PLATE IN TUBE SOLAR DESALINATION TECHNIQUE: REVIEW AND PRACTICE

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ABSTRACT

In this research, an approach has been made to elaborately review the studies conducted on solar desalination, its current status in the world today and the prospectives that are still to come in the future. With the increasing water demand we are running out of available pure water sources day by day. As a last resort solar desalination techniques can be used to convert brakish and ocean water to ultra pure water through installation of very economical settings. The conventional desalination techniques like M.S.F, Multiple Effect, Reverse Osmosis, Vapor Compression, Ion Exchange, Electro Dialysis are expensive for the production of small amount of fresh water, also use of conventional energy sources has a negative impact on the environment. On the other hand solar distillation uses the never ending solar energy which has the potential for meeting and supplementing various energy requirements and also the installation and inspection does not require any expertise. In our subcontinent, the middle-east and in Africa where there is an average of 250 to 300 clear sunny days a year, thus it receives about 5000 trillion kWh of solar energy in a year and average of 4000 kWh/day/m^2. For such type of countries, solar desalination has been proved to be the most efficient and effective way to produce pure drinking water. Many successful attempts and researches have been conducted by different researchers to get the best model for the most efficient solar still. In this paper, an extensive discussion on the different techniques as published in current journals on solar desalination is done as well as a completely new, high efficient solar desalination technique is innovated and experimented which is incorporated with the application of "PLATE IN TUBE" technique. The mortar plate covered with composite cloth provides a vast area for evaporation and the cloth serves as the absorption media for water and heat. Finally the productivity and applicability of this specific type "PLATE IN TUBE" solar desalination technique will be discussed.

Keywords: *solar desalination, solar still, plate in tube technique, saline water, distilled water*

1. INTRODUCTION

Fresh water is an indispensable requirement for humanity and other living beings to continue their daily life in many countries of the world including Bangladesh. Fresh water demand of the people is largely increasing and this demand cannot be met by the natural existing water resources, since existing water resources are becoming scarce and insufficient. Also they are being polluted gradually with the discharge of large amount of sewage and industrial wastes. On the other hand many countries of the world are abundant in solar energy, sea water and underground brackish water. Therefore, it is possible to produce fresh water from sea or underground brackish water using solar energy economically. Consequently increasing of fresh water demand of the people can be solved partially by using solar desalination techniques. Historically, it was seen that solar desalination has been the most expensive way to produce drinking water at the commercial scale because of high capital and energy costs. However, desalination is increasingly recognized as a viable option due to the rapid increase in population. It is projected that close to 70% of the world population will face water shortage issues by 2025 and approximately 50% of the world's population lives within 200km of the coastline. Fresh water is a very important resource for our life. Its availability enhances the economy and quality of life of a country. Bangladesh is a tropical country with a hot and humid climate. In our country the people in the southern zone face a scarcity of drinking water due to increased salinity in the region. One of the major concerns in the third world at the present is to find new resources and new processes of providing cheap fresh water especially for people in remote areas.

Desalination systems use traditional fuels in many countries of the world and particularly in the middle- east and the gulf-states where water resources are very scarce. Solar desalination technique can gain more momentum and solve the water deficiency problem in this region due to the abundance of solar energy. Previously it was thought that solar desalination for producing drinking water could not compete economically with other methods of desalination. However, the increase in the cost of energy and the appearance of environmental pollution problems have created renewed interest in solar distillation. Various kinds of stills have been discussed and studied since the 1960's. In this paper we are going to review various types of experimental works on solar desalination published in different journals, thereby suggesting a new technique "Plate In Tube Technique" in this field.

