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SOLAR STILLS: A COMPARATIVE REVIEW OF SUSTAINABLE TECHNOLOGY

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Abstract: *Technological innovations vive incessantly, to provide pragmatic and innovative solutions to routine problems. At times conventional methods with modern adaptations prove to be effective and efficient solutions in a realistic manner. In a low resource setting, simple low-energy technologies are likely to succeed. One such technology available for water purification is the solar still. Solar stills use sunlight, to kill or inactivate many, if not all, of the pathogens found in water. This paper attempts to consider the prominent variants of solar stills available and compare the operational and functional parameters. An attempt has been made to provide an integrated comparative assessment so as to identify the optimal performance indicators in deciding the technology adaptation.*
Keywords: *Solar still, Comparative review, Sustainable technology.*

1. INTRODUCTION

Technology has affected society and its surroundings in many ways. In many societies, technology has helped the economic growth of countries and some technological processes produce unwanted byproducts, and deplete natural resources. There are various technologies which cater to the different needs for users. The available decentralized technologies such as Reverse Osmosis (RO), Electrodialysis (ED), Ion-Exchange (IE), Mechanical filters, etc. are asily available in the market but are energy intensive, require operational and maintenance (O&M), needs a skilled labour etc. Most of these technologies would tend to fail due to the lack of institutional support to sustain Operational and Management (O&M) Hence, in a country like India simple low-energy technologies are likely to succeed. One of such technologyis a solar still to treat the water. Solar stills would supply the basic minimum drinking water of man. Solar stills use sunlight, which can be used to kill or inactivate many, if not all, of the pathogens found in water.

Solar stills using solar energy could be an economical process since it doesn't cause air pollution, has no movable parts, and it is simple and flexible to produce fresh water. Solar stills can be broadly classified into passive and active solar stills. Active solar stills require external mode of thermal energy such as waste thermal energy from chemical/ industrial plant for faster evaporation. If no external mode is used then that type of solar still is known as passive solar still [1, 2, 3, 4]. From the literature review, it can be concluded that the passive solar stills can be economical to provide potable water and active solar stills system can be economical from a commercial point of view [5].

2. HISTORICAL PERSPECTIVE

The technology for converting sea and brackish water to potable water is well established. The first written description of desalination is traced to the Old Testament (Bible) (Vetus, M.Dc. XXVIII), in Exodus (22-25) (about 1500 BC).

In the first century A.D., the Romans are reported to have filtered sea water through lay soil to obtain drinking water [6]. Evaporation was known since the fourth century B.C., Aristotle described a method to evaporate impure water and then condense it for potable use. Della Porta (1589) used wide earthen pots, as shown in Figure 1 to evaporate water and collect the condensate into vases placed underneath [7,4,8].

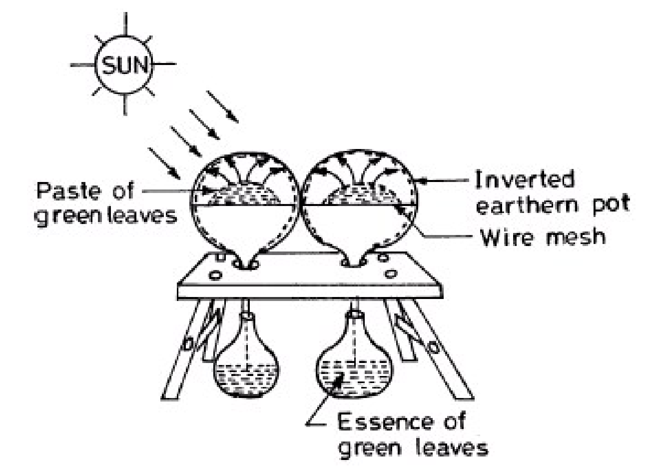

Figure 1: Historical Solar Distillation Apparatus

Source: [8]

The collection of water by distillation and condensation is a survival technique which can be used to collect small quantities of water from the ground, and is well-known, as shown in the Figure 2. Water evaporates from the soil, condenses on the underside of the plastic sheet, and collects in the cup or bowl. The disadvantages with these units are that algae growth underside of the sheet must be controlled, and the unit must be effectively sealed [9]. Stills made by making holes in the ground have advantage of their simplicity [10]. The output of each still falls off daily; this is due to the lesser availability of moisture content in the soil.

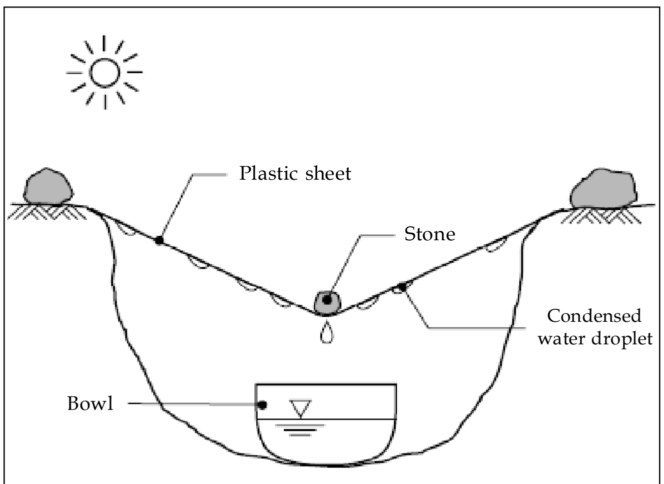

Figure 2: Simple Distillation and Condensation

Source: [9]

A simple low-cost method (Figure 3) to desalinate sea water by distillation is used in some countries where fuel is available [9].

