AN IMPROVED METHOD OF SOLAR DESALINATION: TUBE IN TUBE TECHNIQUE

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ABSTRACT

Water is one of the quintessential elements that enable our existence on earth. However, around 97% of that water is contained by the ocean which is saline. The remaining 3% of water is fresh and is found in rivers, lakes, snow on mountain top and underground water resources which fulfills the demand of both plants and animals. With the expansion of the human civilization, scarcity of fresh water is also increasing. This ever increasing scarcity of water can be mitigated through desalination. This research makes an attempt to desalinate water with a new and improved method named "Tube in Tube" technique. The research was conducted at the terrace of a local building in Dhaka, Bangladesh. In this research three variation of Tubular technique, Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute) was prepared and some selected parameters were observed to compare those setups. Each setup observed in this research had the same dimension of 0.254 m in diameter and 0.914 m in length. After analyzing the acquired data it was derived thatTube in Tube (Jeans) and Tube in Tube (Jute) gave 72% and 53.5% increased distillate output and an increased temperature of 11^{o}C and 8^{o}C respectively than simple Tray in Tube setup. It was also observed that use of composite fibers to increase the evaporation surface area accelerates the distillate output production rate.

Keywords: *Solar Desalination, underground water, Tubular technique, potability, palatability*

1. INTRODUCTION

With the advancement of the human civilization, more and more water is required every day. This ever increasing scarcity of water can be mitigated through desalination of sea water. The systems that are used at present for desalination mostly harness non-renewable energy and are very expensive in terms of installation, operation and maintenance. Bearing that in mind, an attempt has been made to develop a system which will use renewable energy only and which can be constructed with readily available inexpensive materials. This system is extremely easy to construct and can be transported easily. This method of desalination is termed as 'Tube in Tube' technique which was first applied in Department of Civil Engineering, Ahsanullah University of Science & Technology in 2015. It is suitable for many remote and arid areas of the world that are blessed with plenty of solar desalination.

The prime objective of our work is to compare selected parameters between the different arrangements of the 'Tube in Tube' system. These parameters include temperature variation in different zones within the system, distillate collection rate and effect of composite fiber. In addition to that, salinity of the treated water is also measured in order to assess its potability and palatability.

The aim of this research is to make an attempt in solving numerous issues that arise due to salinity of water and scarcity of fresh water such as reduction in agricultural production, lack of usable water of standard quality, impact of saline water on infrastructures etc. We observe the temperature variation in different zones within 'Tube in Tube' system; evaluate the distillation output rate, cost estimation, and salinity measurement.

2. REVIEW

Several techniques have been used to desalinate water over the years. Here some of these have been studied and the outcome was observed. The techniques were divided into five categories.

a) Wick Type
b) Basin Type
c) Tubular Type
d) Humidification-Dehumidification Type
e) Enhancement to existing System

2.1 Wick Type

A paper by Karaghouli, *et al.* (1995) states that floating wick type solar still can generate a higher water production compared to basin type still and tilted wick type solar still. Also the production output doubled when tracking mechanisms were used.
In a paper published by Anand, *et al.* (1992) the authors presented that combined tubular multi wick solar still gives more output than tubular multi wick or basin type solar still.
A paper published by Mahdi, *et al.* (2010) presents that increase in the mass flow rate of feed water decreases the efficiency of the wick type solar still and if there is an increase in salinity of feed water, efficiency of the still will be reduced.
A study conducted by Bhattacharyya (2013) states Passive solar still especially the wick or capillary type seems to be an attractive choice to get water for drinking and other domestic purposes.

2.2 Basin Type

A paper published by El-Bassouni, *et al.* (1993) states that basin type units are not effective for desalination. They can be improved by increasing the incident solar radiation.
Firozuddin, *et al.* (2013) conducted a research to investigate the effect of evacuated tube on the the performance of a single basin solar still in outdoor condition. Productivity in this method increase 50.2% compared to normal basin type solar still
Minaisian, *et al*. (1992) Good productivity and limited operation requirements, the proposed floating vertical still seems to be well suited for ensuring fresh water for drinking purposes in marsh areas of poor water quality.
A study conducted by Farid, *et al*. (1993) shows an increase in still productivity with the increase in ambient temperature and decrease in wind velocity. This suggests that the still must be placed in the lowest wind velocity.
Murugavel, *et al*. (2008) figured out some work progress to improve the productivity. The production can be increased by increasing the condensation area, increasing the incident radiation through painting black and by intermittent shading on part of the condensation surface.
Arunkumar, *et al*. (2012) performed an experimental study & stated that hemispherical solar still produces more distillate than many other stills because of its large contact surface.

