PHYSICS OF SOLAR STILLS

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THESIS

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TO MY PARENTS

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SUMMARY

The present thesis is incorporated with the designing, testing and the theoretical modelling of the different type of solar stills. A brief historical review and a discussion on basic thermophysical processes in a solar still have also been given. The basic assumptions in developing the theoretical models for the basin type stills are:

(i) The basin water mass is assumed to be constant which is true for large water depths.

(ii) The glass and water surfaces are assumed to be parallel and of equal area.

(iii) The observed dependence of saturated vapour pressure on temperature in a narrow temperature range can be expressed by the relation which is a linear function of temperature. So the linearized Dunkle's relations have been used in evaluating different heat and mass transfer coefficients.

It has been observed experimentally that black dye is most useful in increasing the still output. It is also seen that a solar still kept over the roof of a building helps in reducing the heat flux entering the room in summer with a reflective basin whereas the system enhances the heat flux in winter when it is used with water mixed with black dye. The system assists in the airconditioning of the building and provides distilled water. The periodic analyses have been made assuming the solar intensity and ambient temperature to be periodic function of time. Since the establishment of periodic conditions takes a finite time, the transient analytical models have been developed to study the performance of

single and double basin stills; the analyses have been validated by experiments. The possibilities of using waste heat available in the form of hot water for producing distilled water have been explored. The analytical models for different modes of waste heat utilization have been presented.

Since economics is the key consideration in all the processes, an inexpensive and light weight new design solar still has been developed. This yields about 20% more distilled water as compared to the conventional basin type stills. An analysis making use of Dunkle's relations is also given.

A field closely allied to solar stills is the cooling of a building by open evaporation of water over the roof. A comprehensive analysis applicable to the different cooling techniques viz. open water pond, water film and a moving water layer has been included in the thesis. The numerical calculations to investigate into the effect of different parameters are also given.

PREFACE

Solar Stills, in common with many solar devices, have been technically viable for a long time. The concept and use of solar stills as a means of producing potable water from saline/brackish water dates back to 1872 in Chile, but it is only in recent years that attention has been focussed on the basic aspects of still operation in an attempt to describe the performance for design.

Solar still essentially consists of an airtight and blackened basin, covered with a transparent material, and exposed to the sun. The transparent cover lets solar radiation pass through to the water surface but stops most of the infra-red re-radiation; it also greatly decreases convective heat loss to the surroundings. The energy, trapped in this way, is responsible for water evaporation; the water vapour gets condensed at the underside of transparent cover, which is sloped to allow the fresh water to trickle into a catchment drain.

Solar distillation has been practised for a long time;however, the lack of appreciation of heat and mass transfer relationship hindered the full exploitation of the concept for quite sometime. The different heat transfer modes governing the still operation may be classified into two

distinct but coupled regions — external and internal. External transfer incorporates

(i) radiative and convective heat transfer from the cover glass to the atmosphere, and

(ii) conductive losses through the base and sides of the still to the surroundings.

Internal transfer includes the combined convective, evaporative and radiative heat transfer from the surface of water to the underside of cover glass. It is normally ensured that the leakage of water vapours from the assembly is negligible.

With a view to improve the system efficiency, solar stills in the last decade have been extensively studied. Apart from the common basin type stills, new concepts such as air inflated design (Telkes,1945), V-covered (Hay,1966), tubular and plastic covered circular (Tleimat and Howe, 1966, 1969), tilted tray (Achilov et al, 1972; Howe and Tleimat, 1974), tilted (Talbert et al, 1970) or vertical wick (Coffey, 1975), chimney type (Bartali et al, 1976) solar stills have emerged; attempts have also been made to exploit the multi-effect concept in solar distillation.

Lof et al (1961) attempted a steady state formulation of the equations governing the still performance considering the heat capacity of the still to be zero. Morse and Read (1968) and Cooper (1973) amongst others have developed graphical and

numerical methods to study the performance of basin type solar stills. Periodic solutions have also been attempted by Hirschman and Roefler (1970) and Baum et al (1970) assuming that the solar intensity and ambient temperature can be expressed as a sine function of time.