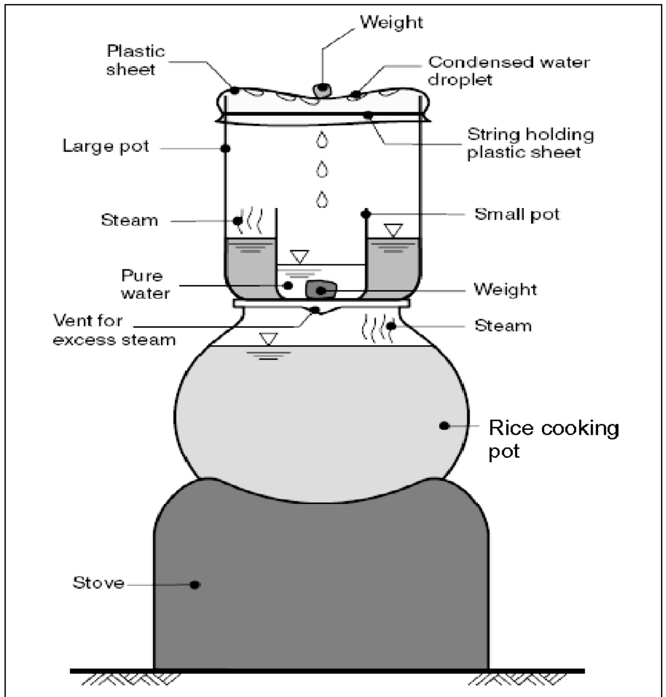

Figure 3: A Simple, Low-cost Method of Desalination by Distillation and Condensation Reproduced from RYFO Handout 655, (Courtesy of Dr Felix Ryan)

Source: [9]

3. TYPES AND COMPARISON OF SOLAR STILLS

Different types of solar stills available in the literature are conventional solar stills, single-slope solar still [11], double sloped solar still [11], vertical solar still, Multi-Wick solar still [3,4], Hybrid solar still [12,4]. The factors influencing the solar still productivity can be put into 3 categories: atmospheric variables (solar radiation, ambient temperature, wind speed etc), design features (brine depth, vapor tightness, condensate leakage etc) and operational techniques (Feed water preheating, feed water treatment etc) [13].

3.1 Principle of Solar Still

Solar stills are used to produce fresh water from sea and brackish water by directly utilizing sunshine. Construction and operation principles of solar stills are simple. A black-painted basin contains brackish or seawater. This is enclosed in a completely airtight area formed by a transparent cover. Incident solar irradiance passes through the transparent cover and is absorbed by the water and mainly by the black basin surface. Consequently, water contained in the basin is heated up and evaporates in the saturated conditions inside the still. Water vapors rise until it comes in contact with the cooler inner surface of the cover. There it condenses as pure water, runs down along the cover surface and water gutters due to gravity and is collected in vessels nearby [14]. While there are different variants as described in this paper, the fundamental principle of the function of a solar still is the same.

Characteristics of an Ideal Solar Still

Solar distillation [1], if a basin still is used, has a number of economic characteristics that are different from the other sea water conversion processes:

1. Unit construction cost is not affected appreciably by still size.
2. Power requirement is negligible.
3. The still is constructed on-site using unskilled or semi-skilled labor.
4. Operation and maintenance can be handled by people with little technical training.
5. Materials of construction are durable and readily available.

The still design is essentially modular; capacity of an existing still can be increased by any desired increment with practically no cost penalty.

3.2 Comparison of Carious Solar Stills

Figure 4 and Figure 5, depict single and double-basin solar stills. Each still's inner dimensions were 0.90X0.50 m and hence the effective distillation area of each still was 0.45m^2. The condenser surface of the still is made of 4mm ordinary glass. The angle of inclination of the front glass cover (facing south) is 36° to the horizontal while it is 90°for the back cover (facing north). The bottom side of the still is insulated with 50 mm polystyrene material. The double basin as shown in Figure 5 consists of two evaporators and two condensers. The upper evaporator is made of 0.01 m plexiglass to allow solar radiation to pass through and reach the lower evaporator. The lower evaporator is also made of plexiglass of same thickness, but painted black to absorb the maximum amount of incident radiation. The angle of inclination of both condensers is 12° to the horizontal. Double-basin still with insulation will enhance the water production compared to the single-basin still with or without insulation especially regions where there is more solar radiation such as Bahrain [11].

A conventional solar still is a single effect process and is characterized by the thermal disadvantages of single operation. This is mainly due to the horizontal surface of water intercepting less solar radiation than a tilted surface, heat loss by convection currents in the large air space, and also due to loss of latent heat of condensation to the air via the glass covers [15]. The efficiency of the solar still can be increased by,

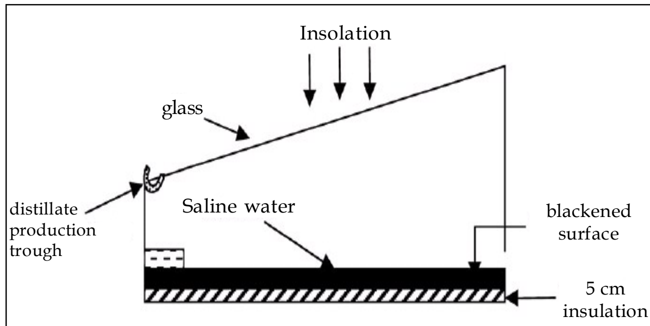

Figure 4: Cross Sectional Side View of the Single-basin Solar-still

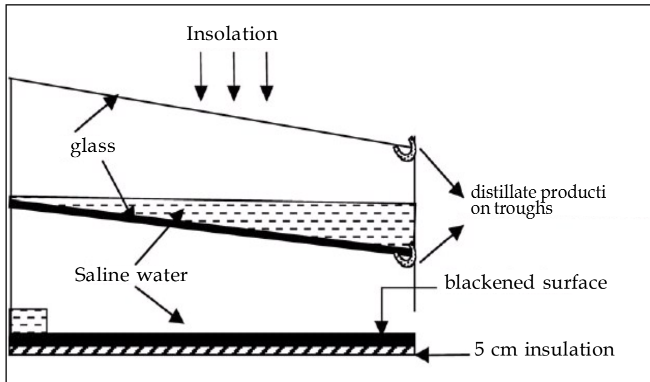

Figure 5: Cross-section of the Double-basin Water Solar-still Designed at the University of Bahrain