2.3 Tubular Type

A study conducted by Bari, *et al*. (2016) explores use of composite fiber in 'Tube in Tube' technique and observes that it gives around 70% increase in production.

In a study conducted by Anwar, *et.al*, (2016) the authors showed that use of composite fiber in 'Plate in Tube' technique increases the production to 2.3-3.61 l/m^2/day.

Hossain, *et al*. (2016) states that painting the outside of the tray with heat resisting paint increases production by 4%.

Chen, *et al*. (2013) performed an experimental analysis of the characteristics of heat and mass transfer of a three effect tubular solar still and showed that the yield rate is higher under saturation vapor pressure at a high temperature. The performance ratio can reach 1.3 when the heating power is 300W.

A paper published by Ahsan, *et al*. (2010) makes a comparison between two models of tubular solar stills (TSS). The first model uses vinyl chloride sheet and the second model uses ordinary polythene film. . In the end, it is concluded that the second model is simpler, lighter, cheaper and more durable than the first one because polythene film is much more durable and economic compared to vinyl chloride. However, the hourly evaporation and production are slightly lower in polythene cover method.

2.4 Humidification-Dehumidification Type

A study conducted by Khalil, *et al*. (2015) presents the air bubble column achieves higher performance than that for the conventional humidifier. The characteristics of the generated bubbles are modified by using a different sieve plate with different hole size.

A system carried out by Karke, *et al*. (2013) presented that a multistage flash and multiple effect distillation is mainly the whole process in fresh water production from salty water by enhancing the evaporation and condensation. It achieves 58% collector efficiency.

A study carried out by El-Agouz, *et al*. (2014) presents an experimental result for solar desalination using sprays evaporation technique. The whole system is designed to improve the evaporation rate by spraying water at low temperature.

A study conducted by Fath, *et al*. (2001) investigates the performance of a simple solar desalination system using humidification-dehumidification process. From the results the heater efficiency is in the range of 45%. Solar air heater significantly increases system efficiency. Also, increase in the solar intensity and ambient temperature along with the decrease in wind speed increases system productivity. Increase in air flow rate up to 0.6 kg/s increases the amount of seawater desalination.

2.5 Enhancement to Existing Systems

A paper conducted by Jitsuno, *et al*. (2012) presented a system for desalination of sea and brackish water using vacuum distillation system and solar heat. Using electric heater, 80% of heat was increased than that of sun ray. The amount of fresh water was about 15 liter/day. In this process, thermal efficiency was 70% which was equivalent to 10kg/m^2 of water per day.
A paper conducted by Auti, *et al*. (2013) presented a domestic water desalination system with condenser without using electricity in rural areas. . In collecting process, there occurred some heat loss. In this desalination process, for 8 liters of salt water, 10 hours was needed to evaporate the water to get pure drinking water.
A paper was presented by Sadeek, *et al*. (2014) about the experimental process of the development of hybrid water treatment system using solar still cum sand filter with ceramic media. In winter, average daily production rate was 2.1 L/m^2. In summer, daily production rate is 3.15 L/m^2.

A study conducted by El-Agouz, *et al*. (2014) discusses about the desalination using spray evaporation in a one-stage technique. The daily maximum efficiency of this plant was 87%. The cost estimation for each liter of distilled water was $0.029.
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 use of 5mm gap decreases the productivity by 40%. 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 spacers has a production of 14.8-18.7 kg/day.

3. METHODOLOGY

This method is based on the general principle of water turning into vapor as a result of temperature increase after absorbing solar energy. This method would consist of some primary elements such as; an outer transparent tube, a tray to hold saline water, an inner tube to increase the surface area and some composite fibers to increase the evaporation surface area. Solar radiation would pass through the outer tube and the water in the tray would absorb the solar radiation and evaporate. The use of composite fiber on the inner tube would work as a wick and increase the evaporation surface area. The evaporated water would condense at the inner side of the outer tube and roll down along the tube to the outlet. This output would be free from Salt and other impurities and could be used as drinking water.

