7. CONCLUSIONS

To study the flow distribution in a solar collector array having collectors in parallel, a theoretical model was developed. The model was used to study the effects of collector parameters-riser and manifold diameters, riser spacing and length, and array parameters-collector spacing, number of collectors in parallel and flow rate, on the flow distribution in the risers.

Experiments were carried out using electrochemical technique to measure directly the flow in the risers. To verify the model, eighty experiments were conducted. Based on the experiments and the computer simulations of the effects of collector and array parameters on the flow distribution in a large solar collector array the following conclusions are drawn.

1. For the first time a model has been developed to compute collector array efficiency given the collector and array parameters. The collector and array parameters are used to determine the flow distribution in the risers, which in turn alongwith the thermal and optical properties of the collector is used to calculate the collector array efficiency. The model has been developed both for asymmetric (Z-manifold) and symmetric (U-manifold) flow configurations.

2. The model was verified by experiments by directly measuring the riser flow rates. An excellent agreement within 4.5-7.5 % was observed.

   It was also checked with the outdoor experimental data reported in the literature for an evacuated tubular solar collector array. The agreement was excellent. The isothermal model thus can be used for actual non-isothermal operating conditions for the range of parameters which is normally encountered in solar collector array.

3. The effect of collector parameters on the flow distribition are summarised below. The observations are with respect to the baseline collector geometry and flow rate of 0.0075 $kgs^{-1}m^{-2}$.

   Manifold Diameter

   Flow maldistribution decreases with increase in the manifold diameter, other parameters remaining the same. This is due to lower pressure drop across the manifold.

   Riser Diameter

   Flow maldistribution decreases with decrease in the riser diameter, other parameters remaining the same. This is due to increase in the riser pressure drop.

Riser Spacing

Flow maldistribution increases with reduced riser spacing. Reduction of riser spacing for the same header length implies more number of risers per collector, which results in lower pressure drop offered by the riser.

The effect of array parameters are as follows.

Number of collectors

Flow maldistribution increases with number of collectors in parallel. Flow maldistribution is lower in symmetric flow for a few number of collectors as the manifold pressure distribution is more conducive for flow uniformity. As the number of collectors increases the reverse is true.

The increase in flow maldistribution is due to increase in the flow rate entering the array as also the manifold pressure drop corresponding to increase in the manifold length for the same riser length.

Flow Rate

Flow maldistribution increases with flow rate.

Collector Spacing

Flow distribution is marginally affected for the range of spacing normally encountered in solar collector array.

Based on the computer simulation results, **area ratio** was found to be a critical design parameter. Area ratio is defined as the ratio of cross-sectional areas of a single riser to that of manifold.

Flow maldistribution decreases with a decrease in the area ratio. This essentially means that the riser pressure drop should be controlling to ensure uniform flow distribution.

This could be achieved either by increasing the manifold diameter keeping the riser diameter fixed or reducing the riser diameter for a fixed manifold diameter, the area ratio remaining the same for both the cases. This is true both for asymmetric and symmetric flow configurations.

4. Unlike the general belief, symmetric flow configuration can be used, with flow maldistribution and small reduction in collector array efficiency, provided proper area ratio is chosen.

5. Collector array efficiency depends also on the optical properties of the absorber in addition to the flow distribution in the risers. Both selective and non-selective collectors were considered. In general, the

collector array efficiency is pronouncedly lower in non-selective collector due to higher collector loss coefficient for a given flow distribution.

Collector array efficiencies have been presented for selective and non-selective collectors for area ratios of 0.05, 0.10, 0.20 and 0.40, both for symmetric and asymmetric flow configurations. A suitable area ratio can be selected for a prescribed limit in the collector array efficiency reduction.

Specifically, if the reduction is to be within 1 %, an area ratio 0.10 is adequate for upto 5 collectors in parallel. For 10 collector modules in parallel an area ratio of 0.05 is required.

It was established that a single value of manifold porosity, defined as the ratio of the cross-sectional areas of total number of risers to that of the manifold, could correlate the collector geometry to the prescribed reduction in the collector array efficiency for upto 10 collectors in parallel. For 1 % loss in the collector array efficiency the porosity of the manifold should be 4.

6. Three methods of array flow balancing techniques were proposed. The first one was by controlling area ratio. The second was based on the observations made during large

collector array simulations that flow uniformity could be achieved by having the upper manifold diameter greater than the lower one. Thirdly, employing calibrated orifice inserts to redistribute the flow in the array.

It was established that area ratio is a simple and yet an effective balancing technique avoiding the use of different manifold diameters or complication of using pre-calibrated orifice inserts. The orifice inserts technique is applicable for asymmetric configuration only. Area ratio method is universal and is applicable both for asymmetric and symmetric flow configurations.

To extend array balancing beyond 10 collectors in parallel the same porosity value of 4 is to be maintained. Alternatively, two arrays, each having 10 collectors, can be kept in series at reduced collector flow rate of 0.0050 $kgs^{-1}m^{-2}$.

7. The baseline collector and the flow rate are used widely in the industry within a small variation. Thus, the findings of the present study can be universally applied to collector array design for solar water heating systems.