2. REVIEW

Solar desalination has a quite long history in its back. Application of this technique helps the general people to collect drinking water in the problematic area where there is a scarcity of fresh water. This technique has always been a fact of interest of the researchers. Many researches had been carried out in this field and many more new aspects are to be considered. Abdel-Monem and Bassouni (1993) studied on the different factors that affect the desalination process. Desalination being very economic when done in the presence of solar energy as no pollution occurs, has no movable parts, is simple and flexible to produce significant amount of fresh water. There are many factors that affect desalination such as intensity of solar radiation, material of the still sides, fitting of fins on the back sides and providing glass tubes. These factors were studied more or less. The stills made of glass are more productive than the stills made from galvanized iron and fins. From their study they found that the productivity can be increased by increasing the condensing area. Tiwari et al. (2003) made a study on the future perspectives of solar desalination including the classification of this system. Solar distillation systems are classified as passive and active solar stills. In the case of active solar stills, an extra-thermal energy by external mode is fed into the basin for faster evaporation. In the passive solar stills no external mode is used. Also different types of solar stills are available like Conventional Solar Stills, Single-Slope Solar Still with Passive Condenser, Double Condensing Chamber Solar Still, Vertical Solar Still, Conical Solar Still, Inverted-Absorber Solar Still. A study was conducted on FRP multi-wick solar still. To increase the output it was suggested to reduce bottom loss coefficient, reduce water depth in basin/multi-wick solar-still.

Arunkumar et al. (2012) performed an experimental study on seven solar still designs. All the solar stills were constructed and analyzed under same atmospheric condition. From the study the productivity of spherical solar still is about 2300 ml/m^2/day. This type of still provides more contact surface than single slope solar still. The average daily production of double basin glass solar still is about 2900 ml/m^2/day and this type of still is more effective during night. The hemispherical solar still produces more distillate than many other stills because of its larger contact surface. According to them the tubular solar still coupled with pyramid solar still is the best with the production rate of 6928 ml/m^2/day. Al-Karaghouli and Minasian (1995) proposed a new type of floating wick solar still. This type of solar still is based on the good capillarity of jute wick. The blackened jute wicks are floated with a polystyrene sheet. The productivity averages 5103ml/m^2/day with a peak of 6250 ml/m^2/day. The use of jute wick increases the productivity almost 77% compared to a basin type solar still. Different wick type solar stills are effectively studied and compared by Manikandon et al. (2012). In the study they found that the floating wick type solar still by Al-Karaghouli and Minasian provided the maximum distillate with an optimum flow rate of 1.5 m/s. As an absorber medium in the basin, jute wick and charcoal wick, cotton cloth and floating polystyrene plate were used that affects the productivity of the still. Other solar stills were also compared on the basis of still type, geometry, results, advantages and their disadvantages during practical observations.

Kumar and Anand (1992) proposed a new tubular multi-wick solar still and compared its performance with simple multi-wick and tubular solar still. The proposed system was able to produce distillate about 8% more than tubular solar still and 13% more than the conventional basin type solar still. This is because of the use of some additional features-the use of black coloured jute cloth as the absorbent of solar radiation, the curvature of the upper half of the glass cover provides a larger condensing area. Zurigata and Abu-Arabi (2001) performed a study on performance analysis of a solar desalination unit with double-glass cover cooling. The experiment was conducted on single basin solar still by flowing water between a double glass glazing. The result shows that the efficiency of the double-glass desalination unit increased by over 25% compared with the conventional single-basin single-glass solar still. According to Bhattacharyya (2013) the "Capillary Still" is the most promising among the newly invented solar stills. In this still the evaporation rate is made faster by using a thin fabric and this still is very useful in rural areas.