3.1 Construction Materials

All materials used to make all the setup were locally available, cheapand collected from different sources. We used **stainless steel tray** having a dimension of 0.66m length, 0.178m

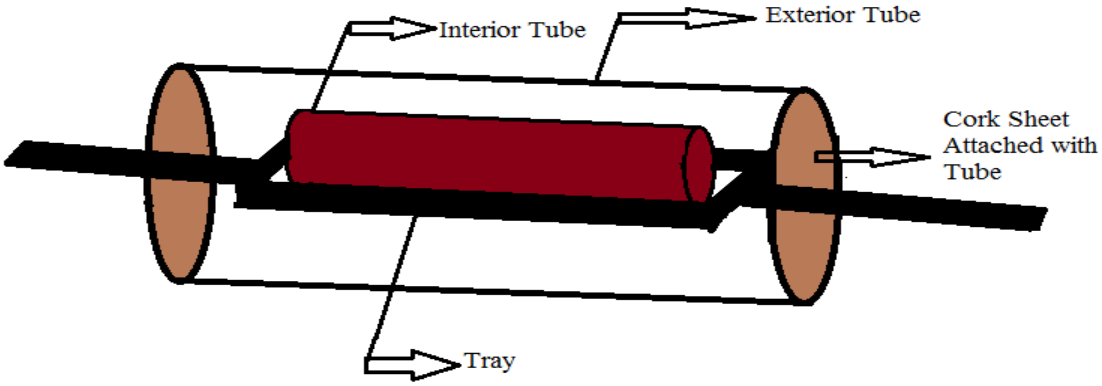

Figure 1: Schematic Diagram of the Setup

(0.254m in diameter & 0.076m thickness), transparent plastic sheet (TPS), composite fibers (jute, micro fiber cloths & jeans), thermometer (digital & analogue), inlet & outlet pipe, custom made elevated steel frame and filter paperto purify the distillate output.

Figure 2: Rolled TPS Sealed With CorkSheet Disc at Both End.

3.2 Model Setup

Transparent plastic sheet were cut out to obtain segments of dimension 0.914mX0.609m. Then two of those segments were taken and glued with super glue to one another along their width to form a sheet of dimension 0.914mX0.914m. Then the sheet was rolled into the form of a tube having a diameter of 0.254m and a length of 0.914m. Two circular disks were made from cork sheets and the end sections of the tube were covered.

(a) (b)

Figure 3: PVC Pipes Wrapped Up with Composite Fiber

To ensure that the distillate output will not leak out of the tube, the end near the outlet zone was attached with the cork sheet with melted stick gum.PVC pipe was wrapped up with composite fiber. First the PVC pipe was wrapped up with microfiber cloth and then the upper part of the pipe was covered with jeans or jute fiber to complete the implementation of composite fiber. The

jeans or jute fiber was stitched with microfiber cloth in such a way that the saline water in tray will not touch the jeans or jute fiber. The water would flow through the microfiber cloth to the jeans or jute fiber and then evaporate. Then the pipe segment was placed in the tray. Afterwards the tray along with the PVC pipe was placed inside the transparent tube through the open end and the end was sealed with cork sheet disc as mentioned before. It was made sure that the handles of the tray remained outside of the tube and necessary adjustments were made to the discs to help the handles probe out of them and act as a support.

Figure 4: Placement of Wrapped PVC Pipe inside the Tray

3.3 Model Placement

We made six tubes in total at a time for this test. Two of them were made for Tube in Tube (Jeans),another two of them were made for Tube in Tube (Jute)and the last two of them were made simply where no fiber was used. After completing the setup, all the six models were placed on the roof of a building from where the adequate solar radiation is to be achieved. All models were from the same elevation from the floor and also were the same location where the temperature and humidity was same.

Figure 5: Placement of final model at roof top.

