SOLAR DESALINATION PLANTS FOR FAMILIES LIVING IN COASTAL AREAS

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ABSTRACT

The main hindrance in the development of an appropriate water supply system for communities in coastal area is that deep aquifers containing sweet water are not found at all possible locations in those areas. In Bangladesh 19 out of 64 districts are in proximity to the Bay of Bengal. Although various desalination technologies are practiced all over the world, the traditional methods of desalination are energy intensive and expensive. Those techniques, if adopted, would become an extra burden for low-income families. Solar energy is free of cost and abundant in nature. The technology involved in distillation of saline water using solar energy is relatively simple and maintenance can be carried out by semi-skilled and unskilled operators. Moreover, rural communities are settled at widely spaced intervals; hence, a centrally operated treatment plant would become costly in terms of supply pipes, etc. Therefore, this study attempts to develop a family-size solar desalination plant. Plant operation was performed for four months to observe the output quality and quantity of a solar desalination unit. The study also includes the steps and cost involved in constructing the solar still. A solar desalination unit makes use of renewable energy and hence offers a green solution to the water scarcity problem. Locally available and cheap materials were used to construct the solar still. Hence, low cost and sustainability are the key points of the current study.

KEYWORDS: *Solar energy; coastal area; desalination plant; cost effectiveness; sustainability*

1.0 INTRODUCTION

The planet's water reserve is gigantic, covering more than 70% of the Earth's surface. Yet obtaining potable water is often a big challenge because the water is very unequally distributed. About 97% of all water is in the oceans, with the remainder mostly found as glaciers or perpetual snow. A very tiny portion is consumable. Although, according to the MDG Report (2011), access to safe drinking water has improved over the last decades in almost every part of the world, it is estimated that more than 1 in 10 people may still have been without access in 2015. Moreover, our demand for water is constantly increasing. Some observers have estimated that by 2025 more than half of the world's population will be facing water-based vulnerability (Kulshreshtha, 1998).

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Being an agrarian and riverine country, Bangladesh in particular is heavily dependent on water for human consumption, crop irrigation, transportation, and conservation of biodiversity. Inefficient river management and pollution, etc., further deteriorate the situation. The coastal region covers almost 20% of the country, area wise, which is about 29,000 sq. km (Islam, 2004). Utilization of groundwater in the coastal zones is very significant because groundwater forms the major – and sometimes the only – source of potable water there. Unfortunately, this valuable resource faces severe threat from seawater intrusion and salinization due to both natural and man-made causes. In some areas, although deep aquifers, contain water of acceptable salinity, installing deep tube well is very expensive.

One of the most convenient options to ensure potable water is to make use of the abundant source of seawater and brackish water. To bring the salinity under the specified limit, desalination is widely practiced all over the world. There are many desalination methods. However, the conventional methods of desalination of salt water to produce fresh water by distillation, electrolysis and reverse osmosis are energy-intensive techniques. Due to increasing energy costs and declining energy sources, there is a growing interest in the use of low-cost technologies.

Solar energy is a free, inexhaustible resource and it is available in nature in a sufficient amount. Solar desalination aims to produce drinkable water from seawater by directly utilizing sunshine. It is a viable alternative to expensive methods to address the water shortage in low-income areas.

The present work emphasizes the quantitative measurement of the plant output to verify its effectiveness. This is because the viability of the plant is very dependent on the fact that it can fulfill partially, if not fully, the need for drinking water in coastal areas. Regarding the current circumstances in Bangladesh, where research of this kind is still in its infancy, quantitative measurement of the plant's discharge is taken as the main objective of our study. Apart from that, the study has the following specific objectives (i) to simulate real plant operating sequences to focus on various problems likely to be encountered in the construction and maintenance phases; (ii) to determine salinity removal efficiency of the desalination unit; (iii) to investigate some other parameters to make the water acceptable to users and (iv) to use renewable energy so that the system becomes a sustainable and clean source of drinking water.