To minimize conductive losses from the bottom of the still, Garg and Mann (1976) studied experimentally the effect of addition of dyes in the basin water. However, they have neither presented an analysis of the still with a dye nor detailed experimental data to enable empirical generalizations. Recently, Rajvanshi and Hsieh (1979) have reported a systematic investigation into this effect but the analytical model developed by considering energy exchange between different layers of the water-dye system, is a complicated one; the coduction in ground has also not been taken into account. In the present work, a periodic analysis of a solar still with water-dye system in the basin has been presented; the explicit expressions for water and glass temperatures and hourly distillate output have been obtained. The results of the analysis are borne out by the experimental results. The analysis may be further extended to investigate the performance of the proposed 'Still-on-Roof' system; the system can be used for heating/cooling of buildings in addition to providing distilled water. The

author has obtained analytical expressions for the hourly heat flux into the building and the distillate output from the system.

Since the establishment of periodic behaviour takes finite time, the author has developed transient solutions (assuming negligible heat capacity of insulation) for the behaviour of the usual basin stills. Further, to reduce the convection and radiation losses from cover glass, Lobo and Araujo (1977) have suggested a double basin still but not presented the analysis. Malik et al (1978) studied the double basin still experimentally and developed a numerical model for predicting its nocturnal output; however, the model is difficult to use. Sodha et al (1980) have presented its comprehensive study, assuming all the relevant parameters (climatological as well as still performance parameters) to be periodic the author has developed a transient theory of double still. It may be mentioned here that for the time intervals of the order of 3-4 days; the theory reproduces the results of periodic analysis.

The nocturnal production in a solar still has attracted attention at times. The use of waste heat available in the form of discharged hot water from power plants and other industries for production of distilled water is another interesting possibility. The earliest work on nocturnal operation of

a deep basin solar still was reported by Grune et al (1962). Later, Tleimat and Howe (1966) studied the nocturnal production of a tubular glass still in which the city water supply was fed at constant rate. Further, Malik and Tran (1973) and Malik et al (1978) discussed in detail the effect of various meteorological and still parameters on nocturnal production from single and double basin solar stills respectively. However, their deductions did not take into account the available solar intensity and since it is unlikely that the still will be located in dark (during day), the author has presented analyses of the operation of a solar still in which waste hot water is used.

Economics being a key consideration, an inexpensive and light weight solar still has been developed, in which a series of black jute cloth pieces separated by thin polythene sheets, along an inclined plane, forms the liquid surface. This new design solar still has main advantages that it can be oriented to intercept maximum solar radiation and has very small thermal capacity.

A field closely allied to solar stills is the reduction of heat flux through the roof of a building by open evaporation of water over the roof. This can be achieved by (a) open pond of water (b) spray cooling/gunny bags, and (c) the flow of water over the roof. Numerous workers (viz.

Houghton, 1940; Sutton, 1950; Jain and Rao, 1974; Yellot , 1969, and Jain, 1977) have carried out detailed experimental studies, but no analysis of the techniques used for cooling (taking into account the time dependence of different parameters) appears to have been made. To investigate the effect of different parameters explicitly , the author has presented a general analysis of the water evaporation system; the water film, moving water and roof pond are the special cases of the general model.

A chapterwise summary of the thesis is as follows:

CHAPTER-I

The introductory chapter presents a brief historical review of the work on solar stills. A discussion of the basic heat and mass transfer relations necessary for the description of the operation of a solar still has also been presented.

CHAPTER-II

A periodic analysis of a solar still with water-dye system in the basin has been presented. Experiments on the effect of dye on the output of the still have been carried out with identical stills having (i) a dye (ii) no dye, during June, 1979 at I.I.T.,Delhi, India. The experimental observations on the mounted still are seen to be in good agreement with theory. It is also observed that the use of dye on the daily distillate is more effective at higher depths. Black and violet

dyes are found to be more effective in comparison to others.

CHAPTER-III

This chapter presents an analysis of periodic heat flux through a roof, on which a still has been placed. It is seen that on a typical hot day in Delhi, for high reflectivity of the bottom of the basin (on account of deposits or otherwise) the daily heat flux in the room gets reduced by 40% and the production of distilled water is 0.6 kg/m^2 day; the produced swings in the heat flux also get reduced in magnitude. For a typical cold day in Delhi, if a black dye is mixed with basin water the daily heat flux in the room increases by a factor of two and the yield of the distillate is typically 5.0 kg/m^2 day.