Ranjanl and Kaushik (2013) analyzed the reasons for low energy efficiency of a still. According to them the largest single heat loss is the radiation loss from the saline water surfaces. The techno-economic analysis was also reviewed. The passive solar still saves ~2.625 KWH electricity in place of using RO system. It is equivalent to 2.57x10^3 tonne of CO_2.From the study it can be said that desalination by solar energy in no doubt is feasible in terms of renewable energy.Tanaka et al., (2002) proposed a new type of solar still and its performance is greatly enhanced by narrowing diffusion gaps in between the partitions. The use of 10mm diffusion gap decreases the productivity by 10% and the use of 5mm gap decreases the productivity by 40%. Consequently, the productivity of the 5mm gap can be increased by sandwiching nine small spacers in every diffusion gap. The still with 5mm gap with 11 partitions/spacers has a production of 14.8-18.7 kg/d. A different type of experiment was carried out by Zeraoul et al., (2011) in the region of Ouargla(Algeria). They tried to enhance the efficiency of the solar still by two different techniques. The first one include the cooling of condenser by flowing water on the north glass cover throughout the run and in the second one incorporated the use of the intermittent shading procedure of the north glass cover. The yield of the double slope simple solar still increased around 11.82% when cooling its north glass cover by flowing water but in case of the intermittent shadow procedure the increment in the yield was only 2.94%. The fact behind this result is the temperature difference between the water and the north glass cover which is higher for the first series experiment.

Sebaii et al., (2008) carried out an investigation to improve the daily productivity of-a single effect solar stills, a single- slope single- basin solar stills integrated with a shallow solar pond(SSP) was studied to perform solar distillation at a relatively higher temperature. The optimum values of the flowing water thickness and the mass flow rate for this typical configuration of the SSP-active solar still were obtained as 0.03 and 0.0009kg/s. The annual average values of the daily productivity and efficiency of the still with the SSP were found to be higher than those obtained without the SSP by 52.36% and 43.80% respectively.Li et al., (2013) reviewed the current solar desalination research activities first, followed by discussions of solar assisted desalination processes and a variety of possible combinations. Solar assisted desalination has been proved technically feasible, however the combined solar and fossil fuel desalination and desalination using low grade waste heat could be more cost effective at this time. Though solar assisted desalination processes have not been commercialized yet, with the current ongoing research, they remain a valid option for future desalination plants.

Abdallah and Badran (2008) found out that the use of sun tracking system instead of a fixed solar still to improve the performance of the traditional fixed single slope solar system by 22%. A computerized sun tracking device was used for rotating the solar still with the movement of the sun.Al Hinai et al., (2002) proposed two mathematical models which had been used to compare the productivity of single-effect and double-effect solar still under similar climatic, operational and design parameters. The shallow water basin that was used for the experiment with a cover tilt angle of 23^0, insulation thickness of 0.1m and asphalt coating, were found to be optimum design parameters for both solar stills. The optimum design conditions tend to give an average annual solar still yield of 4.15 kg/sq m/d for the single-effect solar still and 6.1 kg/ sq m/d for the double-effect solar still. A simple cost analysis indicated that, the unit cost for distilled water produced using a single effect solar still is $74/1000 gallons(16.3 $/cubic m) and for a double effect solar still is $62.4/1000 gallons (13.7$/cubic m).Voropoulos et al., (2001) carried out a series of tests and investigated the operation of a solar distillation system coupled with a storage tank. It was seen that the productivity of the coupled system is almost double from that of the still-only system. In his experiment, the continuous heating of basin water from tank water results in higher production rates in all operation periods as a result of significantly higher differences between water and cover temperatures mainly at night. Raising the temperature of the water in the still basin is proven to be one of the most efficient ways to greatly increase the productivity of the solar still. Moreover this technique makes the still a hybrid one capable of supplying hot water as well.

Rahim (2001) carried out an experiment over a period of three years and he drew conclusions from results obtained from this experiment to improve the efficiency of the basin type solar desalination still. He used separate units for evaporation and condensation and used' Force condensing system' to evaporate the water in a separate unit under controlled conditions. Since in this process 'Force condensing system' sucks the water vapour from the evaporation zone and condenses it in a separate unit thus not allowing it to condense on the inner glass roof surface resulting in a more transparent glass top cover. Since this method doesn't rely on convection, it produces more potable water. Also since the evaporator and condenser are kept separately, the temperature difference can be controlled independently to relatively large amounts during the day and hence more productivity can be assured. Moreover as the potable water is collected in the condenser unit which is at lower temperature than evaporator, the re-evaporation of the condensed potable water is eliminated.