2.0 BACKGROUND

Distillation has long been considered a way of making salt water drinkable and purifying water in remote locations. The basic concept of using solar energy to obtain drinkable fresh water from salty, brackish and polluted water is quite simple. A conventional solar still is designed by using simple laws of physics. Water is kept in an airtight basin having a top cover of a transparent material, usually tilted. Incident solar irradiance passes through the cover and is absorbed by the water and the base of the container. As a result, water contained in the basin is heated up and evaporates in the saturated condition inside the still. The base also radiates energy in the infra-red region, which is reflected back into the still by the glass cover, as glass is not transparent in the long wavelength region. The salts and minerals do not evaporate along with the water. Ordinary table salt, for instance, does not vaporize until the temperature reaches over

1400°C, so it remains in the brine when the water evaporates. Water vapors rise until they come into contact with the cooler inner surface of the cover. There they condense in pure water, run down along the sloped cover surface and water gutters due to gravity, and collect in vessels nearby.

Tarawneh (2007) commented upon experimental results that the water depth has a significant influence on the productivity of a solar still. An investigation by Rajamanickam and Raghupathy (2012) shows that the water depth is inversely proportional to the productivity of the still. Yeh and Chen (1986) investigated experimentally a minor effect of the ambient temperature on the productivity of the still. However, their results are limited. Research work carried out by Morse and Read (1968) showed that, with a rise in ambient temperature from 26.7°C to 37.8°C, the output increases by 11%.Although Garg and Mann (1976) reported that the output tends to change very little with change of inclination of glass cover, Tiwari, Thomas and Khan (1994) have optimized glass cover inclination for maximum yield in a solar still. The optimum angle suggested for Indian climates is 10 to 15 degrees (Garg & Mann, 1976).

Different researchers have undertaken numerous innovative approaches to enhance the efficiency of a solar still. Ahmed and Alfaylakawi (2012) used water sprinklers and cooling fans to increase the productivity of a conventional solar still. Rajvanshi (1981) tested the effect of adding various dyes to the solar distillation unit and observed that addition of water-soluble dyes increases the productivity of a deep basin solar still by as much as 29%. Tanaka and Nakataka (2007) found that using a flat plate external reflector with tilted wick solar stills can increase the distillate productivity in all but the summer seasons, and the increase in the daily amount was about 9%. Abdallah and Badran (2008) experimented with how a sun-tracking system increases the solar still's productivity.

The salinity problem of the coastal area (Bux & Rahman, 1994) is that in the problem zones salinity varies between 1000 ppm (mostly) and 25,000 ppm (in worst cases). The desirable salinity limit is 600 ppm. However, the tolerable limit is 1000 ppm for Bangladesh
(DOE, 1993).

Some impurities in drinking water are not very harmful to people, but their presence make the water aesthetically unpleasant. According to Bangladesh Environment Conservation Rules (1997), drinking water's standard color is 15 units (Pt-Co Units) and standard Turbidity is 10 Nephelometric Turbidity Unit (NTU). The optimum pH is usually in the range of 6.5–8.5.

3.0 METHODOLOGY

3.1 Selection of Material

Selection of appropriate materials is important because a solar still has to withstand harsh weather conditions. The materials must not degrade when exposed to sun and brackish water and they cannot leave a bad taste in the distilled water. A number of materials can be used to construct the wall and base of the solar still such as enameled steel, asbestos cement, Ferro cement, reinforced concrete, brick, etc. Construction costs of solar stills with different materials from the local market are roughly estimated in Table 1.

Table 1. Construction costs of solar stills with different materials

Wall and Base Material	Cost of Material and Fabrication (US$)
Mild steel sheet	200
Wood	120
Brick	80
Ferro cement	50

In this study, brick was given preference because of its low cost and easy availability. In addition, laborers with good expertise in brick construction are easily available in our country. The requirement for a transparent cover material can be fulfilled by using ordinary window glass. Some researchers have suggested that plastic sheet can be a cheap alternative to glass as the transparent cover. However, the disadvantages of using plastic sheets include overheating and melting under direct sun, displacement by gusty wind, etc. The sealant is important for efficient operation. It prevents leakage of water vapor and condensate. Window glass putty was used here as sealant material.

On one side of the basin, an inlet is required to fill the basin with a known amount of water. Another pipe is fitted at the bottom of the basin for removing desalinated water from the basin to the storage container. PVC pipes were used for this purpose as this prevents corrosion and they are very cheap.

3.2 Construction of the Plant

The study incorporates the minor details in construction of an experimental solar still including the cost of different materials. The various problems encountered at various stages of construction, operation and maintenance are depicted clearly. As solar desalination units are not easily accessible in this country, this is done with the hope that the current study can be taken as a manual for future construction.

