variation of hourly production rate and ambient air temperature for May 02, 03 and 10 of 2011 for the conventional and stepped type still

5.2 Field Experiment

The field experiments on basin type solar stills have been carried out on the roof top of the Civil Engineering building of Khulna University of Engineering and Technology (KUET) since January 2008. Figure 3 shows the photograph of the field experiment. The vessel for distilled water collection was put in a wooden box covered (inside) with styrofoam (heat insulator) in order to collect the amount of distilled water from the BSS accurately. One end of the TSS was kept fixed and other end could open to clean the trough or to remove the accumulated brine and to feed the saline water in the trough. The daily output from the still is collected approximately two hours after sunset. The hourly output was also measured for some typical days. The hourly outputs were also measured in some typical days to observe the hourly variation of the productivity of the still. Solar radiation flux and ambient air temperature were also measured at one minute interval using a data logger. A pyranometer and thermocouple were used to measure the solar radiation flux and temperature, respectively.

6. ANALYSIS AND RESULTS

Hourly and daily distilled water output from the BSS are used to calculate the daily and hourly production rate per unit surface area of the saline water in the trough. Figure 4 shows the variations of hourly production rate (Kg/m²-hr) for three typical days, from March 16 to 18 of 2010 for the stepped BSS. In a particular day (March 18) solar radiation flux and air temperature are also shown. It is observed from the figure that the solar radiation flux and air temperature increased gradually in the morning till 12.00, then decrease in the afternoon. Whereas, the production was recorded from 9.00 in the morning, increased gradually up to 14.00 and then declined in the afternoon. It was also seen that the slope of the hourly production rate in the morning is steeper than that of the afternoon.

Figure 5(a) and (b) show the variation of hourly production rate and ambient air temperature for May 02, 03 and 10 of 2011 for the CBSS and SBSS, respectively. It is observed from the figure that the air temperature increases gradually in the morning, peak approximately 13.00 and then decreases in the afternoon. Whereas, the production recorded from 8.00 in the morning, increases gradually and peak between 14.00 to 15:00 and then decreases. It is also seen that the slope of hourly production rate in the morning is steeper than that of the afternoon. The daily productions for May 02, 03 and 10 of 2011 are found as 3.55, 2.96, 4.08 lit/m2-day (1.92, 1.60, 2.20 lit/day) and 3.66, 3.73, 4.48 lit/m^2-day (1.71, 1.75, 2.10 lit/day) for the CBSS and SBSS, respectively. The average daily productions for these 3 days are found as 3.53 lit/m^2-day (1.91 lit/day) and 3.96 lit/m^2-day (1.85 lit/day) for the CBSS and SBSS, respectively. Hence, the daily production is found 12.1% higher for the SBSS than CBSS.

Figure 6 shows the variations of the daily production for the conventional and stepped type BSS from January to May of 2011, 2010 and 2008. It is seen from the figure that the production rate for all cases increases gradually from January to May. The average daily production rates are found as 3.97, 3.56, 2.97 and 1.83 lit/m^2-day (1.86, 1.05, 1.60 and 0.38 lit/day) for the stepped 2011, stepped 2010, conventional 2011 and stepped 2008 basin type solar stills, respectively. It is seen from the figure that the output from the stepped type sill is higher than the conventional type. It is also clear that the production is increased after using the side walls as glass.

7. COST ESTIMATION

The construction cost of each SBSS and CBSS are found as Tk. 1400 and Tk. 1500, respectively (Table 1 and 2). The production cost of water from the still are estimated as 0.20 and 0.26 Tk./lit for the stepped and conventional BSS, respectively (Table 3). Table 4 shows the summary of the cost analysis of the different type of solar stills. Though the total cost including the initial cost of a Tubular Solar Still (TSS) (Islam et. al., 2012) is very low but the production cost of the water is higher than the BSS.

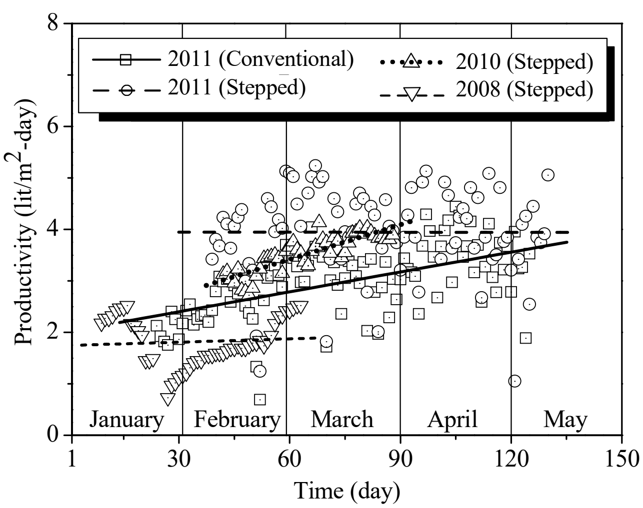


Figure 7: Variation of hourly production rate from January to May of 2008, 2010 and 2011 for the conventional and stepped type still