Source: [11]

having the liquid surface oriented at the optimal inclination to receive maximum solar radiation. This can be achieved by placing the transparent glass cover of the still parallel to the water surface to minimize the reflection losses and exposing smaller amount of saline water on larger surface to solar radiation as to get high temperature of water [16,3]. Some researchers have suggested having 10° glass (0.10 inch thickness) angles for stills from the horizontal [13,17]. The larger the cover angle results in a higher reflection of solar energy by the cover and lower thermal radiation from the basin to the cover [16]. This will minimize the thermal inertia by keeping small space between water and air space, which is also desirable on economic grounds [18]. It has been shown that for latitudes from 0 to 45 deg and cover slopes from 0 to 60 deg, there is little variation in the radiation productively absorbed [19]. The distillate (quantity) is largely a function of the brine temperature and the temperature difference between the brine surface and the cover [13]. An unfortunate side effect of designing stills to operate at high temperatures is that the glass becomes more hydrophobic. This is coupled with high peak distillation rates, promotes partial drop-wise condensation, so increasing the reflection losses from the glass [20]. While Bloemer *et al.* 1965 experiments has shown that the thermal radiation from the basin water to the basin cover as being the largest loss of solar energy followed by the reflected radiation from the basin water and still cover. The percentage reflectance, absorptance and transmittance for the cover, water and basin liner of a typical solar still for different angles of incidences have been studied and it can be concluded that for 45 degree of angle of incidence the transmittance is about 89 per cent. Any significant increase in it by lowering the absorptance is not economically justified considering that, a normal incidence, 5 per cent of the 10 per cent transmission loss is due to reflection (Cooper 1973). For example, the effective absorptance is about 85 per cent for 30 degree of angle of incidence (Cooper 1973) and hence the productivity of solar still decreases because of more losses. Analysis and experiment have indicated that prevention of reflecting layers of salt on the basin water and surface is of far more importance than designing for maximum transmission of radiation [19,21]. In comparison with double sloped solar still; the single slope solar stills absorbs heat more efficiently and has lower heat losses [18]. Several authors suggested a multiple level, double-basin still [11].

In order to increase the output various other kinds of stills have been recommended such as multiple-effect solar stills (For example, Chimney type solar still), but this involves complexity in the designs and increased capital cost. It operates more efficiently at higher temperature. Other examples which were limited to laboratory demonstration units such as cascade solar stills and tilted wick solar stills never reached a scale-up to commercial sizes [2]. In one of the comparative studies done by [22] on conventional basin-type, wick type and wick-basin type it can be concluded that later is more economical and produced higher output and efficiency (43% to 85%).

Figures 6 to 9 are the different designs of solar stills made of fiber reinforced plastic (FRP). The solar stills are made of glass fiber or bisphenol 'A' polyester composite. A novel feature of single slope basin is the absence of the insulation on the sides and bottom. The life expectancy of this kind is atleast 10 years, easy to handle and set-up. Single slope FRP multiwick suffers from some drawbacks; the horizontal surface of water intercepts lesser solar radiation than a tilted surface. The output of basin-type solar still is also limited by the large thermal capacity of the water basin. The double slope FRP multiwick solar still is more economical as compared to single slope FRP

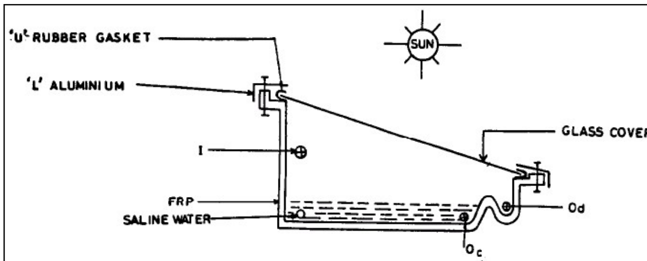

Figure 6: Cross-sectional View of the Single Slope Basin-Type FRP Solar Still

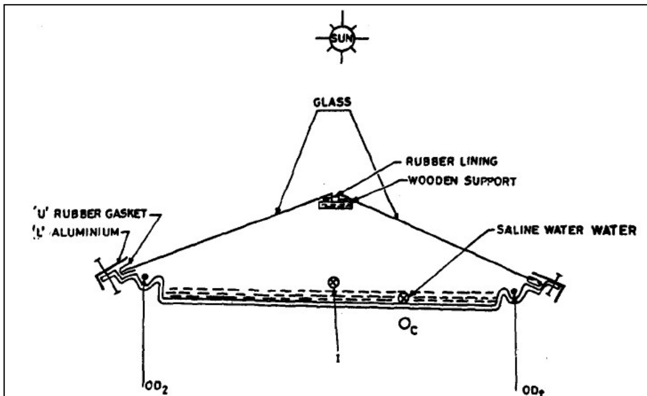

Figure 7: Cross-sectional View of Double Slope FRP Basin Type Solar Still

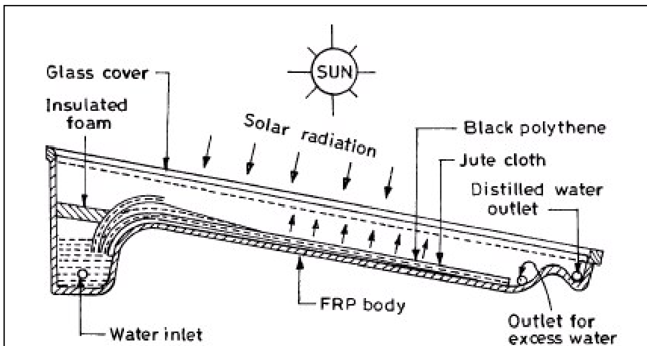

Figure 8: Cross-sectional View of FRP Multi-wick Solar Still

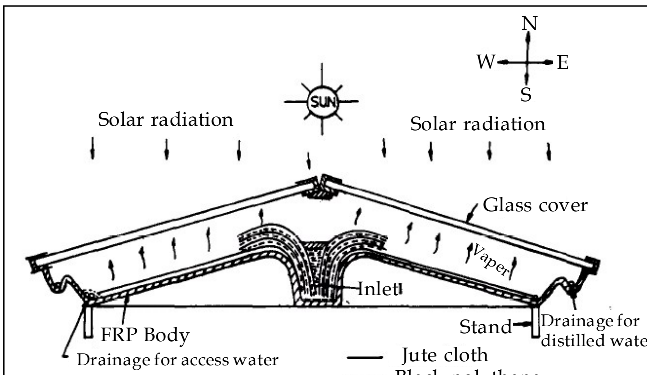

Figure 9: Cross-sectional View of the Double Slope FRP Multiwick Solar Still

Source: [3,4]

multiwick solar still due to absence of two vertical walls and one reservoir. It is evident that single slope FRP still (either basin-type or multiwick type) gives higher distillate output in winter and double slope still (either basin type or wick type) gives higher yield in summer [3,4].