The plant was constructed on the rooftop of the Civil Engineering Department building, Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh. Latitude and longitude of Dhaka are 23°46'N and 90°, respectively. Figure 1 shows the detailed drawing of the system done at the design phase. The basin was constructed within two days. The outside dimension of the basin is 4' x3'. Two side walls on the shorter side were constructed with varying height. One was of 6" and the higher side was 15". A plastic sheet was placed under the floor of the basin just before construction so that it could prevent the building roof from getting damp. The inner wall and floor were covered with a layer of cement mortar.

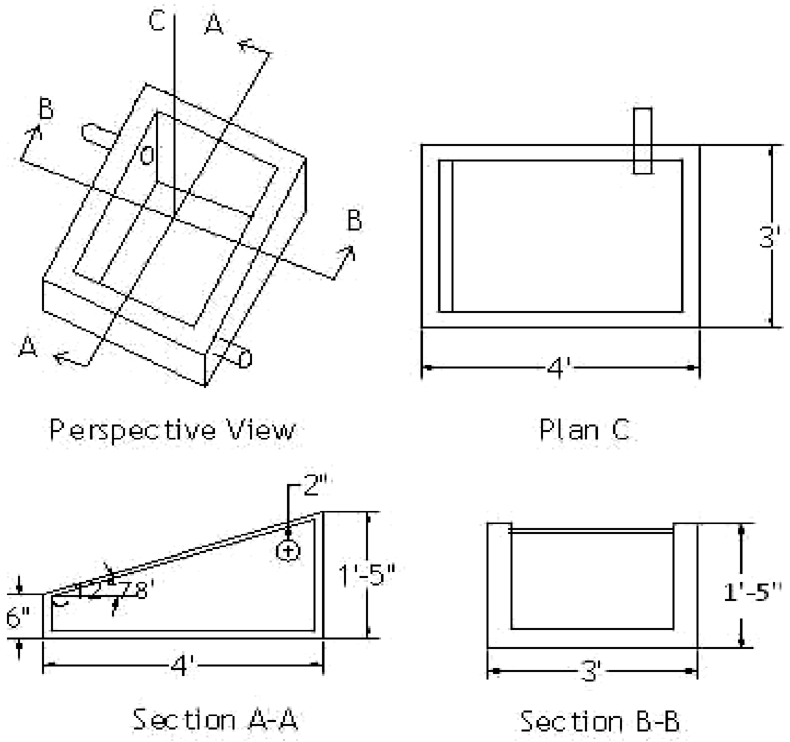

Figure 1. Schematic diagram of the system

A PVC pipe of 50.8 mm (2 inch) diameter was used as the inlet of the basin. To assist collection and bringing out of the condensate, an outlet gutter was used. A 50.8 mm (2 inch) half-cut (U shape) PVC pipe was used to serve this purpose. The same pipe served as the outlet too. That is, the pipe was cut up to a certain length to collect the distillate and the remaining portion was used to bring out the fresh water. The gutter had its one long edge slightly embedded in the basin wall and mildly inclined toward its projection outside the still.

The still was so constructed that the glass cover had an angle of tilt of approximately 12°78’. A plastic pot can be used to store the fresh water coming from the still. To keep dust from dipping into the pot, a cover should be placed over the opening. The desalination unit is shown in Figure 2.

Figure 2. This plant was constructed on the rooftop
of the Civil Engineering Department Building, BUET

3.3 Problems and Countermeasures

The problems faced during the construction and operational phases of the project are discussed here so that in future these circumstances can be avoided. No significant issues arose during the construction of this simple basin. The outlet gutter was set up with a small inclination and, by pouring water down it to be ensured that the distillate would flow to the outlet without any difficulty. Afterwards, casting cracks of 3 to 4 mm formed at some places on the wall and floor. These cracks were filled up instantly by patchwork.

At first only a plastic sheet was applied to the wall adjacent to the gutter to carry the distillate into it. However, this was not enough. A large part of the distillate was completely lost. Thence an additional glass strip of 5 mm thickness and 25 mm width was attached with adhesive inside the glass cover. It was just above the gutter and the strip length was almost equal to the width of the basin. After that, almost the entire portion of distillate trickled into the outlet channel. The loss of vapor through the inlet pipe was stopped by using a plastic bag. The bag was tied firmly at its exterior opening.