3.4 Data Collection Process

Different zones provide different temperature readings. The five temperature measurements that have been made were ambient temperature (T_A), temperature of air inside the tube (Ta), temperature of the tray (Tt), temperature of the composite fiber (Tc) and temperature of the water in the tray (Tw). On the surface of each tube, a number of holes were made to allow access through various regions inside the tube to take temperature readings. Digital thermometer was inserted inside each hole of the tube and kept for a full minute. In the end, temperature readings were taken. Readings were taken every two hour intervals for ten hours. The holes were temporarily sealed up by proper insulating materials after the completion of temperature assessment.

Figure 6: Collection of Distilled Water from System

Water evaporates as a result of absorbing heat from the incident solar radiation. The vapor created undergoes condensation at the inner surface of the exterior tube and roll downs to the bottom. The tube is placed in such a way that the exterior tube creates an angle of thirty degree with the horizontal while the tray inside the tube remains parallel to it. As a consequence the distillate output gets collected at one end of the tube where the outlet is located. Water is collected from the end through an outlet pipe connected to the sealed tube so that the collected water does not undergo further evaporation. Water collection was carried every 24 hours and the volume was measured using a measuring cylinder to acquire an understanding about distillate output rate and the quality of the water collected. Water samples of two different salt concentrations were prepared. One was sea water which had a salt concentration of 35000 mg/l. Another sample was brackish water which had a concentration of 2000 mg/l.

3.5 Salinity Measurement

This process involves determination of salt content from sea water by titration a sample of salt water using silver nitrate solution of known concentration. The purpose of this test is to chemically determine halide content and titration is continued until all halides (Chloride and a small amount of Bromide) have been precipitated as silver halides. The full conversion is ensured by the help of a suitable indicator or electrode system.

4. RESULTS & DISCUSSION

4.1 Data Collection

The data collected from the experimental setup has been analyzed in three segments. The distillate output rate, hourly temperature variation and salinity measurement data were analyzed to evaluate the parameters and to get an idea of the efficiency and effectiveness of Tube in Tube method.

4.1.1 Distillate Output Rate Calculation

Distillate output rate was calculated in ml/m^2 of the area of the tube, area of the tray and the area of the evaporation surface area.
The width of the tube = 0.254 m and the length of the tube = 0.9144 m.
So, the area of the tube = 0.254 m X 0.9144 m = 0.2322576 m^2.
The width of the tray = 0.178 m and the length of the tray = 0.660 m.
So, the area of the tray = 0.178 m X 0.660 m = 0.11741912 m^2.
The perimeter of the composite fiber = 0.2286 m and length of the composite fiber =0.508 m.
So, the evaporation surface area = 0.2286 m X 0.508 m = 0.1121664 m^2.
Three types of Variations were used in this experiment. They are- Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute). Two setups were prepared for each variation. All the tubes have been denoted in the following manner-
Tube-1 of tray in tube system – T1
Tube-2 of tray in tube system – T2
Tube-1 of tube in tube (Jeans) system – T3
Tube-2 of tube in tube (Jeans) system – T4
Tube-1 of tube in tube (Jute) system – T5
Tube-2 of tube in tube (Jute) system – T6

4.1.2 Temperature Variation Analysis

The tubular systems are designed to carry out observations related to temperature variation within the subject. For each system five temperature measurement zones were defined:
Ambient temperature – (Tair)
Temperature of air inside tube – (Ta)
Temperature of tray – (Tt)
Temperature of composite fiber – (Tc) and
Temperature of the water in the tray – (Tw)
Temperature readings are recorded as average temperature for the five months period at a specific time. This is done to keep the investigation as simple as possible.

4.1.3 Salinity Measurement of Treated Water

For the test to be carried out brackish water (2000 mg/l salt concentration) &sea water (3500 mg/l salt concentration) were prepared. It was observed that the Tray in Tube displayed around 36mg/l and 37mg/l salt concentration respectively. The Tube in Tube (Jeans) showed 32mg/l and 38 mg/l respectively and Tube in Tube (Jute) displayed around 32mg/l and 42 mg/l salt concentration respectively.