Zhang et al., (2003) proposed a special type of solar desalination system .This system shows higher desalination rate (18 kg/day) than other still, therefore it has a good prospect .In this system a considerable amount of latent and sensible heat is successfully recycled and utilized for preheating the brine and recycling the air by the use of condensation cavity and heat exchangers. This system runs better at high temperature. The starting temperature affects the system to a considerable extent so the temperature is increased above 70^0C. The development of this thermal performance is due to the falling film evaporation technology. The variation of the distilled yield with the solar radiation intensity, variation of operating temperature with time, the daily efficiency, the mass transfer analysis and the error analysis regarding the data are briefly analysed and discussed.

From the above discussion it is clear that solar desalination is an ancient practice and many researches had been made to make it more efficient. This section summarizes and presents the investigations carried out:

- The factors such as intensity of solar radiation, material of the still sides, fitting of fins on the back sides, providing glass tubes etc affects the productivity significantly.
- By reducing the bottom loss coefficient, lowering water depth in the basin, using solar still made of galvanized iron, jute wick, cotton cloth, polystyrene sheet, narrowing the diffusion gaps the productivity of the still can be enhanced.
- From an experiment it is proved that the largest heat loss is the radiation loss from the saline water surface.
- The concepts of ‘Capillary Still’, ‘Double Glass Cover Cooling’, ‘Cooling of Condenser and Intermittent Shedding’, ‘Sun Tracking System’, ‘Desalination using Storage Tank’, ‘Force Condensing System in Solar Desalination’ have been revealed.
- The combination of solar and fossil fuel desalination system and desalination using low grade waste heat can be much more effective in terms of productivity and applicability.

Considering the above factors of different studies the following effective method is designed for this current research.

3. METHODS AND MATERIALS

In this experiment we used two types of solar still. One is the traditional basin type solar still with some modifications and another is a newly proposed technique “Plate in Tube Solar still”. Both of them differ in construction materials though they run on the same basic principle. The materials used, construction method and the data collection system of both the still is given below.

3.1 Basin Type Solar Still

This type of solar still consists of a wooden basin of 1m x 1m x 0.127m with a wooden frame of inverted “V” shape (Figure 1). The inverted “V” shaped wooden frame is covered with Transparent Polyethylene Sheet (TSP) to provide the area for water to condensate. The bottom of the basin is cover with black painted impermeable paper. An stainless steel channel is used to collect the water. Two ducts are made at the side wall and at the bottom base as the inlet provision and to drain out the stagnant brackish water.

