PARAMETRIC STUDIES ON IMPROVED SOLAR DISTILLATION SYSTEMS

By

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TO

MY PARENTS

SMT. LAKSHMI SESHAMAMBA

SHRI SURYA NARAYANA

CERTIFICATE

It is certified that the thesis entitled,"PARAMETRIC STUDIES ON IMPROVED SOLAR DISTILLATION SYSTEMS" being submitted by Mr. V.S.V. Bapeshwar Rao is worthy of consideration for the award of the degree of 'Doctor of Philosophy' and is a record of the original bona-fide research work carried out by him under my guidance and supervision. The results contained in this Thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

G.N. Tiwari

June, 1986. (Dr. G.N. TIWARI)

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SUMMARY

The present thesis incorporates various studies, theoretical as well as experimental on the performance of solar distillation systems. The investigations have been directed towards the development of improved designs for better performance in terms of efficiency and output in basin and inclined type of stills.

In this study the concepts of cooling the glass cover and pre-heating of basin water have been thoroughly investigated. By maintaining a thin uniformly moving water film over the glass cover and by feeding preheated saline water into the basin remarkable improvements have been observed. Preheating has been done in two ways: using waste hot water and by coupling a flat plate solar collector with a basin type still. The experimental results have been supported by theoretical analysis.

A set of parameters viz. water depth, flowrate, length of still have been prescribed for improved performance in each case.

A number of stills have been designed and fabricated with galvanised iron (G.I.), Fibre Re-inforced Plastic materials and G.I. sheets with FRP coatings. To provide a justifiable cost analysis, all these stills (six in number) have been put under continuous operation for one year and the performance has been extensively studied.

An efficient and durable FRP (multiwick) inclined type still has been developed and it has been observed that there is a significant improvement in the quality of distilled water.

The studies based on the performance of a solar distillation plant consisting of 24 FRP multiwick stills show a number of advantages of such plants for medium scale applications. There is significant increase in the life time, remarkably low maintenance and excellent quality of output, over long term periods of operation.

PREFACE

Numerous processes have been proposed for the desalination of salt water. Distillation, electrodialysis and reverse osmosis are already applied to practical installations, while solvent extraction, ion exchange, freeze separation and hydrate separation have been less developed. Distillation is applicable to the entire range of salinities upto sea water while the other methods are limited to the purification of brackish waters. Since the cost of heat plays a decisive role in various distillation processes, viz. single, multistage, flash and vapour compression, it seems advantageous to harness the heat of the sun for this purpose. Over a period of hundred years several types of solar stills have been designed and tested. There has been a significant progress in the field of solar distillation during the past three decades, perhaps due to the general increase of interest in solar energy utilization. Because of cost free energy and low operating cost, as there are no moving parts involved in these systems, the solar distillation shows a significant economic advantage over other sea water distillation processes. Lof had presented a historical review of solar distillation until 1953. Later, various aspects of a wide range of solar stills have been thoroughly reviewed by Malik et al. (1982).

According to Mauchot (1869), the earliest documented work is that of Arab alchemists in 1551, in which polished concave mirrors were used for solar distillation. Nebbia and Menozzi (1966) mentioned about the solar distillation apparatus of

Della Porta (1589) in their review. Later, Lavoisier (1862) concentrated solar energy on the contents of distillation flasks.

The conventional solar still was first emerged in 1872 for supplying fresh water to a nitrate mining community in Northern Chile (Harding, 1883). Interest in solar distillation did not grow much till the end of First World War. Later, several new designs, e.g., roof type, V-covered, tilted wick, inclined tray, tubular and air inflated stills were developed. Among the suggestions made to improve the operating efficiencies were to enhance the vapor condensation rate by forced air circulation and making use of the latent heat of vaporization in either multi effect stills or preheating the brine. Extensive investigations have been undertaken to study different aspects of basin type stills. Graphical (Morse 1970, and Read, 1968) as well as digital simulation (Cooper 1969, 1970, 1973) methods have been formulated to study the transient performance of a still. Frick (1970) has proposed a model for the still based on Sankey diagrams and thermic circuits. Malik and Tran (1973), Garg and Mann (1976) and Hrèschmann and Roefler (1970) are among those authors who have developed theoretical models.