3.4 Plant Operation and Experiment

Different salinity concentrations, between 3,000 ppm and 100,000 ppm, were used in the feed water. The distillate amount was measured three times a day – at 09:00, 13:00 and 17:00 for the period of November 2011 to February 2012. In cases where the data was missing due to some unavoidable circumstances, they were interpreted using statistical methods such as interpolation.

Desalination of brine, the main purpose of the study, was well investigated on some samples collected from the outlet. The samples were collected on a rather random basis, especially when the input salinity was varied. Then the percentage removal of salinity was found by the following formula:

$$\%\ \text{Removal of Salinity} = \frac{\text{Input salinity}\left(\text{ppm}\right) - \text{Output salinity}\left(\text{ppm}\right)}{\text{Input salinity}\left(\text{ppm}\right)} \times 100 \qquad (1)$$

A total of 24 samples were tested in the laboratory for color and turbidity along with salinity. The presence of these two impurities can make water unpleasant to the users and the purpose of desalination plants may be hampered. pH was also tested on a few occasions to find out whether it was within the prescribed limit.

4.0 RESULTS AND DISCUSSION

The quantitative estimation of the plant yield was taken as one of the main purposes of the current study. The diurnal variation of the plant output during the test period (Nov 2011 to Feb 2012) was from 0.364 L/m^2 to 2.032 L/m^2. The average for the entire period is 1.198 L/m^2. This can be compared to the output found by Rahman (1994) in similar conditions. He observed solar still output between 0.2 L/m^2 and 2.3 L/m^2 for four months in 1994. For the current study, the monthly averages are 0.783, 0.887, 0.838 and 1.311 L/m^2 respectively for Nov 2011, Dec 2011, Jan 2012 and Feb 2012.