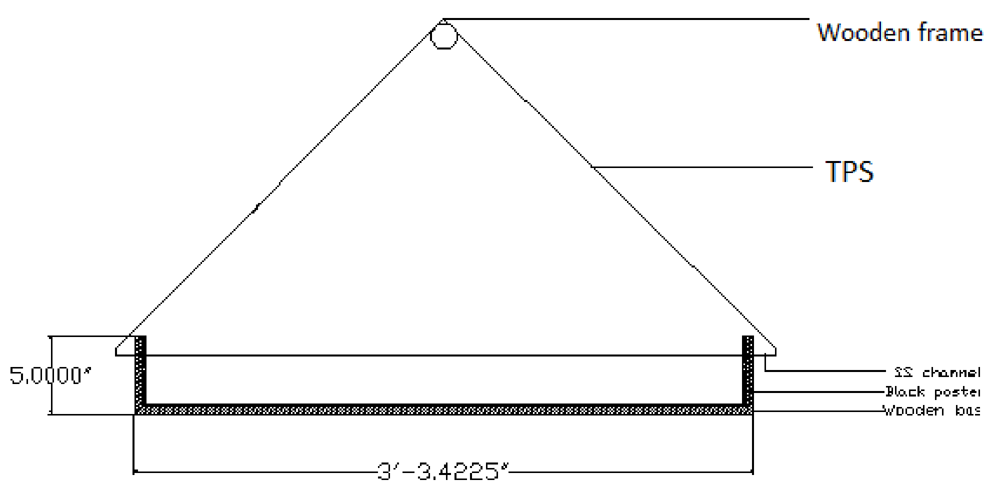

Figure 1: Cross-section of Basin Type Solar Still

The water is entered into the basin through the inlet pipe. The height of the water layer is usually kept around 5cm. The basin is heated up as the solar intensity increases. The bottom portion of the basin gains more solar energy, thereby heated more than the cover. This difference in temperature initiated the evaporation-condensation process. Water in the form of droplets are received through the channel and then collected at the collection tube. There are two small holes on both sides of the TPS through which a digital thermometer is inserted to take the temperature reading. The thermometer is usually held for about 1 minute to take the reading. The ambient temperature is taken by simply holding the thermometer just outside the solar still.

3.2 Plate In Tube Type Solar Still

This type of solar still is a set of six units with same characteristics and materials. The single unit consists of a tube which is of six inch diameter and made from Hard Transparent Plastic Sheets (HTPS) as shown in Figure2.There is a stainless steel tray which is situated inside the tube to hold a vertical mortar plate. The mortar plate covered with composite cloth made of soft cotton cloth and jeans cloth is the interesting part of this still. The mortar plate is made by using ferro-cement. It is 36 inch in length, 0.75 inch in width and 4 inch in height. The open sides of the tube are made airtight by using cork-sheet and plastic composite cap. Provisions for inlet and outlet are also provided. A tilt angle of 20^0 is provided to all tubes for free flowing of water through the outlet.

The mortar plate covered with the composite cloth provides a vast area for evaporation and the composite cloth acts as the absorption media for water and heat. This arrangement could provide high temperature difference between the plate and cover tube, which ultimately increase the productivity. Raw water is fed through the inlet pipe and after condensation distilled water is collected in the collection pot. There is a small hole on the cover tube through which a digital thermometer is inserted to take the reading. The hole is then sealed carefully to remain the tube airtight.

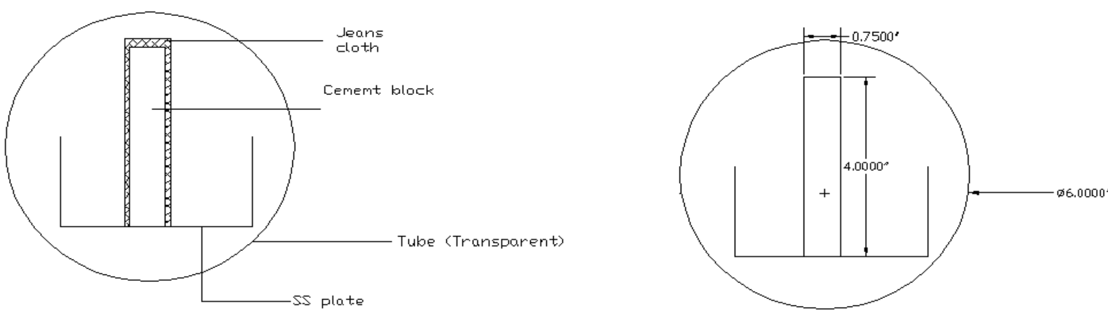

Figure 2: Cross section of Plate in Tube Solar Desalination Technique (Single Unit)

4. RESULTS AND DISCUSSION

The production rate of both types of still for seven days based on distillate production area are shown in Table 1. It is clear that the 'Plate in Tube' technique has more productivity compared to the traditional basin type. It is seen that the average productivity for the 'Plate in Tube' technique is 6.46 l/m^2 with the peak of 6.76 l/m^2.

