CONFIGURATION, THEORETICAL ANALYSIS AND PERFORMANCE OF SIMPLE SOLAR STILLS

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Keywords : Solar distillation, Solar still, Solar Earth Water Stills, Multi-Basin

Contents

Summary

Solar distillation is an area having importance for providing drinking water to households or a small community. It utilizes solar radiation to heat the water and produce fresh water out of the saline or brackish water. This section deals with solar stills, which are simple in design, construction and operation in three parts. The first part discusses operating principles of these units, design classification and design configuration. The components of a typical solar distillation plant are also discussed in this part. The second part deals with theoretical analysis comprising of a detailed account of heat and mass transfer processes occurring in a solar still, solar radiation balance, and development of energy balance equation. Solution procedures for obtaining

the performance parameters are also discussed in this part. The third part gives an idea about the performance of these solar stills, based on the results of tests during their development and installations in the field.

Information is also included here on case studies pertaining to operating experiences and lessons learnt in Greece, Australia and India.

1. Introduction

Solar stills are the devices which produce fresh water from either seawater or brackish water by utilizing freely available solar energy. There is a considerable amount of literature on solar stills, which dates back to the work of the Arab alchemists of 1551. It is apparent from the literature that initial efforts, up to nineteenth century, were more focussed on concentrating the sun's rays by means of mirrors and lenses for producing distilled water. The first noteworthy practical application of solar distillation was erected by a Swedish engineer, Carlos Wilson, in Northern Chile in the year 1872 for supplying fresh water to the nitrate mining community. The system design was based on basin type solar stills made from wooden bays covered with glass. The plant remained in operation for about 40 years (Harding 1883). Since then, much research and development work has taken place for improving efficiency of the basin type solar stills. The effort has also resulted in the evolution of new designs, which appear to hold promise at the level of proto-type models. The solar stills are also referred to as "greenhouse type" signifying the basic principle of their operation.

2. Configuration of Simple Solar Stills

It is important to understand the basic principle underlying the operation of solar stills, before deliberating on the various configurations.

2.1. Basic Principle

Solar distillation of water is effected by introducing brackish or salt water in an airtight assembly whose interiors are painted black. The top of the assembly is covered with an A-tent roof of a material which allows solar radiation to pass through it, but does not let thermal radiation (emanating from interiors including the water mass) from going out. At the end of the roof, a V-trough is provided at each of the sides for collecting distilled water. The whole unit is kept in the open in the sun. The solar radiation passes through the top cover, gets absorbed predominantly by the blackened surface and also to some extent by the water mass. As a result, the evaporation of water takes place filling the inside air with water vapor and leaving the salts behind. The inside humidity increases and the condensation takes place on the underside of the top cover, which is sloped gently on both sides to allow condensed water to trickle down into the V-troughs. A schematic diagram of a single basin solar still is shown in Figure 1.

The most important factor affecting the production of distilled water in a solar still is the intensity of solar radiation, which depends upon the geographical position of the place, season of the year and time of the day. Typically, the daily distillate output of a solar still is evaluated as follows:

$$M_e = \frac{Q_e}{L} \tag{1}$$

The daily average efficiency of a solar still may be expressed as the ratio of energy utilized in vaporizing the water and the amount of solar radiation received by the system i.e.

$$\eta = \frac{Q_e}{\sum_{day} I} \tag{2}$$

The productivity of a solar still gets influenced by climatological factors, design parameters and also by the choice of materials. The efforts for addressing these issues for maximizing the distillate output have culminated in several types of designs which are discussed in the succeeding sections.

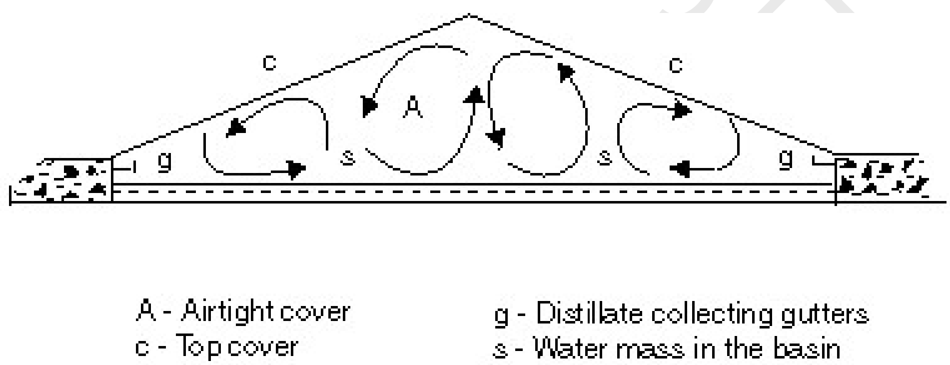

Figure 1. A schematic diagram of single basin solar still showing air-vapor mixture circulation. Reprinted from Delyannis E and Belessiotis V (1995), Solar Distillation - Is it effective? Part I: Conventional Solar Distillation, Desalination and Water Reuse, 4(4), 9-14, with permission from authors.