The performance of ordinary basin-type solar still can be enhanced by increasing the solar radiation penetrating and increasing the rate of vapor condensation in the still by extending the condensation surface or by lowering the temperature in the interior of the still. Five stills as shown in the Figure 10 (1a-1e) of same dimensions but different designs were considered. The (1a) basin is the ordinary basin still with glass top cover and side walls of galvanized steel. The (1b) is same as the (1a) but modified with four open glass tubes crossing the still and the back side made of finned galvanized steel. The (1c) is modified design where two side walls and front as well as the top cover are fabricated from glass; the (1d) one is similar to still (1c) except that back side is fabricated from finned galvanized steel. The last still (1e) is similar to still (1d) besides having four open glass tubes crossing the sides of the still. (1e) still marked highest efficiency both in summer and winter respectively, because of the fins and crossing tubes in comparison with unfinned stills. The advantage of fin stills are it allows convection currents of air to remove some of the heat from the still interior, thus enhancing the condensation of the vapor phase. It can also be noted that glass sided still has a higher productivity than a still made of galvanized iron, because, the former allows more solar radiation penetration to the basin and thereby increases the brine temperature that affects evaporation [23].

There are various other physical and chemical means to increase the productivity such as addition of charcoal pieces to the basin liner, adding dye to saline water, treating glass glazing with either sodium metasilicate or hydrofluoric acid and cooling the cover [23]. The addition of dye increases the productivity of the still because about 2-6 per cent radiation is directly reflected back by the clean water, and the rest is transmitted through the water surface in the basin, 30 per cent of the radiation is absorbed by the water, and the rest is further reflected and absorbed by the basin liner [17]. While the other researchers [24] states that each method mentioned above has some drawbacks, namely the distillate quality is affected because of addition of dye, low production rate, need of pumps with flow control and screen rusting etc.

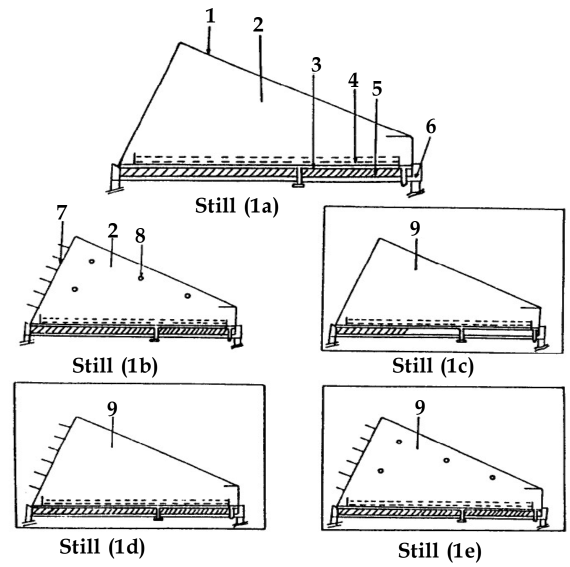

Figure 10:(1a-1e) Schematic Drawing of Different Ordinary Single Basin-type Stills. 1. Top Cover (glass) Trough. 2. Still Sides (galvanized steel). 3. Condensation. 4. Saline Water. 5. Insulation. 6. Stand Tubes. 7. Finned Back (galvanized. 8. Open Glass. 9. Still Sides (glass).

Source: [23]

Figure 11, depicts the combined effect of black dye and reflectors (mirrors). A solar still is made of a square basin from galvanized steel with three upright sides truncated toward south at an angle of 45°. The sides are covered with on the reflectors inside. The base and sides are insulated with glass wool. The 3mm thick glass was used as a glazing surface. The basin was covered with an asphalt layer to maximize solar absorption. The still works on the bulk evaporation principle. The humid air inside still, as it ascends into the space above the water surface due to buoyancy effect, due to its internal energy and reaches the interior surface of the glazing, it cools down the surface and may reach an over saturation condition where the moisture in it becomes drops of water or dew. Some amount of heat is released from the condensation surface to the atmosphere through convective heat transfer. It is experimentally found that, the combined effect improves the still performance considerably. But using only dye has small or minimal effect and it is recommended not to use dye due to the pollution related problem and distillate quality. However, reflectors have a major effect. The effective product of the experimental ones is relatively less to that of theoretical ones because occurrence of the dropwise condensation which in turn reduces glass transmissivity [25]. The cooling of

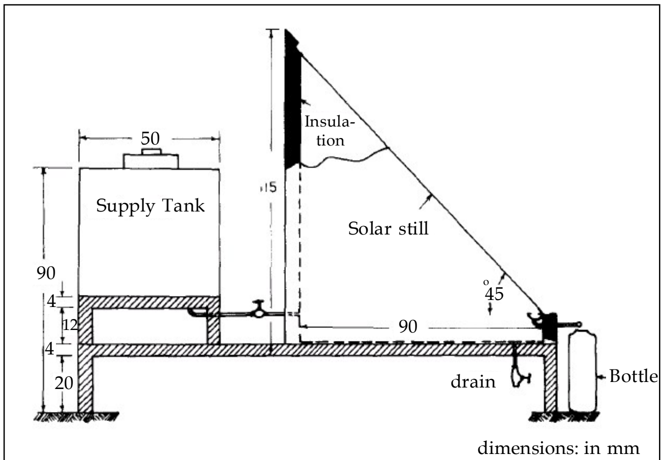

Figure 11: Solar Still with Reflector and Black Dye

Source: [25]

the cover by running ice water immediately showed high increase in condensation rate [10].

The experimental setup as shown in the Figure 12, consists of a Perspex rectangular shaped box. Saw dust was spread evenly on its bottom and a plastic sheet was placed above. Charcoal particles (fine, intermediate and coarse) of uniform size are placed on the plastic sheet. The glass plate was sealed to the box air tight. The still was placed at variable inclination to the horizontal and at 17° inclination higher productivity was observed. The experiments were carried out at different flow rates. In general it can been concluded that at high flow rates both coarse and intermediate particles showed the best productivity, whereas both moderate and low flow rates for fine charcoal gave slightly better productivities. This could be due to the fact that coarser the charcoal is glossier, its surface resulting in light reflection through the cover with consequent

