ESTIMATION OF PRODUCTION COST OF A TRIANGULAR SOLAR STILL FOR REMOTE AREA OF BANGLADESH

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ABSTRACT

People in southern Bangladesh have great difficulties accessing safe drinking water and have to drink reluctantly saline groundwater or undesirable pond water. To improve this water environment, we designed and built a triangular type solar still (TrSS) from the results of preliminary production test using our tubular solar still (TSS) in Parbayarjhapa village, which is located 70 km south of Khulna. The water production cost (WPC) of the TrSS was estimated from the fabrication costs, which were calculated based on a market survey on the price of local materials for the TrSS in Khulna and from the production performance of the TSS. The daily production was calculated from our previous experimental results using the TSS. It can be seen from these data that the WPC per litre is initially about 3.1 BDT/L, then decreases sharply in the first 3 seasons and subsequently hovers around 0.82 BDT/L, which is lower than drinking water costs for residential customers (about 1 BDT/L).

Keywords: *triangular solar still, solar energy, distillation techniques, Bangladesh, water production cost*

1. INTRODUCTION

Global warming and natural disasters generate environmental degradation and give serious effects on human activities. The scarcity of drinking water has become one of serious international problems associated with dry weather, sea level rise, earthquake, tsunami, storm etc. Water scarcity also often induces the deterioration of water quality and to leads to a heavy burden of public health costs due to diseases of the digestive system.

Bangladesh is the most densely populated countries of the world, and 28 % of total population live in low-elevation coastal area with a high risk of flooding. Even now in southern Bangladesh, wells for drinking purpose have been decreasing due to the sea water intrusion landward associated with sea level rise by global warming and flooding. People in this area have great difficulties accessing safe drinking water and have to drink reluctantly saline groundwater or undesirable pond water. That is why women, regardless of age, are required to work for about one to two hours to harvest drinking water almost every day.

To solve serious water problems as above, a solar distillation techniques has been worked by many researchers, e.g. single-slope by Feilizadeh et al. (2010), double-slope basin type by Murugavel and Srithar (2011), weir-type cascade by Tabrizi et al. (2010), wick-type by Mahdi et al. (2011). These past studies have focused on the enhancement of the water production (hereinafter referred to as production) associated with the change in the still structure, initial water depth, materials. On the contrary, cost, durability, fabrication and maintenance have not been major themes of the research. Carrying out a project feasible study, we should take account of transportation, weight and size of a solar still and its materials, especially when we extend solar stills remote areas with inadequate infrastructure service. It is also desirable that a solar still must meet needs of local residence. A preliminary test using a tubular type solar still (TSS) was conducted in Parbayarjhapa village in 2014 to provide safe drinking water from the TSS and to understand how the villager's health condition is improved by drinking safe water. From the test results, we designed a triangular type solar still (TrSS) using local materials.

This paper describes the water production cost and life cycle cost of the TrSS estimated from a market survey on the price of local materials for the TrSS in Khulna and from our previous production test results.

2. PRELIMINARY TEST

2.1 Outline of test in Parbayarjhapa

A target village, Parbayarjhapa (hereinafter referred to as village) is located in south part of Bangladesh and about 40 km inland from the coast of the Bay of Bengali. The village has no electricity and about 1,000 inhabitants. Drinking water resources include rainwater and tube well water with high levels of salinity and iron. The village lies below sea level and seawater intrusion due to sea level rise or flooding has contaminated water resources in the village. In dry seasons, most villagers cannot help but use unsanitary pond water or saline water from only one shallow tube well.

To solve the above water problem, the TSS was designed and was built by Shafiul et al. (2014). The TSS consists of a tubular cover (1.1 m long and 0.3 m in diameter), a ferro-cement trough (1.1 m long and 0.28 m wide, 70 mm high and 25 mm in thickness), a water-collecting vessel and a pair of a ferro-cement T-shape basement (leg). A GI wire frame (2.75 mm in diameter) was used to keep a cylindrical shape of the cover. Saline water in the trough is heated by solar energy and then begins to evaporate from the water surface. The evaporated water vapour is transferred to the humid air and is finally condensed on the cover inner surface. The condensed (distilled) water flows down toward the water-collecting vessel. The details of the production process are explained in 3.2.