Table 1: Cost estimation for Stepped BSS (SBSS)

Sl. No.	Item Description	Unit	Rate (Tk.)	Quantity	Amount in Tk.	Item Description	Unit
1	Cement	kg	10	40	400	Cement	kg
2	Sand	m^3	1000	0.06	60	Sand	m^3
3	G.I. wire etc.	kg	75	2.5	188	G.I. wire etc.	kg
4	Transparent glass	m^2	420	1.1	462	Transparent glass	m^2
5	Cork sheet	--	160	1	160	Cork sheet	--
6	miscellaneous				130	miscellaneous	
							Total=1400

Table 2: Cost estimation for Conventional BSS (CBSS)

Sl. No.	Item Description	Unit	Rate (Tk.)	Quantity	Amount in Tk.
1	Cement	kg	10	35	350
2	Sand	m^3	1000	0.06	60
3	G.I. wire etc.	kg	75	2.5	188
4	Transparent glass	m^2	420	1.5	630
5	Cork sheet	--	160	1	160
6	Miscellaneous				112
				Total =	1500

Table 3: Production cost of water for Stepped and conventional BSS

Description	Stepped BSS	Conventional BSS
Design life of a BSS (years)	10	10
Construction cost of the Still including maintenance (Tk.)	1400	1500
Average production of water (lit/day)	1.86	1.60
Total production of water in the design life (lit)	= 1.86×10×365 = 6789	= 1.60×10×365 = 5840
Production cost of water (Tk./lit)	= 1400/6789 = 0.20	= 1500/5840 = 0.26

Table 4: Summary of cost analysis of different type of solar stills

Type of Still	Design life (years)	Initial cost (Tk.)	Total cost in design life (Tk.)	Average production of water (lit/m^2-day)	Production cost of water (Tk./lit)
SBSS	10	1400	1400	3.97	0.20
CBSS	10	1500	1500	2.97	0.26
TSS (not described here)	2	80	110	2.43	0.39

CBSS = Conventional basin type still, SBSS = Stepped basin type still and TSS = Tubular solar still

8. CONCLUSIONS

It is concluded that the production rate of water is higher for basin type solar stills. Though the construction cost of TSS is low but the water production cost is higher than BSS. Among basin type stills, water production cost in stepped type still is lower than conventional type. Considering economic point of view, it is clear that stepped BSS is cost effective than other type of stills. The production rate of a solar still mainly depends on the intensity of solar radiation, so the production rate will be higher in clear weather than rainy and foggy weather when sun light is absent. As the construction, operation and maintenance of stepped BSS is easier and can be constructed using locally available materials, so for drinking and other purposes in remote, coastal and arid areas or in an emergency due to natural disaster, it could be a better solution to meet the small scale fresh water demand.

REFERENCES

Chaibi, M.T.: Analysis by Simulation of A Solar Still Integrated in a Greenhouse Roof, Desalination, Vol. 128, 123-138, 2000.

Clark, J.A.: The Steady-State Performance of a Solar Still, Solar Energy, Vol 44, No. 1, 43-49, 1990.

Cooper, P. I.: Digital Simulation of Transient Solar Still Processes, Solar Energy, Vol. 12, 313-331, 1969.

Dunkle, R.V.: Solar Water Distillation: The Roof Type Still and A Multiple Effect Diffusion Still, Proc. Int. Heat Transfer, ASME, Part V, University of Colorado, 895-902, 1961.

Hongfei, Z., Xiaoyan, Z., Jing, Z. and Yuyuan, W.: A Group of Improved Heat and Mass Transfer Correlations in Solar Stills, Energy Conversion & Management, Vol. 43, 2469-2478, 2002.

Islam, K. M. S. and Fukuhara, T.: Productivity Analysis of a Tubular Solar Still, Journal of Hydraulic, Coastal and Environmental Engineering, Division B, JSCE, Vol. 63, No. 2, 108–119, 2007.

Islam, K. M. S., Rab, M. A., Saha, A. K., Khatun, H., Bokshi, A., Biswas, B. C. and Molla, R. A. (2012). Performance of Tubular Solar Still in Desalination: A Case Study, International Conference on Civil Engineering for Sustainable Development (ICCESD), 23-24 March, KUET, Khulna, Bangladesh.

Malik, M.A.S., Tiwari, G.N., Kumar, A. and Sodha, M.S.: Solar Distillation: A Practical Study of a Wide Range of Stills and their Optimum Design, Construction and Performance, Pergamon Press, Oxford, England, 11-13, 1982.

Shawaqfeh, A. T. and Farid, M. M.: New Development in the Theory of Heat and Mass Transfer in Solar Stills, Solar Energy, Vol. 55, No. 6, 527-535, 1995.