periodic and transient analyses have been developed by Baum et al. (1970), Nayak et al. (1980), Sodha et al. (1980) and Tiwari and Malik (1982). Several other types of stills have also been designed and studies have been made on their performance, viz., multieffect stills (Ottra 1972; Bartali 1976), titled tray or inclined stepped stills (Howe 1961), Akhtamov

et al. 1978) tilted wick type and multiwick type (Frick and Sommerfeld, 1973; Sodha et al., 1980, Moustafa, 1979; Watanabe et al., 1984; Tanaka et al., 1983) indirectly heated solar stills (Soliman, 1976; Malik et al., 1973, 1978, Sodha et al. 1981).

Further, in order to increase the output of a single basin solar still, one of the most essential conditions to deploy is to maintain the highest possible temperature difference between the basin water and the glass cover. This can be achieved (a) either by lowering the glass cover temperature, (b) or by increasing the basin water temperature, (c) or a combination of both the cases. Lowering of glass temperature can be done either by blowing air across the glass or by flowing cold water over the glass surface. Increase in basin water temperature can be made by feeding preheated saline water into the basin. For this purpose a flat plate solar collector can be coupled with the still through a heat exchanger or waste hot water from a chemical/thermal power plant can be used as a feed. Using these two concepts (lowering the temperature of condenser and feeding hot saline water) together enhances the yield of a still further more. The operation of a deep basin still with forced circulation of both water and humid air by pumps and fans was reported by Grune et al., 1962. A complete system of a flat plate collector and a basin type still were designed and studied by Soliman (1976) and Rai and Tiwari (1984). Sodha et al. (1981) have discussed an analytical model of a single basin still in which waste hot water has been considered as a feed into the basin at constant flow rate throughout the day (24 hours cycles).

In the present study the author has developed a simple transient analysis of single basin solar still in which a thin and uniformly moving water film has been considered over the glass cover. The analysis has been extended to a double basin solar still. The concept of cooling the glass cover has been considered in a composite system of a single basin solar still (SBSS) coupled with a flat plate collector (FPC) and a comparative study has been made among various combinations viz. SBSS, SBSS with water flow over glass, SBSS coupled with FPC and SBSS-FPC with water flow over the cover. A periodic analysis which incorporates the hot saline feed from a power plant and the cooling of the glass cover was also attempted. In all these cases the effect of various operationa design and climatic parameters on the performance of each still has been thoroughly studied and a set of optimized parameters has been prescribed with a view to improving the overall performance of each system.

The efficiency of solar stills can further be increased by (i) by maintaining the liquid surface at an optimal inclination so as to receive maximum solar radiation. (ii) keeping minimum amount of saline water exposed to solar radiation at a time to achieve rapid evaporation (iii) reducing the radiation losses by placing the glass parallel to the water surface. Sodha et al. (1981) has developed a simple multiwick solar still and studied its performance. Very recently, Watanabe et al., (1984) and Tanaka et al. (1983) studied the effect of various operating parameters on the performance of wick type inclined stills.

Before proposing to installations on a medium/large scale pattern it is necessary to study the economic viabilities, durability of materials used, maintenance etc. on a long term basis. A successful attempt has been made by the author in choosing fibre reinforced plastic (FRP) materials in making solar still due to its various advantages viz. replaces the conventional insulation, completely eliminates the corrosion problems (which are often associated with conventional metallic solar stills) and hence more life expentancy and less maintenance cost. Six different designs were chosen and fabricated with FRP materials in March 1983 and studied for over a period of one year. On the basis of this data a detailed cost analysis has been made for each of these stills. Careful examination of these economic calculations and other relative merits and demerits of all these units lead to the selection of a particular FRP still with a body of 2 mm thickness. Twenty-four such units were made for a demonstration plant of daily capacity of about 70-90 lts. per day for a comparison with the performance of galvanised distillation plant (Tiwari, 1985) of the same capacity. In order to achieve maximum production, studies have been made on various operational parameters of the distillation plant and optimized. Economic evaluation was done by using the data collected over a period of one year since the inception of the plant in Feb., 1984. All the aspects related to capital investment, production capacity expected life time, periodic maintenance costs, inflation etc. have been given due consideration in the cost analysis.