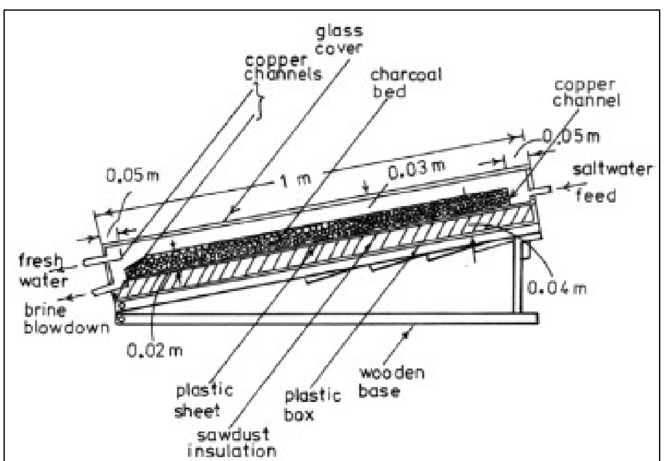

Figure 12: Schematic Diagram of the Charcoal Solar Still

Source: [15b]

heat loss. This effect is observed at low flow rates when the particles are not all completely covered with a water layer, leading to high losses. On the other hand, at high flow rates a layer of water covers the particles so that the long wavelength infrared heat rays, which are reflected from the particle surface, are absorbed rapidly by the water layer and thus made use of. Moreover, at high flow rates, the finer particles gave poor results probably due to the fact that water had diffused into the tiny particles of large surface area with the consequence of temperature drop between inside and outside particles resulting in low rate of heat transfer between the particles and the water, a condition minimum in case pf coarse particles. From the study it was also concluded that charcoal led to a better still productivity (15%) than when a wick type solar basin. The charcoal is resistant and will not wear out as in case of jute cloth. Moreover, purification of the water from soluble contaminants can be achieved simultaneously, which is an important merit of the still [15a]. The main disadvantage with tilted stills is the nocturnal production is zero [26].

For any solar stills to be efficient, it should be able to store some amount of excess heat energy during sunshine hours for the continuation of the process at night. This can be achieved by reducing the temperature of the water in the evaporating zone using energy storage material (ESM), and thereby decrease the evaporation rate during the day. The maximum efficiency for such stills can be found between 57 % to 62% which is higher than that of the insulated shallow horizontal basin still [26]. The excess energy can be stored by using energy storage element such as distilled water, phase change mixture [15b], layer of black cloth or thin plate [27], floating perforated black aluminum plate [28] increases the productivity.

Conventional solar stills suffer from low efficiencies due to loss of heat of condensation to the surroundings via glass cover. The apparatus shown in the Figure 13, is a small-scale still equipped with an energy storage element. It shows the outer container, the saline tray, the frame, the copper sheet and the space containing energy storage material (ESM); the insulation, and in addition the glass cover, inlet and outlet pipes for the salt and distillate water and the fixed thermometers. The inner side is lined with thick aluminum foil. The experimental results showed that the productivity was very low without ESM. By increasing the operational time, the productivity can be enhanced slightly better. If distilled water is used as ESM, the result improved

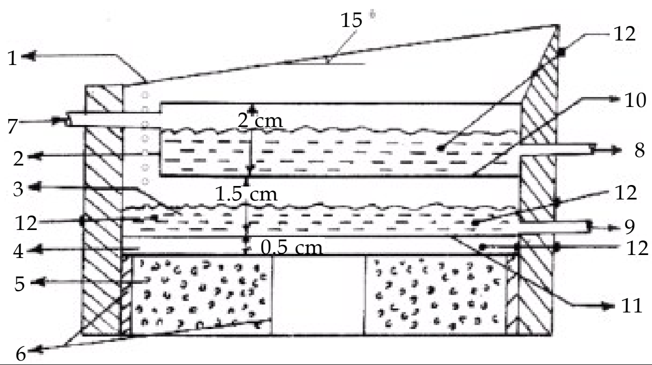

Figure 13: Cross-sectional Schematic Side View of Solar Still Coupled with Energy Storage 1. Glass Cover; 2. Saline Water, 3. Distilled Water, 4. Energy Storage Material (ESM), 5. Insulation (Saw Dust), 6. Frame Holder, 7. Saline Water Inlet, 8. Saline Water Outlet, 9. Distillate Water Outlet, 10. Black Cloth, 11. Copper Sheet, 12. Thermometers.

Source: [15a]

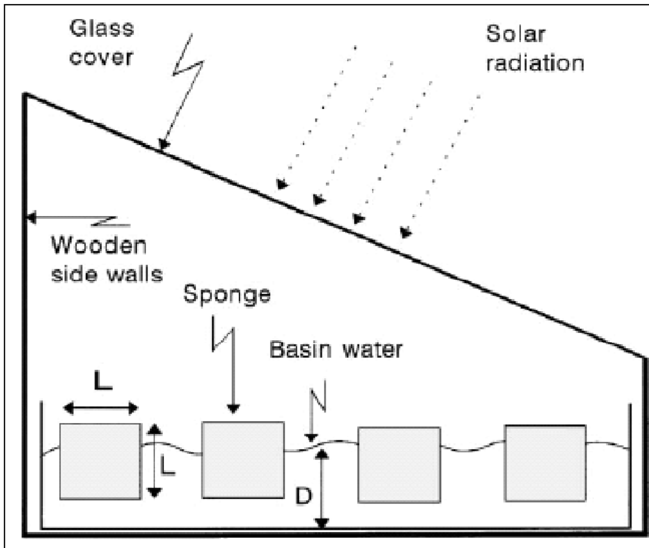

Figure 14: Side View Schematic of the Solar Still with Sponge Cubes

Source: [29]

compared to the above said cases. Using phase change mixture (such as emulsion of paraffin wax, paraffin oil and water with aluminum turnings), the volume collected over night quadrupled when phase mixture was used instead of water. The energy storage mixture which slowly releases its heat overnight during solidification over its melting range was used for production of water. This resulted in less operational time compared to other cases [15b].

Figure 14, shows a schematic of a still with sponge cubes, 50 cm X 50 cm. The glass inclination angle was 23°. Sponge cubes (Yellow, Black, Black steel and Coal) were placed in the cube basin water in order to increase the wetted surface area in contact with the hot air inside the still. The small openings in the sponge cubes also reduce the surface tension between the water molecules, these making it easier for the water molecule to evaporate. The presence of sponge cubes suppresses heat transfer convection currents in the basin that reduces the amount of solar radiation reaching the basin. This reduces the heat transfer losses from the bottom of the still. Basin depths played a vital role in productivity of distillate. Increasing the basin water depth reduces the height of the sponge that is exposed above the water surface. The shorter the height, the more water will rise to the top of the sponge by capillary forces, thus increasing the evaporation rate. If the cube size is increased reduction in productivity as there is reduction in capillary forces to raise the basin water was observed. The evaporation rate of the large size cubes can be enhanced by using low thermal capacity and low thermal conductivity, resulting in larger area of high temperature localized zones.