The preliminary test using the TSS was started from February 2014. We installed about 60 TSSs in the village and investigated the productivity (daily production) of each TSS in a dry season as well as health condition of the villagers.

2.2 Test results

Figure 1 shows TSSs set up by a local house in the village for the preliminary test. The family has a rainwater harvesting system too. Communication to villagers is neccessary to build a reliable relationship with the villagers and to encourage them to use TSS for improving their health condition and for changing women's life style (See Figure 2).

The hearing survey made us aware of the reduction of TSS cost and water production cost (WPC) for sustainable TSS use. The reduction of working time to harvest drinking water is village women's sincere hope. It became obvious from an interview with some women that they would like to spend some more time with their families if they would not need to work for harvesting drinking water. Especially, we strongly desire children to spend more time for productive purposes by introducing the TSS into the village.

Figure 1: Preliminary test in Parbayajapa

Figure 2: Hearing survey in Parbayajapa

3. PROPOSED TRIANGULAR SOLAR STILL (TRSS)

3.1 Basic design and structure

Figure 3 shows a schematic view of TrSS proposed in this paper. The TrSS consists of a frame, a cover, a water-collecting vessel and a trough. The cover is made of a highly durable transparent polyolefin film. The cover has three tubular holes and the upper part of the cover has a roof type (trianglular) shape, which is formed by threading a wooden bar or a bamboo bar through each hole. The wooden or bamboo bar plays a role in the frame of TrSS. The lower part of the cover was deformed like an inverted quadrangular pyramid. Thus, the condensed water on the cover inner surface slips down naturally. The trough has a semi-circular shape and is selected from readily available lightweight materials. The trough was wrapped with a thin polyolefin film to prevent saline water in the trough from leaking directly into the water-collecting vessel and then placed on the frame.

3.2 Production process

Figure 4 illustrates the principle of the production from saline water in the TrSS. The saline water is collected from inland shrimp ponds near the village houses. The solar radiant heat after transmitting through the cover is mostly absorbed by the saline water in the trough. The rest is absorbed by the cover, humid air and the trough. Thus, the saline water is heated up and evaporation takes place in the TrSS. The evaporation increases the vapour density of the humid air. Finally, the water vapour is condensed on the inner surface of the cover, releasing its latent heat due to evaporation. Since the lower part of the cover has an inverted quadrangular pyramid shape described above, the condensed water automatically trickles down and flows into the water-collecting vessel placed at the centre of the bottom cover (see Figures 3 and 4).

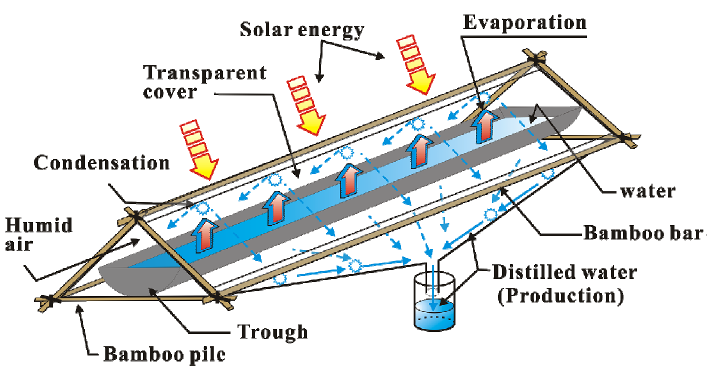


Figure 3: Schematic view of Triangular type Solar Still (TrSS)