In the first chapter, various methods of salt water purification with a special emphasis on distillation techniques have

been discussed briefly. The solar evaporation has been discussed in detail followed by a brief literature review. Basic heat and mass transfer concepts relevant to the present study and the thermodynamic properties of various materials used for the fabrication of different solar stills under the present investigation are also included.

A simple transient analysis of a single basin still which includes the effect of water flowing over the glass cover is presented in the second chapter. The decrease in glass temperature enhances the rate of condensation of water vapor and results in a significant increase in distillate output. The effect of climatic design and operational parameters on the output of this still has been studied. The model has been validated by experimental results. In the next part of this chapter, the concept of cooling the condenser has been extended to a double basin still in which 16 per cent increase in the overall efficiency is recorded relative to an ordinary double basin still without water flow over the upper cover. The effect of inlet water temperature to the lower as well as upper basin over the efficiency and output of the system has also been studied.

In the third chapter, the effect of feeding preheated saline water into the basin of a solar still has been studied in detail. The study deals with the development of a periodic analysis in which waste hot water from a thermal plant is considered as a feed into the still and water flow is considered over the glass cover. Effect of still length, basin water flow rate and water-depth in the basin on the performance of the system

has been studied and a set of optimized parameters have been found for improved distillate output.

The details of a system in which a single basin still is coupled with a panel of flat plate solar collectors are presented in fourth chapter, and water flow is considered over the glass cover of the still for obtaining higher yield. With the help of transient analysis developed for the prediction of the performance of such a system, a comparative study among different configurations has also been made. Explicit expressions for efficiency and output have been worked out for each case.

Chapter five presents a long term study on different designs of solar stills. An efficient and more durable design of an inclined type still has been developed. The investigation focuses on the use of fibre reinforced plastic (FRP) materials in fabricating the body structures of solar stills which it is hoped would provide impetus for obtaining improved performance enhanced life time and significant decrease in maintenance cost. In March, 1983, six different stills were designed and fabricated by using FRP. To provide with a justifiable economic analysis these units have been kept under continuous study for a period of one year. The collected data has been used for making detailed economic calculations.

In the last chapter the details of installation, monitoring and maintenance of a solar distillation plant consisting of 24 units of FRP inclined multiwick solar stills has been discussed. Various operational parameters have been optimized in accordance with other climatic conditions viz. wind velocity, solar intensity,

ambient temperature. Different kinds of problems occurred during the operation of the plant and possible methods of solving them are outlined. A simple and informative cost analysis for this plant on the basis of recorded data for a period of one year is also included and methods have been suggested for the further reduction in cost per unit water.

The above-mentioned work has partially appeared in the following publications:

1. Transient performance of single basin solar still with water flowing over the glass cover, Desalination, 49(3), p. 231 (1984).
2. Transient analysis of a double basin solar still, Energy Conversion and Management, 23 (2). 83 (1983).
3. Analysis of conventional solar still with water flowing over glass cover and in the basin, Int. J. Solar Energy (In Press).
4. Effect of water flow over the glass on the performance of a solar still coupled with a flat plate Solar Collector, Int. J. Solar Energy, 3(2), 1984.
5. Performance and economic studies on fibre reinforced plastic (FRP) solar distillators, Int. J. Solar Energy, 3, 95 (1985).
6. Studies on FRP Multiwick Solar Distillation plant at I.I.T. Delhi, Proceedings of International Solar Energy Congress, Intersol'85 held at Montreal June, 1985.

7. Solar Distillation. A Chapter in a Book entitled,"Applied Solar Thermal Energy Devices, Kamala Kuteer Publishers, India (1985).

8. Solar Desalination - A Project Report submitted to Department of Nonconventional Energy Sources, Ministry of Energy Govt. of India, Grant No. F.4/13/4/82-NES/360 (1985).

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