Table 1: Production of Basin Type and Plate in Tube type Solar Still

Days	**Basin (l /m/day^2)**	**Plate In Tube (l/m^2/day)**
1	1.26	6.40
2	1.44	6.68
3	1.17	6.27
4	1.52	6.42
5	1.39	6.39
6	1.28	6.30
7	1.32	6.76

Table 2: Temperature reading of Basin type solar still on a typical day in ^{0}C

Time of the day	Ambient Temperature T_a	Temperature inside Basin Ti	Temperature of Water T_w
8	22.6	23.4	25.6
9	23.2	26.1	29
10	28.9	29.4	31.6
11	32.7	35.3	39.4
12	37	38.3	40.9
13	38.4	40.2	44.1
14	38.6	41.1	45.7
15	35.2	39.7	42.1
16	32	34	37.5

Table 3: Temperature reading of single unit of Plate in Tube type solar still on a typical day in ^{0}C

Time of the day	Ambient temperature (Ta)	Temperature inside tube (Tb)	Temperature of cement block (Tc)
8	22.6	24.6	32.7
9	23.2	31.3	39.4
10	28.9	30.9	39
11	32.7	33.9	44.7
12	37	39.8	59.3
13	38.4	42.1	64.6
14	38.6	44.8	67.5
15	35.2	45.2	64
16	32	43.1	63.8

The temperature profiles of Basin type and Plate in Tube type solar still on a typical day are given in Figure 3 & 4. Hourly temperature readings were taken from morning 8:00.

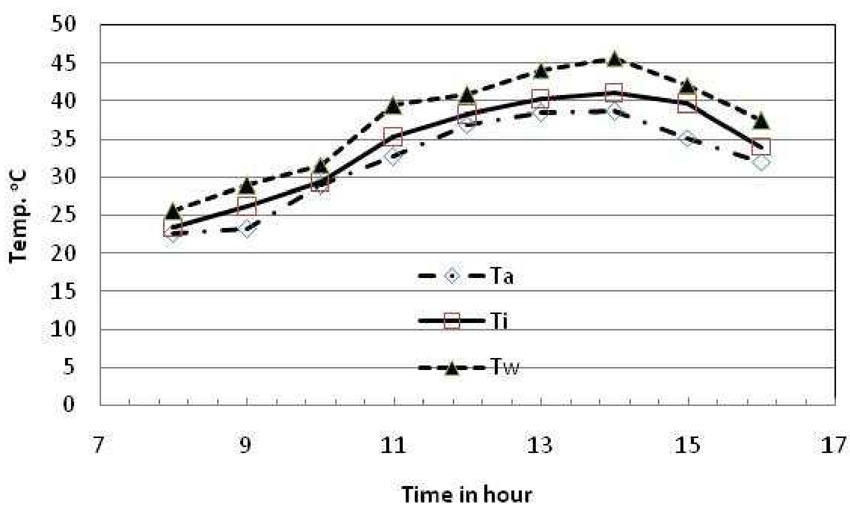

Figure 3: Temperature variation in basin type solar still on a typical day

The ambient temperature is designated by T_a whereas in Figure 3 temperature inside the basin is designated by T_i and temperature of water by T_w and in Figure 4 temperature inside the tube and temperature in cement block are designated by T_b and T_c

The highest temperature of T_i is 45^{0}C and the highest temperature difference between T_i and T_w is 5^{0}C as shown in Figure 3. For the working days the ambient hourly temperature also varies at the mid-day.