4.2 Evaluation of Data

The data collected from the three set ups were meticulously observed and calculated in this segment

4.2.1 Evaluation of Distillate Output Rate

The unit for water production rate is taken as ml/m^2/day and yield of these systems are observed for five months in total. Here as a sample the evaluation of March-2017 is displayed:
Figure 7gives us the Production vs Date curve for the month of March. From the graph we can see that in March, as seen before, the Tube in Tube (Jeans) gives the maximum output of the

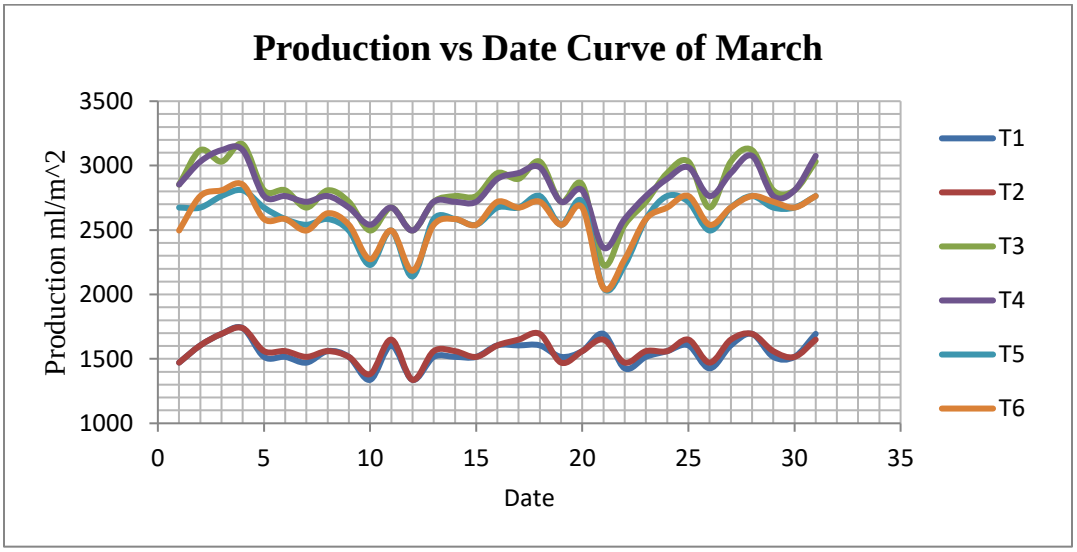

Figure 7: Production vs Date Curve, March 2017

three sets of tubes. There are some rapid drops in production in March as a result of rain fall which hindered the temperature to increase. The graph shows that the Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute) has a production rate of (1300 ml/m2/day–1800

ml/m2/day), (2400 ml/m2/day–3200 ml/m2/day) and (2000 ml/m2/day–2900 ml/m2/day) respectively.