Yellow colored sponge cubes reflects some incident radiation onto the side walls of the still. This increases the heat loss from the side of the still to the ambient, thus reducing the production ratio. The black steel cube showed better production ratio compared to coal cubes. This is due to higher thermal conductivity of steel. In comparison with yellow sponge, the productivity with black steel cube was less, and may be due to a capillary effect. It was expected that black sponge cubes would give higher productivity compared to yellow ones, but this was not so, as the black paint was sprayed to the cubes and the voids were blocked. It must also be noted that, as salinity increases in the basin, its density increases and its vapor pressure decreases and inturn reduced the effectiveness of the capillary forces [29].

On the other hand, researchers (Szulmayer, 1973; Nafey *et al*, 2001) suggested thin layer of water above the float. This gets heated up more quickly and reached a higher temperature than the main bulk of water below the float. This will ensure the base of the still was kept cooler, so heat losses through conduction to the ground were reduced.

The solar desalination unit shown in the Figure 15 was fabricated from galvanized sheets and insulated from all sides except the glass cover. The heat storage zone is constructed by placing an aluminum sheet, painted black at the top surface and thermally insulated at the bottom, 25 mm below the water level. The aluminum plate divided the unit into

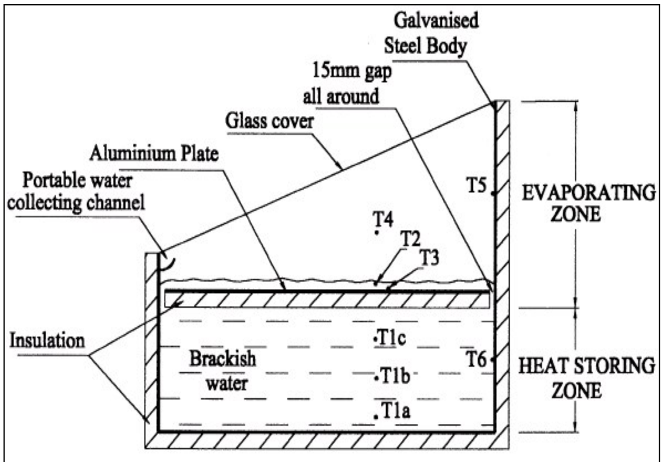

Figure 15: Schematic Diagram of Solar Desalination Rig. T1-T6-Temperature

Source: [26]

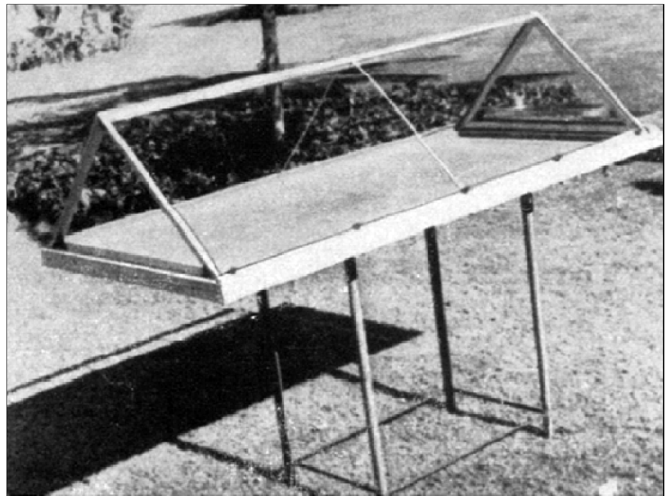

Figure 16: Roof type Solar Still

Source: [31]

a shallow basin evaporating zone above the plate and a heat-storing zone below the plate. This is found to be cheap, simple and effective method to store excess heat energy in horizontal solar stills, able to restore the temperature in day time in evaporating zone and requires no external power required for storing and recovery process. During sunshine hours, the internal face of galvanized walls of the rig above the water level, which is painted black, absorbed part of solar energy, entered the system, and its temperature was raised. Due to the temperature difference, convection currents gradually and continuously replace the relatively cold water by plate by that of hot water below the plate, through the gap. The evaporation and condensation processes will continue until all the heat stored in the system is exhausted. The present system in comparison with shallow basin still, the latter doesn't have heat-storing zone and some amount of heat is lost to the surroundings by radiation mechanism [26]. For a low temperature range, solids (Black rubber mat) may be used for energy storage which enhances the distillate productivity by 38% [28,30].

Figure 16, shows the roof type solar still of shallow depth, made of aluminum and total area of 1.27 m^2. The still was made of aluminum because of its light weight and easy to transport to distant places. It is simple and cheap still which mainly dependent upon solar radiation. From the experiments it can be noted that wind speed also plays a vital role for the productivity. It was recommended to construct the still not directly on the ground but on support to keep it at a higher level, due to fact if there is any maintenance it would be easier to handle and to use a glass cover with relatively greater width. The productivity of roof type solar still is very low during winter [31].

Figure 17, shows the schematic diagram of the Basin-type and Wick-Basin type solar still. The conventional still basin is made of galvanized iron, 1.5 X 0.67 m in dimension and the cover was at angle of 15° to the horizontal. The basin liner was of polystyrene, 5cm thickness and 1 cm thick saw dust. The wick-basin has two parts; the first part was a tilted wick-type solar still had an evaporating area of 1 m^2, whereas the second was a conventional basin-type. The wick material was blackened jute material. The preheated brine water leaving the wick type was arranged to feed directly the small conventional basin-type through a pipe. To receive maximum solar radiation, the wick type was kept at an inclination of 25° during summer months and 45° during winter

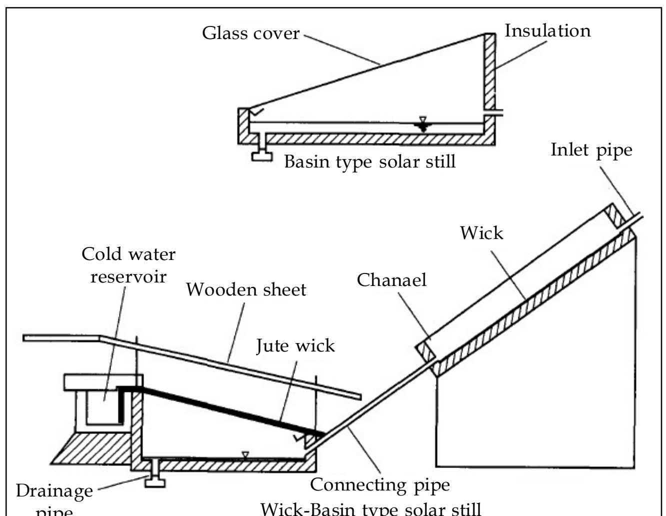

Figure 17: Basin Type Solar Still and Wick-Basin Type Solar Still

Source: [22].