CHAPTER-IV

An analytical model has been developed to study the transient performance of the

(i) single basin solar still

and (ii) double basin solar still.

The explicit expressions for hourly variation of glass and water temperatures and distillate output have been obtained. The results of the analyses are seen to be in good agreement with experiments. Assuming the meteorological as well as system performance parameters to be periodic, the dependence

of the daily yield of a double basin solar still on wind velocity, ambient air temperature and daily incident solar radiation has also been studied. It is observed experimentally that the presence of a black dye in the lower basin of double still increases the distillate output by 10-15%.

CHAPTER-V

The yield of a solar still can be increased by introducing hot water available from power and chemical plants into the still; even in the absence of sun appreciable yield is obtained. In this chapter the performance of solar still has been studied in two modes of waste hot water utilization:

(i) waste hot water obtained from thermal power plants is flowing at constant flow rate through the still.

(ii) feeding waste hot water obtained from thermal power plants once a day only.

The analyses of the operation of a solar still for the cases mentioned above have been presented. Dependence of the distillate output on various operating parameters has also been investigated.

CHAPTER-VI

This chapter presents the design, analysis and performance of a simple multiple wick solar still, in which a blackened jute cloth forms the liquid surface which can be oriented to intercept maximum solar radiation and attains higher temperature on account of low thermal capacity. The wet surface consists of a series of jute cloth pieces of increasing width separated by thin polythene sheets, resting on foam insulation and supported by nylon ribbons; these pieces are arranged along an inclined plane and their upper edges are dipped in a saline water tank. Suction by the capillary action of the cloth fibre provides a thin sheet of liquid; the arrangement ensures that the whole surface, irradiated by the sun is wet at all times. The results of an analysis based on Dunkle's relations (1961) are in excellent agreement with the observed performance of the still. On a typical cold clear day in Delhi, India (viz. Feb.6,1980) the distillate output was 2.5 litres/m^2/day corresponding to an efficiency of 34% (as compared to a maximum of 30% for basin type stills). The still costs less than half of the cost of a basin type still of same area.

CHAPTER-VII

The various aspects of the reduction of heat flux through the roof of a building by open evaporation of water

over the roof have been investigated. A comparative study of (i) roof pond (ii) spray cooling/gunny bags, and (iii) moving water over the roof system is presented. Analysis of the moving water system has been given from which results for the roof pond and water spray can be obtained as special cases. Numerical results, discussion and conclusion have also been presented.

The above mentioned work has been partially appeared in the following publications/communications:

1. Effect of dye on the performance of a solar still. Applied Energy, 7, 147, 1980.

2. Thermal performance of 'Still-on-Roof' system. Energy conversion, 20(3), 181,1980.

3. Transient analysis of a solar still. Energy Conversion, 20(3), 191, 1980.

4. Further studies on double solar still. Int. J. Energy Research (in press), 1981.

5. Utilization of waste hot water for distillation. Desalination (Communicated), 1981.

6. Simple multi-wick solar still : Analysis and performance. Solar Energy (in press), 1981.

7. Cooling by open evaporation of water : A review. J. Ambient Energy (communicated), 1980.

In addition to these, the author has contributed following publications.

1. Double basin solar still; Energy conversion, 20(2),23,1980.

2. Heating/cooling of building by flow of water over the roof; Applied Energy, 7,229,1980.

3. Thermal performance of south facing wall; Int.J.Energy Research, 4(4), 309,1980.

4. Periodic theory of open roof pond; Applied Energy, 7(4),305.

5. Thermal load levelling in a multilayered wall/roof; Int.J.Energy Res.(in press),1981.

6. Heating/cooling of a building by double hollow concrete slab; Int. J. Energy Research (in press), 1981.

7. Thermal design of roof as an inexpensive solar collector/storage system; Applied Energy (in press), 1981.

8. Effect of reflecting sheet in an air gap on the thermal performance of wall/roof; Applied Energy(in press), 1981.

9. Maximum thermal load levelling in a double hollow wall/roof;
Int.J.Energy Res.(in press), 1981.

10. Passive cooling of buildings using multi-air-gaps;
Int.J.Energy Res.(in press), 1981.

11. Optimization of a double hollow slab for maximum thermal load levelling;
Solar Cooling and Dehumidifying Conference, Caracas-Venezuala, 1980.

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