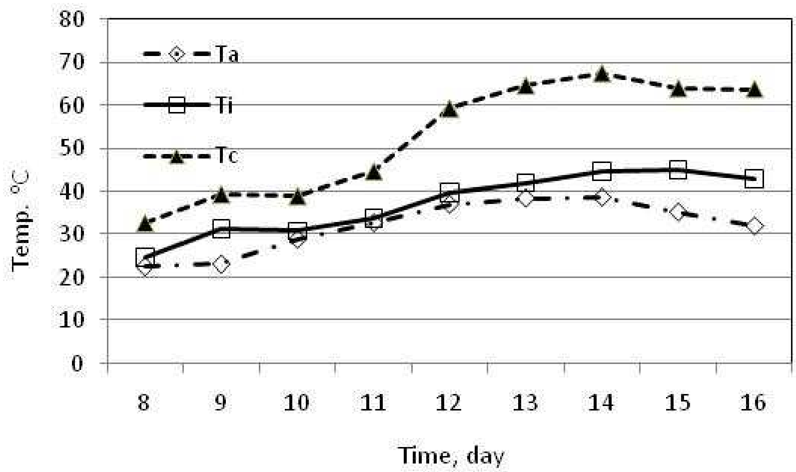

Figure 4: Temperature variation in Plate in Tube solar still on a typical day

Figure 4 shows the average temperature profile of six tubes. It can be seen that the highest average temperature of T_c is 67.5 and the highest temperature difference between T_b and T_c is 22.7^{0}C. This can also be noticed that the temperature difference is more in Plate in Tube type solar still by 7.1^{0}C comparing with basin type. This is because of the use of black jeans cloth, cotton cloth and the cement mortar plate which altogether act as a heat reservoir. The heat that is stored in the cement mortar plate is transmitted to the cloths thereby increasing the temperature to a level that cannot be reached in the basin. Though both of the set up covers almost equal amount of base area which is 1 m^2, the Plate in Tube technique is superior to Basin type because of its larger evaporation area. The stainless steel tray along with the cement-mortar plate provides a vast area for evaporation of the brackish water. The Plate in Tube technique also can desalinate brackish water during night because of its unique setup. These are the facts why the desalination-rate more in ‘Plate in Tube Solar Still’ than the conventional ‘Basin Type Solar Still’.

5. ENGINEERING SIGNIFICANCE

The Plate in Tube technique is a unique concept in the sense that the use of the cement-mortar plate covered with composite cloth as a heat absorver and enlarged area for evaporation. It is a matter of concern that whether this technique will be efficient in terms of productivity, cost and applicability.

The productivity of this still is almost 6.52 l/m^2/day considering the evaporation area. The spherical solar still, the double basin glass type solar still, hemispherical solar still, tubular solar still coupled with pyramid solar still have the productivity of 2.30, 2.90, 3.569, and 6.928 l/m^2/day respectively (Arunkumar et al., 2012). Comparing with these stills the productivity of ‘Plate in Tube Solar Still’ is considerably higher except for one case, that is tubular solar still coupled with pyramid solar still although in terms of cost the plate in tube type still is much less costly. The floating wick type (jute) still has the productivity of 5.103 l/m^2/day (Al-Karaghouli and Minasian, 2002) which also less than our proposed one. Therefore considering the productivity the Plate in Tube technique is very effective. Regarding the cost, each unit will cost around 400 Taka. The cost breakdown is somewhat like Table 4.

In a country like Bangladesh where most the people especially in the coastal region live below the poverty line, they never want to spend more for their pure drinking water. Even in some coastal areas people used to drink saline water. This new technique can be effective in these regions as the cost of installation is much cheap and the productivity is considerably good and the local people can make this with little training. If properly installed and operated this technique can be part of everyday's life for these poor people. Moreover there are many scopes to improve its productivity by further research. Like Bangladesh, this technique has the potential to flourish in other countries also.

Table 4: Cost Breakdown of single unit of 'Plate in Tube' Solar Still in Taka

Parts of Installation	Cost in Taka
Tube(HTPS0	20
S.S Tray	250
Cement Plate	70
Composite cloth(Jeans and Cotton)	25
Closing Caps(Cork Sheet)	10
Glue	20
Total	395

6. CONCLUSIONS

In these times, the demand of fresh water is increasing day by day especially in the coastal region. The direct use of solar energy to desalinate brackish water demonstrates a competitive chance to offer a secure source of drinkable water. Within this context, the 'Plate in Tube' solar desalination still was built and studied. The installation is simple, cost effective, environment friendly and most importantly there is no requirement of fuel. It can be summarized that:

- The average productivity of the still is 6.46 l/m^2/day with a peak production rate of 6.76 l/m^2/day.
- The use of cement mortar plate covered with composite cloth provides a vast area for evaporation which ultimately increases the productivity as compared to other still as their productivity ranged in between 2.3 - 3.6 l/m^2 /day.
- The temperature difference inside the tube is considerably high ranging from almost 13^0C to 25^0C is prerequisite of higher production rate.

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