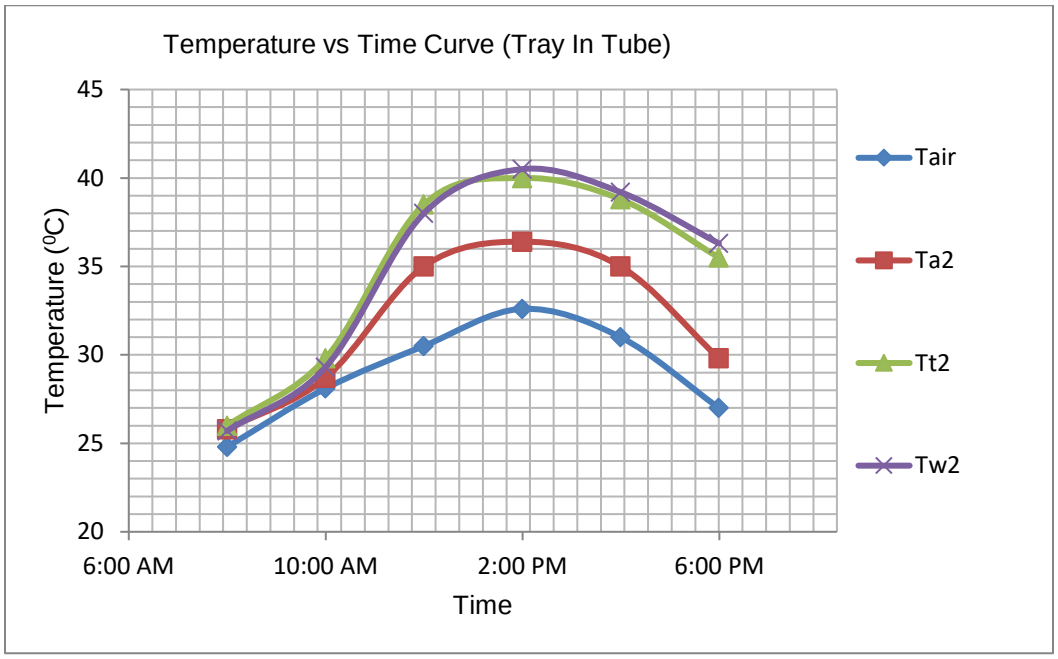

Figure 8: Temperature vs Time Curve (Tray in Tube)

Figure 9 gives us the Temperature vs Time Curve of Tube in Tube (Jeans) system.

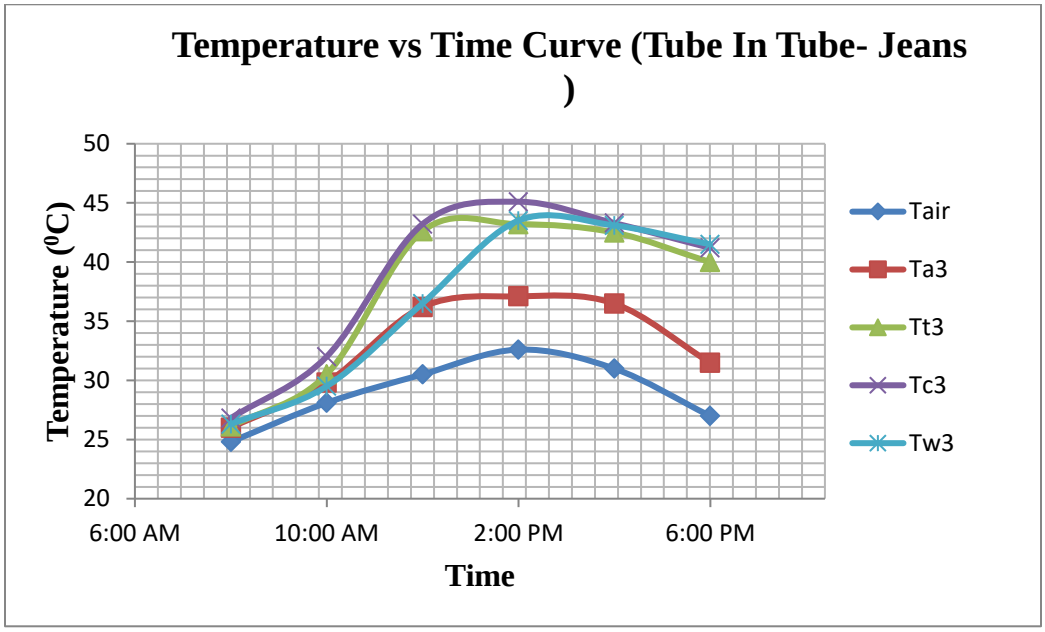

Figure 9: Temperature vs Time Curve (Tube in Tube- Jeans)

Figure 8 gives us the Temperature vs Time Curve of Tray in Tube system. It is seen that in both the graphs the temperature tends to rise from morning till noon and after that the temperature in

different zones start to drop as the ambient temperature starts to fall. Figure 10 gives us the Temperature vs Time Curve of Tube in Tube (Jute) system.

