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Studies on a multi-stage stacked tray solar still

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Abstract
Solar distillation is one of the important and technically viable applications of solar Energy. An application has been filed for getting the design patented in India this paper presented a computer simulations model for studying the steady-state performance of a multi-Stags stacked tray solver still. The results obtained from the model using the modified heat and muss west relationship's proposed in previous study was in good agreement with the experiments.

Keywords: Tray solar still, solar energy, computer simulations model

Introductions

Recently, A new design for a multi-stage distillation, has been proposed and studied in India jointly by the Solar Energy Centre and the Indian Association for Advancement of Science, Delhi (Kumar *et al.*, 1989). An application has been filed for getting the design patented in India. The proposed design is of the indirectly heated type and comprises two components: a distillation chamber and a heat source in the form of a solar collector. The solar collector collects the incident solar radiation and transports heat energy in the form of hot water to the distillation chamber where evaporation and condensation processes occur. Preliminary test results showed a great potential in the design and prompted researches to undertake a series of experiments on the system to rationalize the effect of various design parameters on its performance. The experiments have been conducted at the campus of Solar Energy Centre, Gwal Pahari, Gurgaon, Haryana.

Fernandez and Chargoy (1990) have also published some data on this kind of multi-stage solar distillation unit. This study has also indicated that the proposed design has a great potential. The study, however, lacks in the following aspects which are otherwise critical in the effective utilization of the system:

1. Actual applicability of Dunkle's heat and mass transfer relationships to the present design;
2. Development of a mathematical model for predicting the system performance in a variety of climates; and
3. Optimisation of system parameters.

This paper, presented a computer simulation model for studying the steady-state performance of a multi-stage stacked tray solar still. Because the primary aim of the study was to appreciate and quantify the multi-stage effect in the present design, the model takes into account an auxiliary heating source only (instead of a solar collector). The model is validated by the results of simulated experiments on a three-stage unit having an industrial-type immersion heater as the heating source. The results obtained from the model using the modified heat and mass transfer relationships, proposed earlier by Adhikari et al. (1990) are in good agreement with the experiments. Numerical results are also presented to appreciate the relative performance of a multi-stage stacked tray solar still with a diffusion-type multi-stage solar still.

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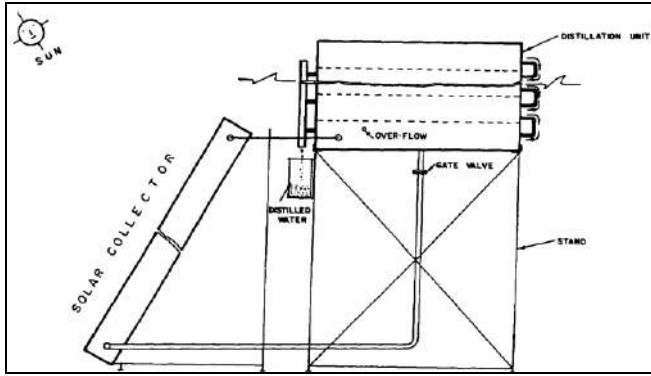Research Scholar, Department of Physics, L.N.M.U., Darbhanga, Bihar, India

Fig 1: A Multi-stage stacked tray solar still

Formulation

The metallic trays are stacked one upon another to constitute the distillation chamber. These trays are slightly depressed in the middle along the length so that the droplets of condensed water roll down into a trough, which consequently leads the collected water to reach the collection chambers. The sides and bottom of the distillation chamber are insulated adequately. Feed water is filled in various trays through the top tray, as shown in Fig. 1.

The water in first tray gets heated using heat from the solar collector. This causes evaporation of water in the first tray; water vapours thus formed, condense over the underside of next tray. The latent heat released during this process is utilized for heating the water in second tray. Subsequently, evaporation occurs in the second tray and the process continues until the last tray, which is exposed to the atmosphere. The condensed water from each stage is collected separately. Assumptions have been made for writing down the energy balance equations.

- Thermal capacity of the metallic tray is negligible.
- Thermal gradient across the thickness of water mass in the trays is insignificant.
- Distillate yield leaves the system at a temperature equal to that of the condensation plate. The sensible heat-losses through distillate yield are evaluated based on this assumption.
- Specific heat of water (Cw) is constant with temperature.
- Heat is supplied to the distillation chamber from an auxiliary heating source.
- Steady-state conditions of heat and mass transfer are achieved.

Energy balance equations

The energy balance diagram for a multi-stage stacked tray solar still is shown in Fig. 2. The energy balance equations for various components of the system are given below.