2.2. Classification

Solar stills are classified in a number of ways. As per one category of classification which is based on the expected life span and application, the solar stills are classified into "permanent" (e.g. glass covered), "semi-permanent" (e.g. plastic covered) and "expandable" (e.g. double tube and floating type) type solar stills. However, one of the most commonly used classifications is based on the novelty of their design, and has been used here also. Following this, the simple solar stills are organized as given below:

- Single basin solar stills
- Inclined solar stills
- Multi-basin solar stills
- Solar earth water stills
- Plastic solar stills

2.3. Single Basin Solar Stills

The single basin solar still represents one of the earliest designs used for distillation of water using solar energy directly. Its main advantage lies in its easy construction and simplicity of operation and maintenance. Basically, it consists of an airtight assembly enclosed at the top by a cover which is transparent to solar radiation, but opaque to the long wavelength radiation. The assembly is partially filled with the saline or brackish water. The absorption of solar radiation by the basin liner and water causes evaporation of water. The air-vapor mixture therefore attains higher temperature and lower density at the water surface. It moves upwards by the convection currents established because of the density gradient so created. When air-vapor mixture comes in contact with the top cover which is at a lower temperature as compared to the water surface, it cools down to saturation resulting in the condensation of water. The condensed water trickles down the inner surface of the top cover and is collected as distilled water in the troughs provided along lower edges of the top cover.

Several configurations have been developed for single basin solar stills using different designs of basic structure and materials of construction. Figure 2 shows a deep basin solar still, designed by Lof et al. (1961) and later installed in 1958 at the Solar Distillation Research Station at Daytona Beach, Florida, USA. The cover of the still was comprised of 0.37 m^2 (approximately) window glass panels sloped at an angle of 15° with respect to the horizontal plane. Timber beams fixed on concrete block pillars were used to provide support to the cover glass. The basin was made air tight by using 12.5 mm thick pre-fabricated asphalt mats, an impervious material, placed directly on the soil and inside surfaces of the still walls. Edge heat losses were checked by using foam glass insulation around the perimeter. Total basin area of the solar still at Daytona Beach was approx. 227 m^2. The depth of basin was kept to be around 300 mm. Another design variation of this solar still is shown in Figure 3, where an air supported transparent plastic film was used in place of window glass panes as cover glazing. The depth of water in this configuration was kept to the order of 25-50 mm. This configuration was also used at the island of Symi in Greece.

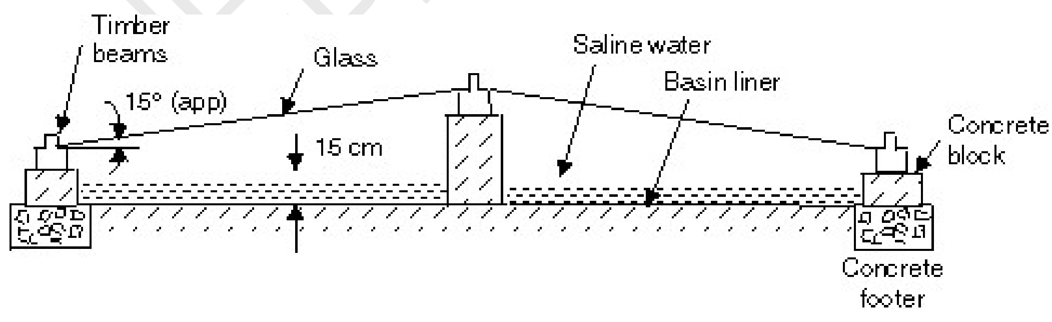

Figure 2. Configuration of a deep basin solar still.

In order to further explore the option of using transparent plastics as cover glazing, two design configurations as shown in Figures 4 and 5 were also developed and studied in detail in Greece (Delyannis and Delyannis 1985). The configuration shown in Figure 4 was used as a replacement for installation erected on the island of Symi. Although it was followed up with more installations, for example, at the island of Aegina, the stability of these designs always posed maintenance problems. This resulted in the development of single sloped configuration (Figure 5), with plastic sheet in stretched condition as the cover glazing. The same design was put up at Aegina as a replacement to the earlier installations. The use of plastics, however, has always been a matter of scientific concern in view of their instability against weather extremes, degradation against UV exposure, etc. A host of special configurations were developed and experimented upon, in the quest of establishing plastics as a possible material for use in solar stills; these are discussed later under section 2.7.