months. Cold water reservoirs were made out of porous ceramics containers to cool the water and a reduction of 10°C in water temperature was observed during hottest day. This may explain the effectiveness and cheapness of cooling. It was observed that jute cloth (wick) possesses good capillary ascension of water. From the experiments it was revealed that wick-basin type gives higher output in comparison with conventional basin type. From the economic evaluation it can be concluded that the cost of distillate making is low for wick-basin type compared to wick-type and conventional basin-type stills [22]. One major disadvantage of wick-type could be wear and tear of jute cloth [15].

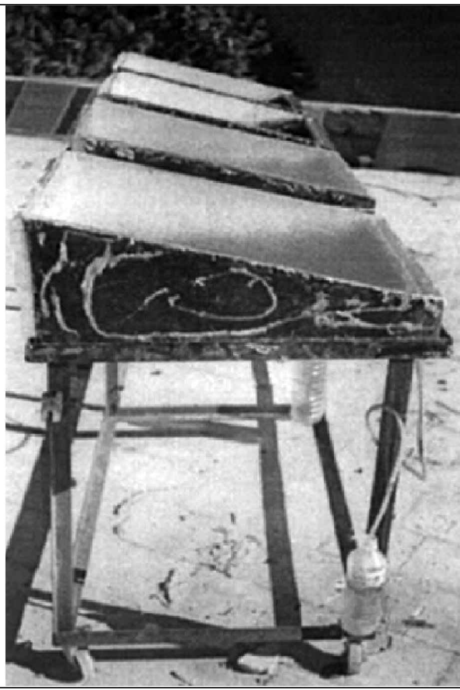

Figure 18: Four Units of Single Sloped Solar Still

Source: [28]

The fresh water productivity can be enhanced by 38% by using black rubber mat was suggested by [28]. [30] reported that solids have been used for energy storage in low temperature range, particularly in solar systems for space heating.

The Figure 18, shows four units of a single sloped solar still, the sides were made of steel sheet (0.002m thick) and were painted with white paint from inside in order to reflect the solar radiation to the water surface. The basin (0.5m X 0.5 m) was painted with black color to increase the solar absorptivity. The outside walls and the base of each unit were insulated with foam (thermal conductivity = 0.04 W/m K) of 4 cm thick. Silicon rubber sealant is used to prevent leakage from any gap between the glass covers and the still box. To examine the effect of black rubber thickness on the solar productivity, three pieces of black rubber material with thickness of 2, 6 and 10 mm were used with different brine volumes of 30, 40, 50 and 60 L/m^2. It was further extended by using black gravel of 7-12, 12-20, and 20-30 mm, sizes respectively for 30, 40 and 50 L/m^2.

The daily productivity increases as the rubber thickness and brine volume increases. The productivity of the solar stills can also be increased by 15% for 2 inch deep basin and 20-30% for 1 inch deep basin by providing insulation under the basin [33]. It can be said that productivity increases with decrease in water depth of the insulated; as thermal mass, higher operating temperatures and efficiencies are attained [17,20]. For a given ambient temperature, the driving potential for base and side losses increases as the water temperature increases, so underlining the importance of insulating the still [20]. For a large-basin still, the practical minimum brine depth is about 2 inch for reasons of economical grading, handling feed water and prevention of dry spots on the basin liner. The basin liner needs to be cleaned periodically because of build up of deposits. This becomes an expensive maintenance item, as part of the cover must be removed and considerable labor expended [13]. This deposit can be readily be removed by cleaning with a dilute acid solution such as citrix acid or oxalic acid [34]. Various authors suggested [35] usage of insulation at the bottom of the solar still such as fiber board or fiber glass, foam etc to provide light weight, low cost of the still and a significant output. While Bloemer et a., 1965 experiments have shown that the heat losses due to conduction and convection from the still to the surrounding exclusive of the still cover as being relatively small. But it is reported by another author [36] that the minimum brine depth inside the solar still is recommended as 5 cm depth to prevent dry spots from occurring on the basin liner. Around 20 % of increase can be observed with 60 L/m^2 brine depth for black rubber.

Similarly for black gravel experiments were conducted; the daily productivity of the solar still increases as the gravel sizes increases. This may be explained by the capability of large gravel size to absorb large amounts of the incident solar energy. Also, for the same weight of gravel, the spaces between the large sizes if gravels are considerably wider, this is occupied with a large amount of water, which in turn results, in a thin layer of water above the black gravel. Therefore, an increase of the evaporation process is obtained. The enhancement was about 19 % for 20 L of brine water and glass cover inclined to 15°. The enhancement in this case showed decreasing trend by increasing the brine volume. From the general behaviors it can be concluded that the curves were close in black rubber case and the curves were slightly separated in black gravel case. It may be concluded that the gravel is faster than the rubber in absorbing solar radiation and is faster in releasing this energy to the basin water.

4. CONCLUSION

There were various suggestions provided by various researchers to increase the solar output, such as rain water collection, usage of glass instead of plastic, using pre-heated water or waste hot water or solar collector feed. After having a thorough review of various literatures there is a need for modification in design. This is expected to yield a higher distillation rate to meet the drinking water needs of society. This can be achieved by incorporating retention of higher latent heat in the system during day as well as night, when the productivity is actual zero in most of the other designs as discussed previously. The design should be robust, easily available, affordable and easily maintained. Implementation of social marketing of solar stills will help to promote the products for wider dissemination to use the technology. Thus the above technology has all the potential to be one of the cost-effective and pragmatic solutions to the water problems of rural areas in developing countries.

Implementing this technology on a pilot basis to ascertain the effectiveness and design factors would enable it to be adopted on a large scale basis. Social marketing techniques and modern management principles may be used appropriately to augment and promote the adoption of this technology on a large scale basis across the nations.