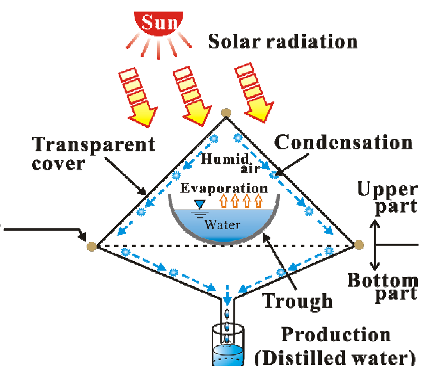
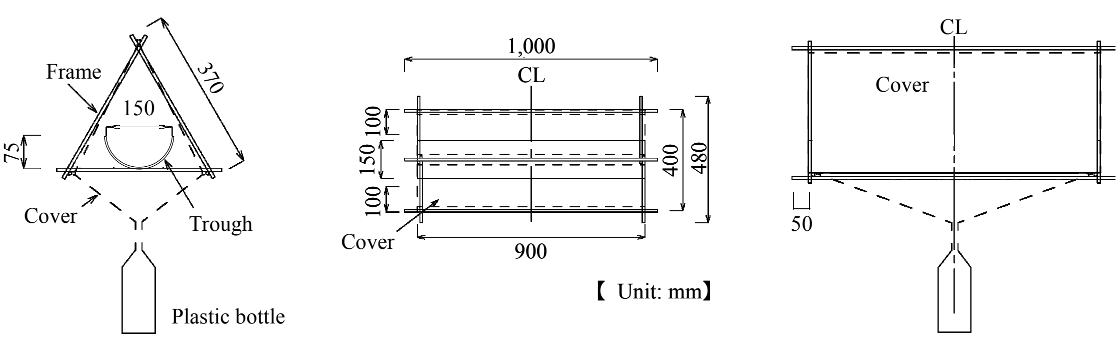


Figure 4: Production mechanism of TrSS

3.3 Fabrication

Figure 5 shows scale drawings of the TrSS designed for experiments in the near future. Table 1 summarizes an overview of specifications of the TrSS. The cover was an agricultural polyolefin film with 0.1 mm in thickness.



a) sectional view b) plan view c) side view

Figure 5: Scale drawings of TrSS

The upper part and lower part of the cover were made by heat welding polyolefin sheets cut off according to the assembly diagram, and the welding can prevent water leak at the junction of the pre-cut polyolefin sheets. Finally, the cover was made by heat welding the junction between the upper part and lower part of the cover. The semicircular trough was made by dividing longitudinally a vinyl chloride pipe (0.15 m diameter and 0.9 m length) into two equal parts. The colour of the trough was chosen gray or dark gray to raise the water temperature in the trough due to high solar energy absorption. A bamboo bar of 10 mm or more diameters is preferable as the frame of TrSS. A hemp rope is useful for firmly tying the bamboo to strengthen the frame structure of the TrSS because the rope is strong and durable. As shown in Table 1, the weight of TrSS per unit length is 5.1 kg/m and this lightweight made it possible for even women to easily carry the TrSS. The life of the cover is guaranteed for 2 years and the trough has more than 20-25 years guarantee, while the life of frame may be about 5 years. Although the life of bamboo frame is short, an old bar can be easily exchanged for a new one. Thus, it is very convenient and easy to move and assemble the TrSS without using special techniques and tools.

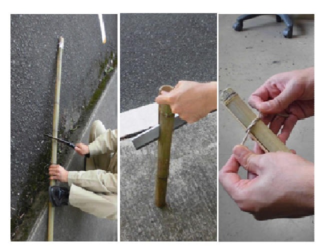
Figure 6 shows the fabrication process of TrSS and the fabrication can be achieved as follows;
(1) Drawing and cutting a polyolefin film according to the assembly diagram,
(2) Heat welding overlaps between the cut polyolefin sheets to make the cover,
(3) Cutting a bamboo tree, making bamboo bars, and tying them together,
(4) Assembling the TrSS frame,
(5) Covering the TrSS frame with the cover made in the process (2),