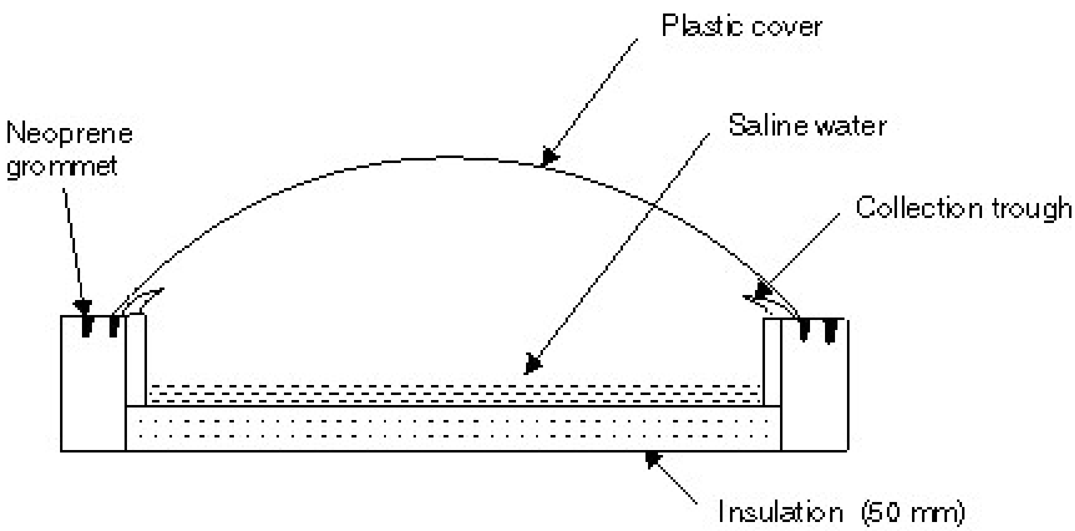

Figure 3. Solar still with air-supported plastic cover.

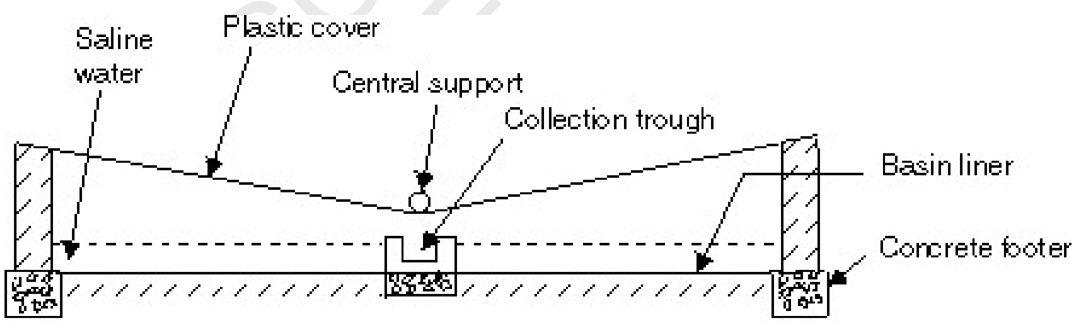

Figure 4. Solar still with V-shape plastic cover.

In Australia, the principal requirements for acceptance of a particular configuration were its robustness and modular nature, in addition to its higher efficiency in utilizing solar energy to produce distilled water. A typical configuration using glass as the cover material is shown in Figure 6 (Cooper and Read 1974). Essential features of the configuration are the use of cement concrete as the side members, 0.76 mm thick butyl rubber as the internal lining, and 25 mm insulation at the bottom. The configurations had minor variations in design depending upon the application of solar stills in large units for a community, or in individual units for small families. A similar configuration was also applied in India by the Central Salt and Marine Chemicals Research Institute, Bhavnagar (Gomkale 1988); cement concrete was used in preparing basin bottom, while pre-cast reinforced cement concrete was used to provide supports for cover glass and at other places.

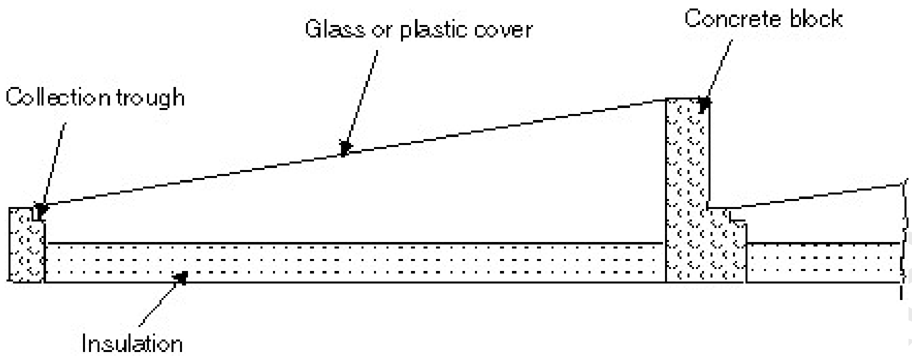

Figure 5. Single slope stretched plastic cover solar still.