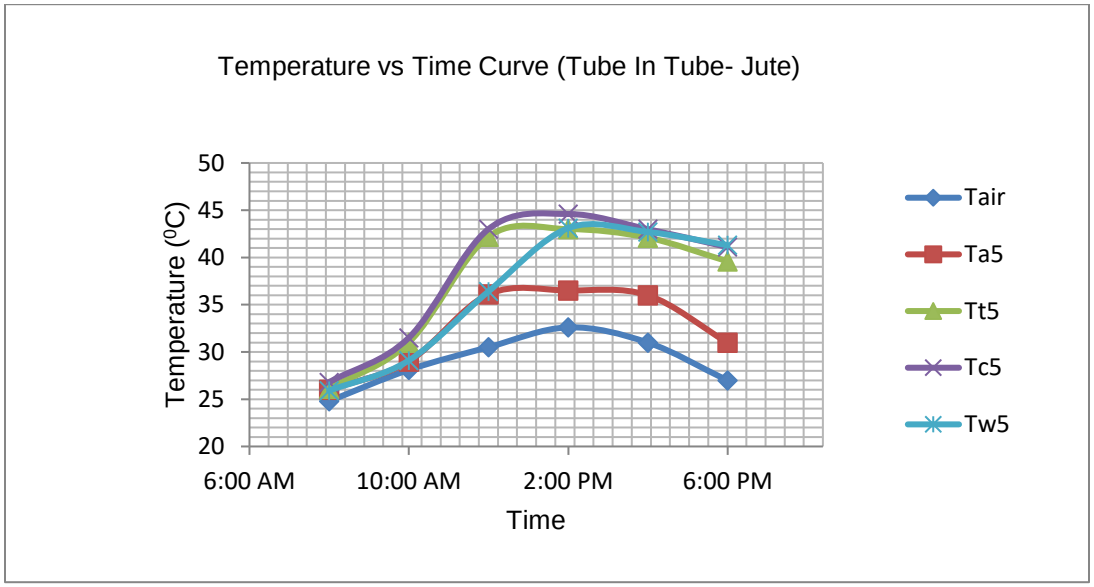

Figure 10: Temperature vs Time Curve (Tube in Tube- Jute)

The evaporation surface area was increased by wrapping a PVC pipe with composite fiber and placing it inside the tray. Two types of composite fiber was used- a) Jeans with microfiber cloth and b) Jute with microfiber cloth. It was found that the Tube in Tube (Jeans) gives a maximum of 72% increase and Tube in Tube (Jute) gives a maximum of 53.5% increase in distillate output from simple Tray in Tube system.

4.3 Cost Estimation

All the materials used in this experiment were locally available and easily affordable.
Total apparatus was handmade which made it very cheap. If it is fabricated commercially the cost of construction of the apparatus might be more reasonable than the cost mentioned above.

Materials	**Cost (BDT)**
Stainless Steel Tray	300
PVC Pipe	45
Cork Sheet	25
Transparent Plastic sheet	35
Composite Fibers	15
Super Glue	20
Stick Gum	10
Inlet pipe	15
Outlet pipe	15
Filter Paper	2
Total Cost	**482**

4.4 Discussion

This work could be implemented at a large scale to test its feasibility and broaden the scope for research. Systems for the research are assembled manually without taking quality under consideration. So, errors may occur in deriving output from the experiment.The mild curvature at the top of the tube slightly hampered the rolling down of water along the inner surface of the tube. So, a square tube placed at 45^0 angle with the horizontal may assist in overcoming the problem.

5. CONCLUSIONS

Tube in Tube (Jeans) outperforms Tray in Tube and Tube in Tube (Jute) systems in distillate output production. Although Tube in Tube (Jute) comes as a close competitor when it comes to distillate output collection. Tube in Tube (Jeans) gives 72% increase and Tube in Tube (Jute) gives 53.5% increase compared to Tray in Tube system. Tube in Tube (Jeans) seems to give a higher temperature reading compared to Tube in Tube (Jute) because it is superior in heat absorbing and storing than Tube in Tube (Jute) and Tray in Tube system. Jeans facilitates in rapid evaporation of water than compared to jute fiber. It was found that the Tube in Tube (Jeans) and Tube in Tube (Jute) exhibit 11^{o}C and 8^{o}C respectively. The salt concentrations measured of both feed and treated water were well below the acceptable 500 mg/l of World Health Organization (WHO). Although theoretically there should be no salinity at all. This indicates there might have been some mistakes along the course of the study.

ACKNOWLEDGEMENTS

We are very grateful to the Almighty Allah for giving us the patience and power to initiate and successfully complete this research. We would also like to express our sincere gratitude towards Prof. Dr. Quazi Hanidul Bari for his kind supervision and invaluable guidance which enabled us to complete the research

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