Solar Desalination

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In spite of the large quantities of fresh water supplied by rainfall in Sri Lanka, there is uneven distribution of rainfall in many regions. In some arid areas, even ground water is brackish and no other source of drinking water is available. Hence there is a definite need for distilled water for drinking purposes although such requirements are limited. Also, distilled water would be required in lesser quantities for lead-acid batteries and for chemical laboratories.

Vapour compression desalination, electrodialysis and flash distillation are some of the existing methods of producing fresh water. However, these techniques involve high capital investment and utilise conventional energy sources.

Solar energy can be used for desalting of saline or brackish water. Solar distillation does not produce water where there is none but simply purifies water supplies in areas where there is adequate water which is unfit for human consumption or other activities. Solar distillation plants have been known for more than a hundred years. The first solar still was established for the mining community in Las Salinas, Chile, in 1872. Exhaustive development work on solar stills have been carried out only in recent years and the largest one in operation today covers an area of one hectare and is situated in Greece. Solar stills, however are not yet competitive with conventional desalination plants. Considering the transport costs or supply of water by pipe lines in remote areas where no other source of drinking water is naturally available, small scale stills may serve its purpose and be economically feasible.

Sri Lanka is situated 8^0 N latitude, and is blessed with sufficient sunshine where the intensity of solar radiation could vary between 300 to 500 cals to cals/cm^2 /day during the year. Hence due to the abundance of solar energy, solar distillation could suffice when water requirements are small and no other cheap energy source is available for desalination. Thus development work on solar stills was carried out at the Ceylon Institute for Scientific and Industrial Research (CISIR) with a view to setting up of small community stills to provide drinking water and also providing distilled water for lead-acid batteries and chemical laboratories.

THE WORKING PRINCIPLE

The simplest type of solar still is the basin type which consists of a shallow basin covered with a transparent roof (Fig. I). The basin is coloured black and the saline or brackish water is introduced on to this black surface. Incident solar radiation passes through the transparent cover and is absorbed on the black bottom and provides the heat to evaporate the saline water. Water vapour moves upwards towards the transparent covers which are cooler and condenses on the underside and rolls down into channels and is collected in receivers.

The shortwave radiation of visible light is able to pass through the transparent cover but the longwave radiation of heat does not. Thus most of the heat generated in the still is trapped as longwave radiation emitted by the hot water which cannot escape through the cover to the outside. The temperature in the still raises steadily and stabilizes when the heat losses to the outside equal the incoming radiant energy.

Part of the solar radiation falling on the still is reflected or absorbed by the cover. The energy falling on the evaporation surface is not completely used for distilling but is lost by reflection, convection, radiation from the covers and through conduction from sides and bottom. Any leakage of vapour of liquid from the still involves additional thermal loss. Due to losses and the diffuse and intermittent nature of solar radiation, the efficiencies obtained in practice are low and the output of a solar still per unit area is low. Efficiency is calculated in the following manner.

$$\text{Efficiency} = \frac{\text{Energy required for vaporization of distillate that is recovered}}{\text{Energy in the sun's radiation that falls on the still}}$$

EFFECTS OF CLIMATIC FACTORS ON SOLAR STILL PRODUCTIVITY

Intensity of solar radiation, ambient temperature, annual rainfall and wind velocity are four major climatic factors that influence the productivity of a solar still.

The most important factor affecting the solar still performance is the intensity of solar radiation. The higher the intensity, the greater is the distillate output. As the direction and intensity of solar radiation impinging on the still varies throughout the day for various months of the year, the output varies both by hour of the day and by season.

The solar energy received on the earth is a combination of radiation from the rays of the sun (direct radiation) and energy originating from the sun but scattered by clouds, or dust particles in the air (diffuse radiation). Although in a solar still both direct and diffuse radiation are utilised, most of the energy available for distillation arrives as direct radiation. The maximum direct radiation occurs at the hours and seasons when the sun is directly overhead. During the day this occurs at noon and radiation intensity is nearly zero in the early mornings and late afternoon hours. Hourly productivity in a solar still follows the solar radiation intensity pattern but lagging behind it. This is due to the time lag in heating and cooling the water within the still.