Table 1: Overview of specifications of TrSS

Cover	Shape	Triangular	Weight	0.14 kg	Cover cost: 210 JPY (132 BDT)
	Material	Polyolefin film	Total area	1.39 m^2	
	Color	Colorless, transparent	Transmissivity	95%	
	Length	0.9 m	Junction	Heat welding	
	Thickness	0.1 mm	Durability	2 years	
Trough	Shape	Semicircular	Weight	3.95 kg	Trough cost: 564 JPY (355 BDT)
	Material	PVC	Sectional area	7.9×10^{-3} m^2	
	Color	Gray	Width (diameter)	0.15m	
	Length	0.9 m	Capacity	8.8×10^{-3} m^3	
	Thickness	5 mm	Durability	20 years	
Frame	Bamboo	1.0 m × 3 pieces	Total weight	0.54 kg	Frame cost: 70 JPY (44 BDT)
		0.4 m × 4 pieces	Building method	Tying	
		0.5 m × 2 pieces	Durability	3-5 years	
Others	Trough end	2 pieces	Hemp rope	3.6 m	Other cost: 14 JPY (9 BDT)
	Glue	5 g	Collector	Pet bottle	
TrSS	water collecting	Center drain	Total TrSS weight	4.63 kg (without a water)	
	Inclination	Not necessary	Total TrSS cost	858 JPY (541 BDT) per TrSS	

1) Drawing and cutting the sheet

2) Heat welding polyolefin sheets



3) Cutting and tying bamboo bars

4) Assembling the frame of TrSS

5) Covering the frame with the cover

6) Installing the trough

Figure 6: Fabrication process of TrSS

(6) Installing the trough in the TrSS and placing it on the base of a triangle frame formed at the ends of the TrSS.

Special techniques are not required for making the TrSS and we confirmed that assembling a TrSS can be completed within 15 minutes by two men. Moreover, since the TrSS is made with locally acquisitioned lightweight materials, it enables the villagers to design and make the most favorable TrSS for each family.

4. TRIAL CALCULATION OF PRODUCTION COST IN KHULNA, BANGLADESH

4.1 Raw cost of TrSS

In order to get information for determining the raw TrSS cost, we performed a market survey on the price of local materials necessary for making the TrSS in August 2015 in Khulna, Bangladesh. The surveyed materials were a bamboo tree for the frame, a polyolefin sheet for the cover, a PVC pipe for the trough and vinyl string, etc.

A PVC pipe with 4 inches in diameter and 1 feet in length was available in a range of prices, 20 to 30 BDT. A larger pipe with 6 inches in diameter and 1 feet in length costs 45 to 60 BDT. A plastic string with 1 kg in weight (longer than 300 m) was available in a range of prices, 40-60 BDT. So far the polyolefin sheet may be imported from Japan, but further search will be unavoidable to find more reasonable sheets for the cover in Bangladesh.

Bamboo trees and transparent vinyl sheets were also easily acquisitioned in Khulna. However, these materials were available in a vast range of prices and the prices depend on shops. The price of a bamboo tree with 13-15 m in length and 80-130 mm in diameter is about 250 BDT on average.

Table 2 shows a fabrication cost scenario of TrSS for the village, which was made by the data from the marketing survey in Khulna. The expected fabrication cost may be 248 BDT per one TrSS.

Table 2: Fabrication cost scenario of TrSS

Item	Specifications	Durability	Unit cost	Subtotal
Polyolefin film for cover (Imported from Japan)	Length: 1.4 m, Width: 1.5 m, Thickness: 0.1 mm, Area: 2.1 m^2	3 years	63 BDT/m^2	132 BDT
Trough	Diameter: 6 inches, Length:0.9 m	10 years	150 BDT/pipe	75 BDT*[1]
Ends of trough	Vinyl chloride plate, 2 pieces	10 years	5 BDT	10 BDT
Vinyl string or hemp rope	10 m (100 m roll)	1 year	0.1 BDT/m	1 BDT
Bamboo bar	Diameter: about 15 mm, Total length: 6 m	5 years	5 BDT/m*[2]	30 BDT
PET bottle	Recycle item	1 year	0 BDT	0 BDT
			Total cost of TrSS	248 BDT
			*[1] Half pipe, *[2] Using bamboo after cutting	

4.2 Production cost assumptions

The production cost (WPC) of TrSS was estimated taking into account the fabrication cost and using the following assumptions.