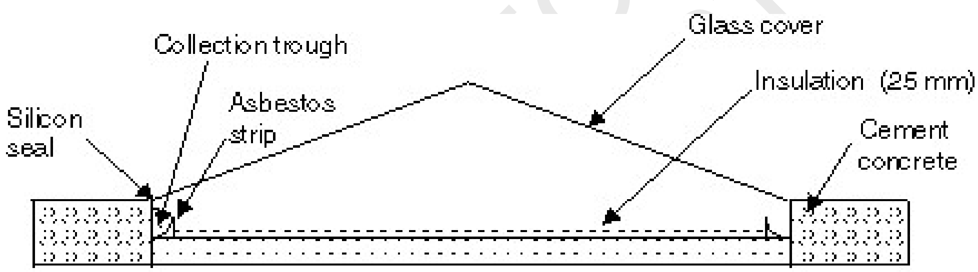

Figure 6. Double slope glass cover solar still.

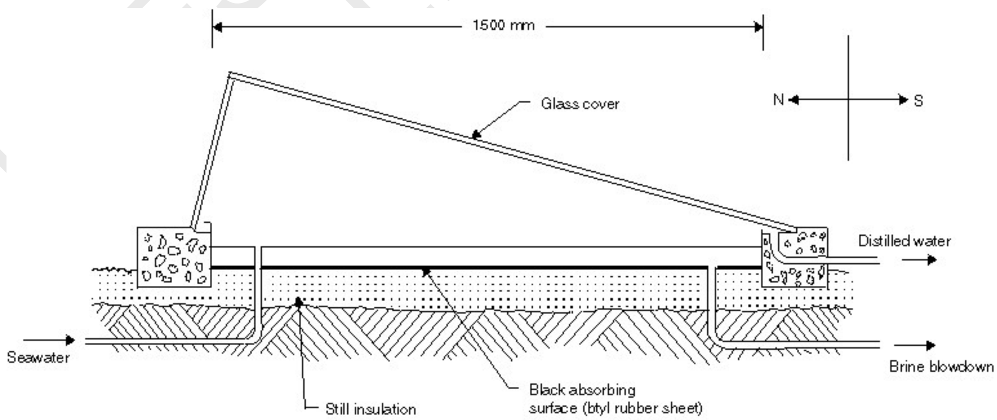

Figure 7. Asymmetric cover double slope solar still.

The Australian design with symmetrical double sloped glass cover was modified by Delyannis and Delyannis (1983) by having non symmetrical double slopped or single sloped glass covers, as shown in Figure 7. These designs have been applied in Greek islands; in Gwadar, Pakistan; in Byobujima Island, Japan; and in Porto-Santo Island, Portugal. A more sophisticated design of non-symmetrical type is developed by Interdisciplinary Project Group for Appropriate Technology (IPAT) of the Technical University of Berlin in co-operation with GATE, the German Appropriate Technology Exchange. In this design, the condensation of humid air is not intended on the transparent cover, but is cooled by seawater in a heat exchanger. The design has a provision for an easy opening of the rear glass frame to carry out cleaning and repairs of inside parts of the still. A tubular heat exchanger is also provided at the back cover to preheat the feed water by utilizing latent heat of condensation released during the condensation of water vapors onto it. A solar distillation plant applying this design was also erected at the island of Porto-Santo in Portugal. The plant consisted of two units of IPAT design and two units of Delyanns modified design (Figure 7) with an evaporation area of 30 m^2 each. The details of IPAT configuration may be seen in Delyannis and Belessiotis (1995).

As seen above, glass covered solar still are shaped with either a double sloped cover (symmetrical as well as asymmetrical) or a single sloped cover. The asymmetrical designs are required to be oriented in such a way that a low sloped cover faces due south for maximum collection of solar radiation during the whole day. The slope of the cover with horizontal is usually 10°, although its value has varied from 5° to 18°. At slopes less than 5°, dripping of the condensed droplets may occur affecting the performance adversely. For symmetrical covers, orientation of the axis does not have much influence as the solar radiation is collected from both sides of the transparent cover.

The black bottom liner may be made from rubber sheets, asphalt or asphalt impregnated jute, or specified black paints which are resistant to saline/brackish water. In general, any material having high absorptance for solar radiation, good insulating properties to brine leakage and resistance to corrosion may be used as black bottom liner. Solar stills may be erected directly on the dry ground having a layer of insulation at the bottom, as was done in Australia. This type of solar stills are called 'ground still'. The solar stills may also be mounted in a box, which is insulated on all sides except at the top. Such a design is referred to as a "mounted still".

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