References

Bloemer, W. J., Eibling A. J., Irwin R. J., Lof G O., George. (1965), A Practical Basintype Solar Still. Solar Energy Society Conference, Phoenix, Arizona, March 15-17:197-200.

Delyannis, A., Delyannis, E. (1983), "Recent Solar Distillation Developments", *Desalination*, 45, 361-369, Elsevier Science Publishers B.V., Amsterdam.

Yadav, Y. P., Tiwari, G. N. (1987), "Monthly Comparative Performance of Solar Stills of Various Designs", *Desalination*, 67 ,565-578.

Tiwari, G. N., Singh, H. N., Tripathi, R. (2003), "Present Status of Solar Distillation", *Solar Energy Elsevier,* 75, 367-373.

Singh, H. N.,Tiwari, G. N. (2004), "Monthly Performance of Passive and Active Solar Stills for Different Indian Climatic Conditions", *Desalination,* 168, 145-150.

Ayoub, J., Alward, R. (1996), "Water Requirement and Remote Arid Areas: The Need for Small-scale Desalination", *Desalination,* 131-147.

Nebbia, G., Mennozi, G. (1996), A Short History of Water Desalination. Acque Dolu Dal Mare, II Inchiesta Internazionaole, In:Proceedings of International Symposium, Milan, 129.

Delyannis, E. (2003), "Historic Background of Desalination and Renewable Energies", *Solar Energy,* 75, 357-366.

Smith, M., Shaw, R. (1999), "Desalination. WEDC Loughborough University Leicestershire LE 11 3TU UK, *www.lboro.ac.uk/departments/cv/wedc/*

Ahmadzadeh, J. (1978), "Solar Earth-Water Stills", *Solar Energy,* 20, 387-391.

Al-Karaghouli, A. A., Alnaser, W. E. (2004), "Experimental Comparative Study of the Performances of Single and Double Basin Solar-stills", *Applied Energy Elsevier,* 77, 317-325.

Varol, H. S., Yazar, A. (1996), "A Hybrid High Efficiency Single Basin Solar Still", *Int. J. Energy Res.*, 20, 541-546.

Eibling, J. A., Talbert, S. G., Lof, G. O. G. (1971), "Review Article-Solar Stills for Community Use-Digest of Technology", *Solar Energy,* 13, 263-276, Pergamon Press.

Bouchekima, B. (2002), "A Solar Desalination Plant for Domestic Water Needs in Arid Areas of South Algeria", *Desalination,* 153, 65-69.

Naim, M. M., Mervat, Abd El Kawi (2002(a)), "Non-conventional Solar Stills Part 2. Non-conventional Solar Stills with Energy Storage Element", *Desalination*, 153, 71-80.

Naim, M. M., Mervat A., Abd El Kawi (2002(b)), "Non-conventional Solar Stills Part 1. Non-conventional Solar Stills with Charcoal Particles as Absorber Medium", *Desalination*, 153, 55-64.

Moustafa, S. M. A., Brusewitz, G. H., Farmer, D. M. (1979), "Direct Use of Solar Energy for Water Desalination", *Solar Energy*, 22, 141-148.

Garg, H. P., Mann, H. S. (1976), "Effect of Climatic, Operational and Design Parameters on the Year Round Performance of Single-sloped and Double-sloped Solar Still Under Indian Arid Zone Conditions", *Solar Energy*, 18, 159-164, Pergamon Press.

Szulmayer, W. (1973), "Solar Stills with Low Thermal Inertia", *Solar Energy*, 14, 415–421.

Cooper, P. I. (1971), "The Transient Analysis of Glass Covered Solar Still", Ph.D. Thesis, Univ. of Western Australia, Australia.

Cooper, P. I. (1973), "The Maximum Efficiency of Single Effect Solar Stills", *Solar Energy,* 15, 205-217.

Cooper, P. I. (1972), "Some Factors Affecting the Absorption of Solar Radiation in Solar Stills", *Solar Energy*, 13, 373.

Minasian, A. N., Al-karaghouli, A. A. (1995), "An Improved Solar Still: The Wick-basin Type, Energy Conversation Mgmt, 36 (3), 213-217.

Monem, A., El-Bassouni, A. (1993), "Factors Influencing the Performance of Basin-type Solar Desalination Units", *Desalination,* 93, 625-632.

Lawrence, Gupta, S. P., Tiwari, G. N. (1988), "Experimental Validation of Thermal Analysis of Solar Still with Dye", *Int. J. Solar Energy*, 6, 291-305.

Tamini, A. (1987), "Performance of a Solar Still with Reflectors and Black Dye, Solar and Wind Technology", 4, 443-446, Pergamon Journals Ltd.

Rahim, N. H. A. (2003), "New Method to Store Heat Energy in Horizontal Solar Desalination Still", *Renewable Energy*, 28, 419-433, Elsevier.

Malik, M. A. S., Tiwari, G. N., Kumar, A., Sodha, M. S. (1982), *Solar Distillation, Solar Energy,* Pergamon Press, Oxford UK.

Nafey A. S., Abdelkader M., Abdelkader A., Mabrouk A. A. (2001), "Solar Still Productivity Enhancement." *Energy Conversion and Management*, 42, 1401-1408, Elsevier.

Bassam, A/K Abu-Hijleh., Rababa'h M. H. (2003), "Experimental Study of a Solar Still with Sponge Cubes in Basin", *Energy Conversion and Management*, 44, 1411-1418, Pergamon, Elsevier.

Mustafa, M. E., Taha, I. S., Sabbagh, J. A. (1994), "Design of Solar Thermal Systems", King Abdulaziz University, Jeddah: Scientific Publishing Center.

Elnesr, M. K., Soliman, S. H. (1964), Experimental Studies on Solar Stills and their Performance Characteristics, Pure and Applied Geophysics. *Birkhauses Basel,* 59 (1), 261-266.

Cooper, P. I. (1969), "The Absorption of Radiation in Solar Still", *Solar Energy,* 12, 333-346. Pergamon Press, Great Britain.

Ward, J. (2003), "A Plastic Solar Water Purifier with High Output", *Solar Energy,* 75, 433-437.

Sodha, M. S., A. Kumar, Singh U., Tiwari G. N. (1981), "Utilization of Waste Hot Water for Distillation", *Desalination,* 37, 325-342.

Mansour, A. M. (1974), Investigation of Engineering and Economical Evaluation of Solar Distillation, M.Sc Thesis, Cairo University.