(1) Daily production, M_{pd} (kg/m^2day), is proportional to daily solar radiation flux, R_{sd} (MJ/m^2day), and is expressed by Terasaki et al. (2011),

$$M_{pd} = 0.24R_{sd} - 0.73 \quad (1)$$

(2) Transport cost from Khulna to Parbayarjhapa is not included.
(3) A polyolefin film is available in Bangladesh at the same price as Japan.
(4) Monthly production is calculated based on monthly average solar radiation in Khulna by Debazit et al. (2014).
(5) Durability of each material is assumed as follows;
polyolefin film: 3 years, dry bamboo tree: 5 years, semicircular PVC pipe and cap: 10 years.

(6) Annual maintenance expense is 5 BDT.
(7) Water surface area; 0.12 m^2.

4.3 Results

Figure 7 shows the monthly change of average daily production, $M_{pd\text{-}d}$, per one TrSS estimated from the above assumptions. Considering that since TrSS is effective during the dry season (December to May), the valued of $M_{pd\text{-}d}$ is more important in the dry season rather than in the rainy season. The averaged daily production per one TrSS for the dry season (about 0.44 kg) is equal to nearly one fourth of the minimum drinking water consumption per day per capita. This means four TrSSs will be needed per person according to Henry and Chambron (2013).

Figure 8 shows the time variation of the WPC with elapsed dry season. The WPC is initially about 3.1 BDT/L, then decreases sharply in the first 3 seasons and subsequently hovers around 0.82 BDT/L, which is lower than drinking water costs for residential customers (about 1 BDT/L).

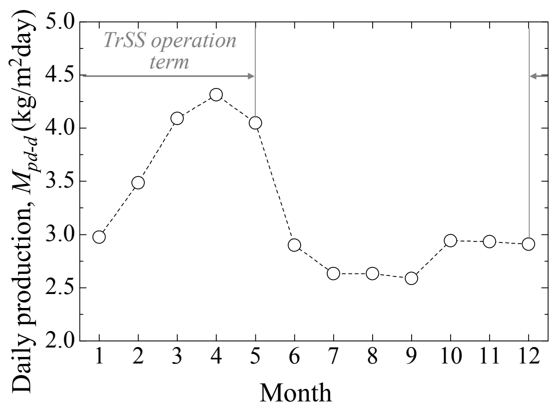


Figure 7: Monthly change of average daily production

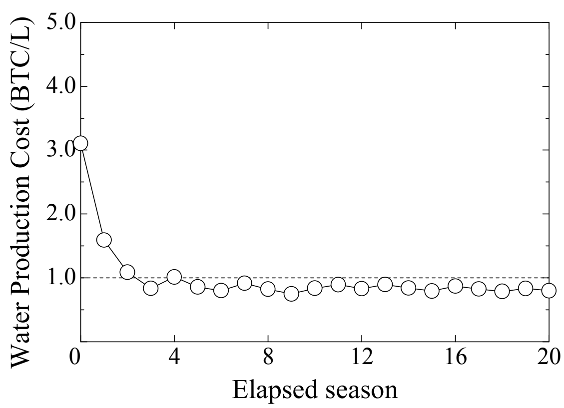


Figure 8: Time variation of water production cost

5. CONCLUSIONS

In order to provide safe drinking water to people in remote areas in Bangladesh, we designed a triangular solar still (TrSS) with data from the market survey in Khulna and preliminary production test in Parbayarjhapa village in 2014. The daily production was calculated from our past experimental results. When the TrSS with the size listed in the paper is adopted in Bangladesh, four TrSSs are needed per person for drinking purpose. It can be estimated from these data that the water production cost is initially about 3.1 BDT/L, then decreases sharply in the first 3 seasons and subsequently hovers around 0.82 BDT/L, which is lower than drinking water costs for residential customers (about 1 BDT/L). Further study in Bangladesh should be required to design the optimal TrSS from the viewpoint of cost and assembly.

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