Higher ambient temperatures increase the output of solar still slightly. Rainfall will stop the

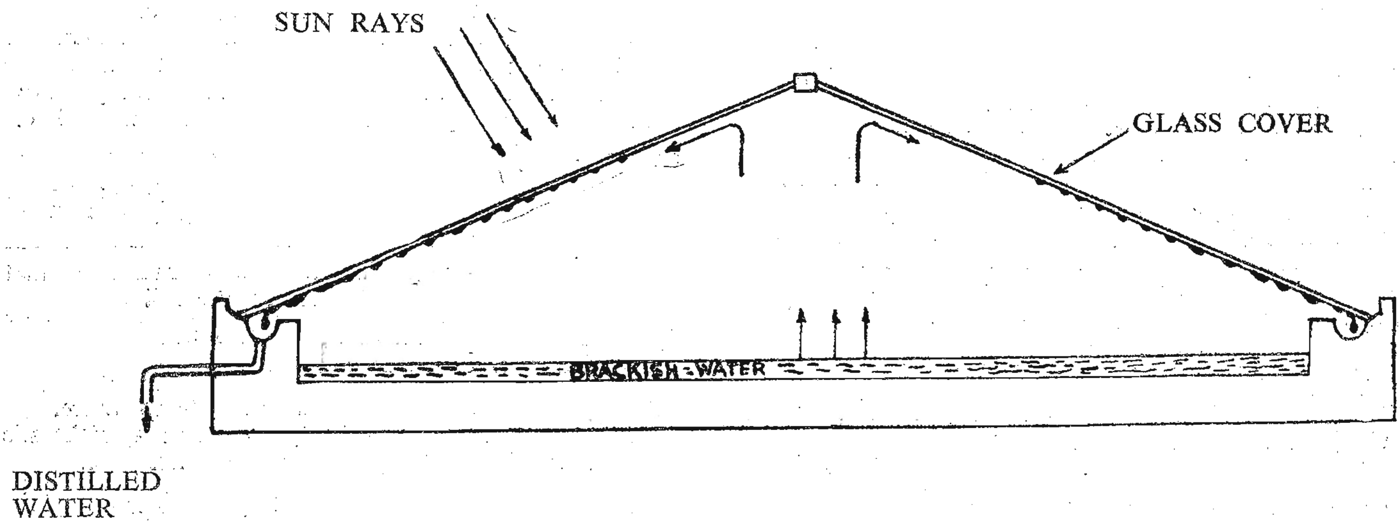

FIGURE 1 BASIN TYPE STILL

production of solar distilled water but a solar still cover could be used as a catchment for rainfall which could compensate for the loss. High wind velocities tend to cool the covers rapidly, thus lowering the temperature of the still, which in turn would decrease the productivity.

EFFECTS OF DESIGN ON PRODUCTIVITY

The basin type still is generally accepted as the best design in that it is the most economical and practical. Brine depth, vapour tightness, condensate leakage, basin insulation are factors which could appreciably affect the productivity of a still and to a lesser extent cover slope and elevation.

Shallower brine depths reduce the heat capacity of the still, thus giving higher brine temperatures, resulting in increased productivity. However nocturnal output is greater with deep layers. This is due to the fact that the large heat capacity of the brine layer causes water temperature to rise to a lower value and distillation proceeds slowly until a lower water temperature is reached. Hence distillation after sun set accounts for a larger fraction of the total. In contrast, the high rate of distillation during sunny hours in the case of shallow brine depths causes rapid cooling of water so that soon after sunset the temperature of water becomes too low to cause evaporation and night time distillation is a minimum. However, the total productivity in a day seems higher for shallower brine depths. In our experience, a brine depth of 2.5 cm seems adequate to ensure that there will be no dry spots due to an uneven basin bottom and also to give maximum productivity.

Vapour tightness is very important in the construction of a solar still. Sealants should withstand extreme environmental and weather conditions so that the still performance may not deteriorate with time. Although silicone sealants have been widely used in developed countries, our efforts in using bitumen based materials have proved successful in minimising vapour leaks. However, proper care in application of these sealants is important.