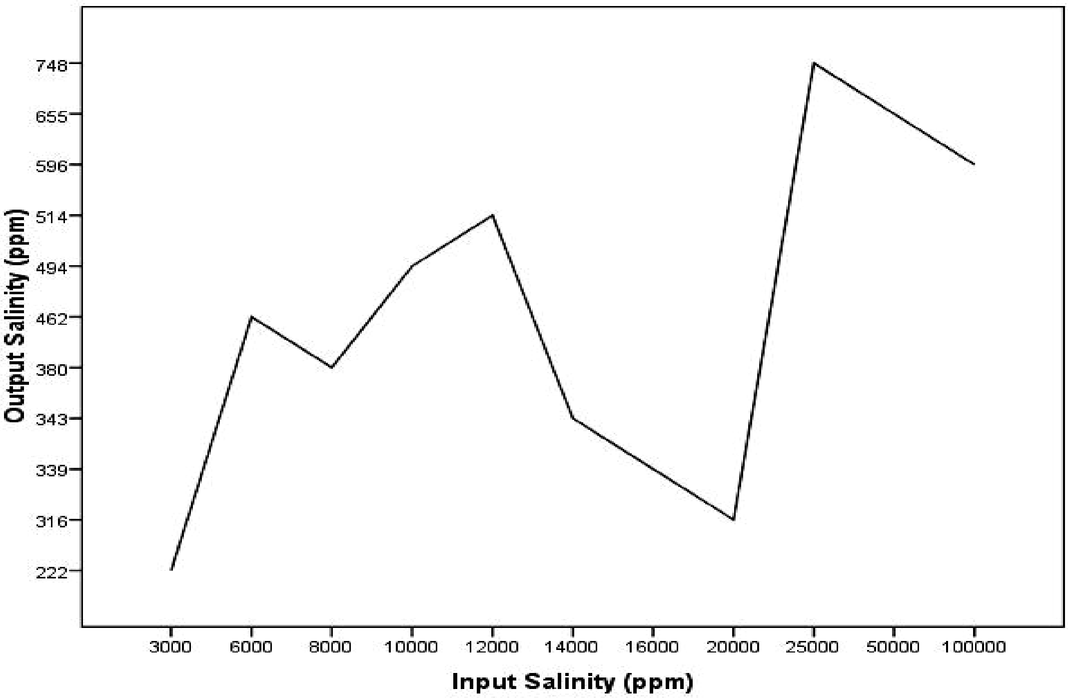

Figure 3. Output salinity vs. input salinity

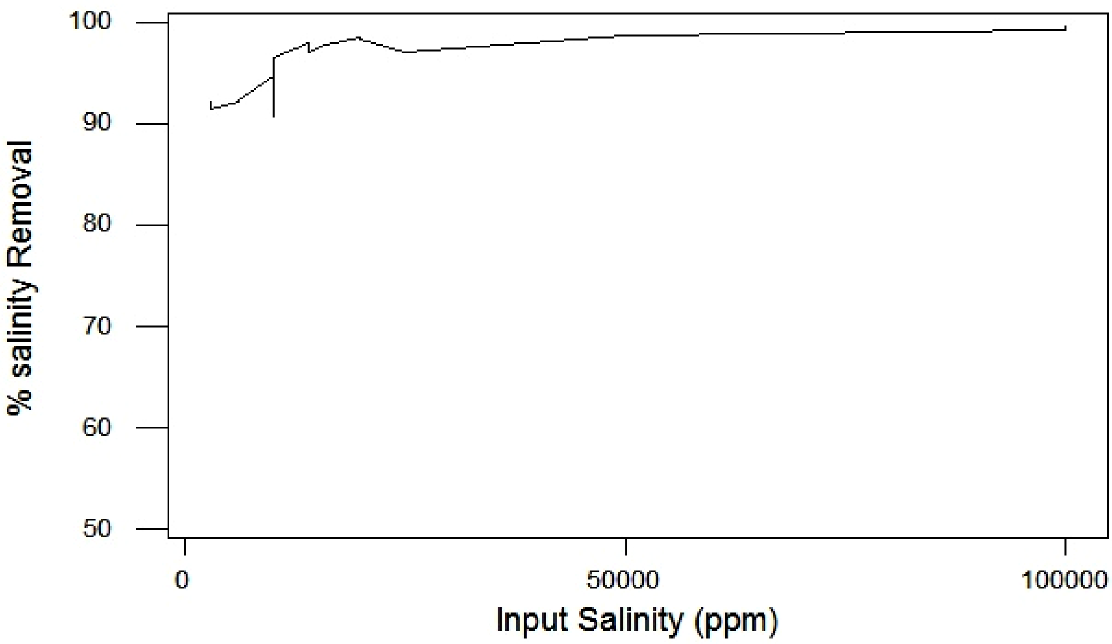

Figure 4. Salinity removal vs. input salinity

The total cost required for materials is broken down in Table 1 because cost is a prime concern while setting up stills in low-income areas. It can be seen that the materials cost only US$450 in total, and the construction worker was paid US$30. In rural areas, labor is cheap compared to the capital city. Laboratory tests performed on several samples found as output of the solar still indicated that salinity was in the range of 200 ppm to 800 ppm. The applied doses of salinity in the feed water varied between 3,000 ppm and 100,000 ppm. Moreover, the percentage removal of salinity was calculated to find that at least 92% salinity was removed in all the cases, irrespective of the input salinity. Figures 3 and 4 present output salinity and percentage removal respectively with respect to input salinity.

The plant output was tested for color and turbidity in the laboratory simultaneously with the chloride test. In all cases, color was found to be less than or equal to 15 Unit, except for one case, when it was found to be 17 Pt-Co Unit. Similarly, all the samples had turbidity within tolerable limits, the maximum being 7.28 NTU. Some of the samples were tested for pH too. The pH values ranged between 6.52 and 7.53.

5.0 CONCLUSION

A brick-built basin with a glass cover appears to be a cheap and durable type of solar still. Among others, Ferro cement wire mesh is a good option. Reduction in construction cost may be possible with the cheap labor available in rural areas. Local amateur crafts people are capable of building this simple solar still.

The maximum and minimum diurnal outputs of the plant were 0.364 L/m^2 and 2.032 L/m^2 respectively with an average of 1.198 L/m^2. The salinity removal efficiency of the plant is more that 92%, independent of the input salinity. Hence, the daily distillate can be mixed with feed water to bring the overall salinity under a tolerable limit. Diluting the salinity concentration of the source water thus can increase the consumable water quantity.

Water, as well as being safe, is aesthetically important to the users. The water produced by the desalination unit was tested to be free from unacceptable color and turbidity. The model was developed for experimental purposes but the intention was to represent real-life conditions. The lessons learnt here can be very helpful for solar still manufacturers in the future. This study can be considered as a handbook for future construction.

The efficient utilization of the solar energy could minimize the need to use expensive conventional sources of energy and meet the energy-saving requirements. Thus, this is a sustainable way of dealing with the water insufficiency problem in coastal areas.

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