Bottom tray (Tray 1):

$$-(Q_{p,1} + Q'_{p,1}) - Q_{s,1} - Q_b = 0. \qquad (1)$$

Intermediate (i^{th}) trays:

$$Q_{t,j-1} - Q_{p,i} - Q'_{p,i} - Q_{s,i} = 0 \quad i = 2, N + 1. \qquad (2)$$

Water mass in bottom tray:

$$Q + Q_{p,1} + Q'_{p,1} - Q_{t,1} = 0. \qquad (3)$$

Water mass in intermediate (i^{th}) trays:

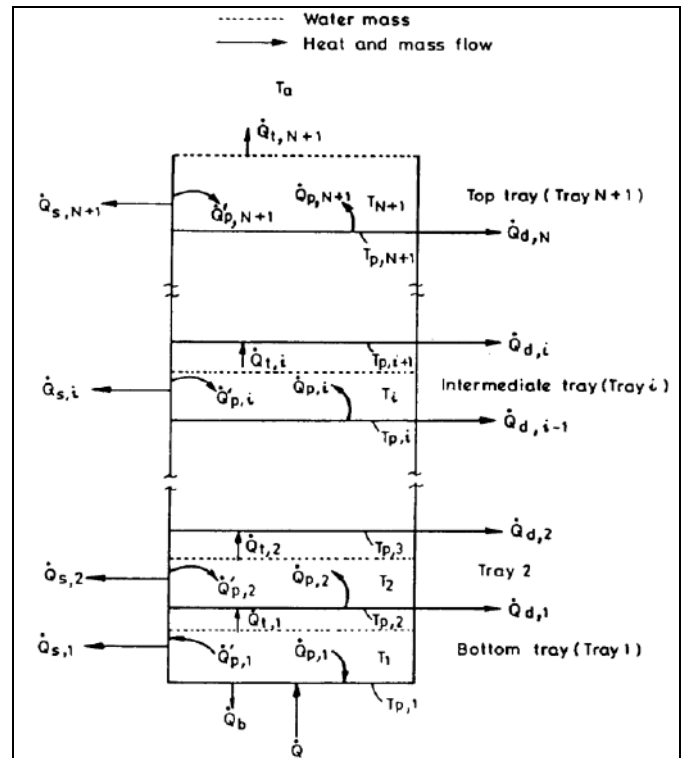$$Q_{p,i} + Q'_{p,i} - Q_{t,i} - Q_{d,i-1} = 0 \quad i = 2, N. \qquad (4)$$

Fig 2: A multi-stage stacked tray solar still for energy balance.

Water mass in top $(N + 1)^{th}$ tray:

$$Q_{P,N+1} + Q_{P,N+1} - Q_{t,N+1} = 0. \qquad (5)$$

Various energy fluxes are defined as follows:

$$Q_{p,i} = A_{b,i} h_p (T_{p,i} - T_i) \quad i = 1, N + 1, \qquad (6)$$

$$Q'_{p,i} = A_{b,i} h_{,p} (T_{p,i} - T_i) \quad i = 1, N + 1, \qquad (7)$$

$$Q_{t,i} = A_{b,i} h_i (T_i - T_{p,i+1}) \quad i = 1, N + 1, \qquad (8)$$

$$Q_{s,i} = A_{s,i} h_{s,i} (T_{p,i} - T_a) \quad i = 1, N + 1, \qquad (9)$$

$$Q_{d,i} = M_{e,i} C_w A_{b,i} T_{p,i} \quad i = 2, N, \qquad (10)$$

$$Q_b = A_{b,j} h_b (T_{p,l} - T_a). \qquad (11)$$

Substituting the values of various energy terms (Q_s) from eqns (6)-(8) and (10) in equt. (1) and (2), and rearranging various terms, one gets the following expressions for tray temperatures:

$$T_{p,l} = \frac{H_l T_l + (h_b A_{b,l} + f_l) T_a}{h_b A_{b,l} + f_l + H_l}, \qquad (12)$$

$$T_{p,l} = \frac{h_{i-l}A_{b,i-l}T_{i-l}+H_iT_i+f_iT_a}{h_{i-l}A_{bi-l}+f_i+H_i} \quad i = 2, N+1 \qquad ..... (13)$$

Where

$$f_i = h_{s,i}A_{s,i}$$

$$H_i = (A_{s,i}h'_p + A_{b,i}h_p)i = 1N + 1. \qquad .... (14)$$

Substituting tray temperatures from eqns (12) and (13), and different Qs from eqns (6), (7), (9), and (11) in eqns (3), (4), and (5), a set of (N + 1) simultaneous linear equations is obtained for water temperatures in various trays. This can be expressed as follows:

$$[C]_{(N+1),(N+1)}[T]_{(N+1),1} = [D]_{(N+1),1} \qquad .... (15)$$
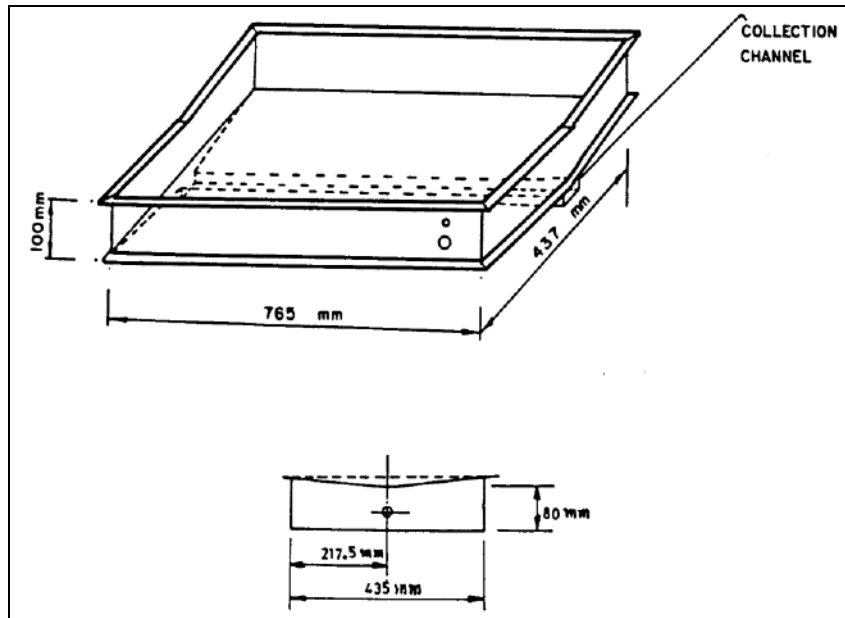

Fig 3: Schematic diagram of an intermediate tray.

Where the subscripts represent show order of the matrices; matrices C and D represent the coefficient matrix and matrix of constants, respectively. Operating eqn (15) by $[C]^{-1}$ on both sides, one gets

$$[T] = [C]^{-1}[D] \qquad .... (16)$$

This equation can be used for evaluating various T_s. On substituting T_s in eqns (12) and (13), tray temperatures can

also be obtained.

Table 1: Experimental and theoretical values of hourly distillate yield for a three stage stacked tray solar still

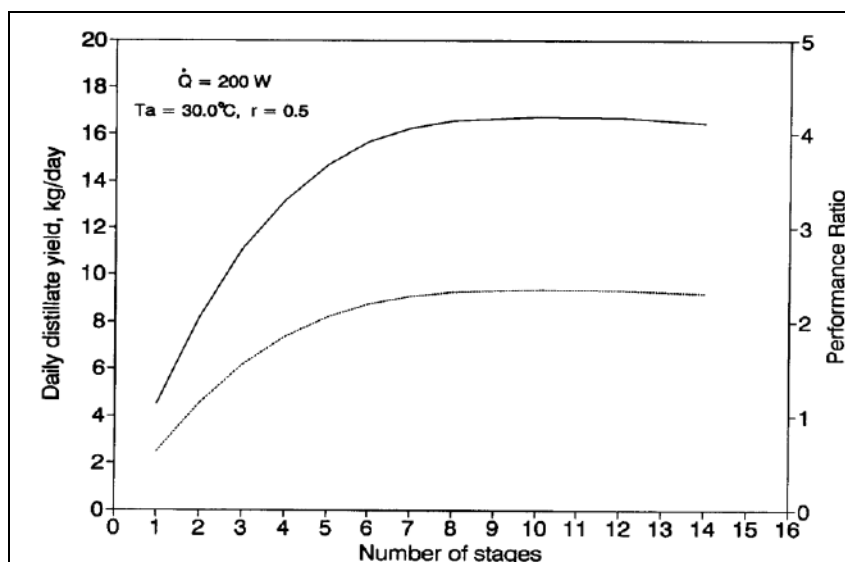|		Hourly distillate yield (kg h⁻¹)	
Series Number	Q(W)	Experimental	Theoretical
1.	358	0.640	0.645
2.	890	2.000	2.207

Fig 4: Daily distillate yield and performance ratio (PR) as a function of number of stages; Daily distillate yield, Performance ratio

Result and Discussion

Results of the experiments and numerical calculations carried out for studying the performance of multi-stage distillation in a stacked-tray design are presented in this section. The experimentally obtained values are shown by the discrete points, whereas the theoretical values are depicted by the continuous lines. The corresponding values of hourly distillate yield, obtained experimentally and theoretically, are presented in Table 1.

It is clear from the results that the theoretical values are in reasonably good agreement with the experimental results. Figure 4 shows a variation of daily distillate yield as a function of the number of stages for a typical set of parameters; a plot of PR (defined by eqn 20) has also been shown in the figure. It may be seen that the daily distillate yield increases with a corresponding increase in the number of stages of the distillation system. Fractional increase in Md decreases with the introduction of any new stage. This behavior suggests that an optimum value should be obtained that corresponds to the local parameters of operation and the costs of the distillation unit. It is also to be noted here that the results presented in the Fig. 4 may change considerably if the level of insulation is different from the one assumed here.

Conclusion

The proposed design of a multi-stage stacked tray solar still shows great potential in terms of higher distillation yield per unit area as compared to other available designs of solar stills. The developed computer model predicts the steady state performance of the system quite satisfactorily and, hence, can be used for predicting the system performance for a given set of parameters.

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