Loss of condensate through cracks in condensate collection channels is common where aluminium, concrete, etc., have been used for the channels. However, we have eliminated such losses in metal and concrete channels by lining with an ebonite compound made of natural rubber. Also these channels should be deep enough to prevent losses by overflow.

Basin insulation to prevent heat losses from the bottom and sides of the basin is necessary for maximum efficiency. However, it would not be economical to insulate large ground based solar stills. To overcome this difficulty, lining of the basin with butyl rubber has been widely accepted as it provides the black surface as well as acts as an insulator for heat conduction towards the ground. Our investigations with a substitute of ebonite compound made of natural rubber has given excellent performance over a period of 16 months to date. Commercially available rubber sheet (1/4" thick) has given good results over a period of 8 months so far.

For the transparent cover, although plastic and glass has been used, glass has proved to be the best. Also, symmetrical double sloped cover set at an angle between 10^0 to 20° to the horizontal is most suitable. The cover angle is so chosen to minimise the direct radiation reflected back to the atmosphere and also allow sufficient slope for the distillate to run down The glass cover should be close to the evaporating surface of water for efficient distillation and also to minimize shadowing from supports.

CONSTRUCTION MATERIALS

Construction materials used in solar stills are those generally used in civil engineering works. Such materials should be strong to resist strong winds, rain storms and have a long life. The basin and distillate channels should be made out of material that would not corrode or contaminate the distillate. Wherever possible, local materials should be used which are of light weight and can be transported easily.

Cover material should be highly transparent to short wave radiation and nearly opaque to long wave radiation. Its surfaces should be wettable, so that water would form a film on it rather than droplets. The material should not absorb water, absorb or reflect large amounts of solar radiation and should be able to withstand high temperatures (100° C), shock caused by wind blown debris. Glass is nearly ideal for covers as it satisfies nearly all the above requirements. Transportation of glass is difficult due to its fragility and is quite expensive in Sri Lanka. Plastic materials have been proved to be far inferior compared to glass although they could be transported easily and quite cheap in other countries. Transparent plastic materials are not readily available in Sri Lanka and are expensive. Therefore for our investigations 3/16" thick window glass was used.

The evaporator basin which contains the saline water should be black on its surfaces which have a high absorptivity for solar radiation, must be watertight, should not corrode or deteriorate at high temperatures (100° C) or for the salinity, should be abrasion resistant and easily cleaned. Experimental investigations were carried out using aluminium, PVC, G.I., concrete, asbestos cement sheet, G.I. with rubber lining, concrete with rubber lining for the evaporator basin. Concrete with rubber lining is the most acceptable as the efficiency is high and cost is low. This is the type of basin recommended in our design but further work is proceeding with commercially available rubber lining.

The supporting structures required for the still should consist of a good structure for the base and a frame for transparent cover. The material used should be strong enough to resist winds, their thermal expansion should be low, and should be easily handled in the field. The cover frame should be made out of members of small thickness to avoid excessive shading for the basin. Well seasoned hard wood like Halmilla, Palu or even Jak were found to be suitable for the cover frame and have lasted nearly five years without deterioration. Concrete or brickwork for the still foundation and basin were found suitable.

The distillate collection channels should be made of materials that are not attacked or corroded by the distillate or contaminate or add taste to the distillate. Metal, plastic and concrete have been used as construction material for the channels. If the base of the still is constructed in concrete it would be very convenient to construct the channels with cement. However, as the cement is not completely impervious to water, in our construction we have used a rubber lining to make it waterproof and have proved successful.

Sealants are being used to hold the cover to its frame and also make the whole still airtight. Such sealants should be able to absorb the expansion and contraction of the cover and frame and the base. They should form a good bond between glass and other materials used, resist weathering and aging while remaining flexible and should possess ease of application. Window putty, asphaltic compound, silicone sealants or even cotton adhesive tapes, rubber have been used as sealants but most accepted ones requiring low maintenance are silicone sealants and asphaltic compounds. We used a sealing compound with the trade name 'No leak' as it is readily available. Silicone sealants are reported to be the best. Special care should be taken in the application of 'No leak' and little maintenance is required.

Insulating materials are generally used to prevent heat losses from the bottom and sides of the basin. Such insulation is necessary only when metal basins are used. If concrete is used with a lining of rubber, insulation is not necessary as heat conducted down is low.

SITE SELECTION AND PREPARATION

In installing a solar still, a suitable site should be selected to avoid problems during normal operation. The selected site should be level firm land where the sunshine is unobstructed by trees, buildings, etc. The still should be constructed with one edge running parallel to the east-west direction, and should be close to the supply of saline water but places where sea spray can cover the transparent cover should be avoided. The site should be fenced with cadjan so that excessive wind could be cut off and also to prevent damage to the still by wind blown debris and to keep out children. However the fence should be sited at a distance from the still to avoid shading.

The land should be cleaned, levelled and treated with a herbicide.

STILL CONSTRUCTION

The ground should be dug and the foundation laid with brick work with a mixture of cement:sand about 1:4. The basin should be given a plaster coating of cement : sand mixture of 1 : 2 mixed with water proofing additive of pudlo. The ebonite compound which is made in sheet form should be held on to the surface with an adhesive. The vulcanisation is done by exposure to sun's heat for about seven days. The distillate collection channels should also be given a coating of the solution of the ebonite compound and allowed to cure under the sun's heat. The roof structure either made of precast concrete or hard wood is placed in position on the still and the glass covers are placed on the frame structure. The lower end of the glass would rest on the distillate collection channels. The glass covers are well sealed on to the frame with 'No leak'. The glass covers at either ends are fitted last with the lower end resting on the distillate collection channels and well sealed.

The piping for saline water feed, distillate collection, rain water collection and basin drain off should be incorporated during the construction of the basin.

OPERATING INSTRUCTIONS

The concentrated brine left over from the previous day's distillation should be flushed out by opening the drain valve and pouring in a few buckets of feed water so as to remove any possible sediment that has settled. This should be done every morning before 7.00 a.m. and the still filled to the required height with the brine. The glass covers should be wiped with a cloth to remove any dust that had collected. The distillate collection vessels should be emptied and the collected water measured to keep a check on the productivity of the still. If there is a decrease in the productivity any faults could then be detected.

The feed water should be poured into the feed tank through a cloth filter to remove any mud or sand getting into the still If there is much sediment in the feed, the feed tank is provided with two compartments so as to allow overflow of water into the second compartment free of sediment This compartment could feed the still. Periodically, the vertical covers at the ends of the still should be removed and sediment collected on the basin should be removed with a brush. Since the distilled water collected is free of minerals, certain amount of the saline water could be added to the distilled water before consumption.

PILOT PLANT

After the laboratory trials on small stills, a pilot plant was set up at Sarvodaya Centre in Pungudutive, Jaffna. The village of Pungudutive is starved for good drinking water and siting the pilot plant here was not only to study the performance of the large scale still but also to study whether such devices would be acceptable to the population.

The still was 3m^2 in basin area and was constructed of brick work and the glass roof was mounted on a wooden frame. The basin was lined with ebonite compound of natural rubber. The cost of construction of the still was Rs. 2,000/-. On an average this still gave an output of 9 litres per day.

CONCLUSION

Experience in the design and construction of solar stills were gained during the laboratory trials. The materials suited for local conditions were chosen and the design for construction of large stills arrived has proved acceptable on pilot plant scale. On an yearly average the productivity of the still is about 3 litres per square meter per day. Although the initial cost of the pilot plant was Rs. 2,000/-, assuming it has a life span of ten years, the cost of distilled water would be about five cents per litre. The maintenance cost is virtually nil. The still being constructed out of brickwork, wood, glass and rubber, the durability of the wood and the rubber lining has to be tested for a few more years.

The Punguditive population has shown great enthusiasm over this method of distillation and are interested in having many more stills set up for individual families as for community use. Generally it would only be possible to set up community stills and not home units due to space and shading problems.