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MASTER

AN INTERFEROMETRIC STUDY OF THE NATURAL CONVECTION
CHARACTERISTICS OF FLAT PLATE, SLAT AND VEE-CORRUGATED
SOLAR COLLECTORS

Final Report

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ABSTRACT:

The natural convection heat transfer relations for the heat transfer between absorber and cover plates of solar collectors has been studied. Interferometric techniques were employed to evaluate the local coefficients. Average values were obtained by integration of the local values. The results are presented in terms of correlations between Nusselt number and Grashof number.

The investigations were carried out over tilt angles of 45 to 90 degrees. The Grashof number range tested was representative of that existing in flat plate collectors. The various geometrics included large flat enclosures, small aspect ratio enclosures representative of honeycomb or slat collectors, vee-corrugated (vee-grooved) collectors, and compound parabolik concentrators.

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RESEARCH RESULTS

1. Natural Convection Characteristics of Flat Plate Collectors

Local and average heat transfer coefficients of natural convection between parallel plates have been experimentally studied using interferometric techniques. The experimental conditions were similar to these existing in flat-plate solar collectors. Correlations have been developed for the local and average heat transfer Nusselt numbers as functions of tilt angle and Grashof number. The results are useful in determining the top loss coefficient for flat plate collectors and, eventually, for finding means of minimizing these losses. The correlation for the average Nusselt number $\overline{Nu}_L$ is given as a function of the tilt angle θ , Grashof number Gr_L , and Prandtl Pr as

$$\overline{Nu}_L = 0.118[Gr_L Pr \cos^2(\theta-45)]^{0.29}$$

This work was presented at the American Section of the International Solar Energy Society Meeting, 1977, and the ASME Winter Annual Meeting, 1977. It was published in the proceedings of the AS/ISES meetings as document C00-2971-1, in the ASME Proceedings entitled "Heat Transfer in Solar Energy Systems" as document C00-2971-2 and the ASME Journal of Heat Transfer as document C00-2971-3.

2. Natural Convection Heat Transfer in Small and Moderate Aspect Ratios—An Application to Flat Plate Collectors

Local and average heat transfer coefficients for natural convection between parallel plates of small and moderate aspect ratios have been experimentally determined using an interferometric technique. The experimental conditions are similar to those existing in solar collectors. Measurements of the heat-transfer coefficient are made over angles of inclination with respect to the horizontal ranging from 45 degrees to the vertical. The Grashof number range studied was 10^3 to 1.4×10^5 . The aspect ratio (the ratio of plate length to plate spacing) ranged from 0.25 to 4. The results obtained in a previous investigation for aspect ratios of 9 to 36 are included to show continuity.

For aspect ratios of 4 and less, the enclosure is partitioned to obtain the required aspect ratios. These conditions are similar to those for slat-type solar collectors. Slat angles, measured with respect to the plates of 45, 60, 90 and 135 degrees, were studied.

The results are useful in determining the top convection loss coefficient and, therefore, in minimizing losses and optimizing the design of solar collectors. The results indicate that the convective losses are strong functions of the aspect ratio for aspect ratios less than 4. Slat angles less than 90 degrees (i.e., oriented downward) help reduce convective losses.

The average Nusselt number was correlated with Grashof number, aspect ratio A , slat angle ϕ , and tilt angle θ as

$$\overline{Nu}_L = C_1 C_2 Gr_L^{0.28} \quad \text{for } \phi > 90$$

$$\text{and } Nu_L = C_3 Gr_L^n \quad \text{for } \phi < 90$$

where C_1 is a function of aspect ratio, C_2 a function of tilt angle, and C_3 and n functions of A , ϕ , and θ .

This work was presented at the ASME Winter Annual Meeting, December, 1978, and published in the proceedings as document C00-2971-4. It was also presented at the International Solar Energy Society Congress, New Delhi, India, in January, 1978. It has been accepted for publication in the Journal of Heat Transfer.

3. Natural Convection of Vee-corrugated Collectors.

Heat transfer by natural convection in inclined vee-corrugated enclosures has also been experimentally studied using interferometric techniques. The vee-corrugated enclosure consisted of a cooled flat surface on top and a vee-corrugated heated surface below.

The effects of Grashof number, tilt angle and vee aspect ratio (the ratio of mean plate spacing to vee height) on the heat-transfer coefficients were determined for the vee-corrugated enclosure. The Grashof number range examined was 1.8×10^3 to 5×10^5 and the vee aspect ratios were 0.75, 1.00, and 2.00. The tilt angles studied were 0, 45, 60 and 90 degrees. Correlations were developed for the average Nusselt number for each angle and vee aspect ratio. The heat-transfer coefficients were as much as 70% higher than those of the flat-plate enclosure under similar operating conditions and the same average plate spacing. Significant effects of tilt angle and vee aspect ratio on the convection coefficients were found. The average Nusselt number was correlated with Grashof number as

$$\overline{Nu}_L = C Gr_L^n$$

where C and n are functions of tilt angle and vee groove aspect ratio.

This was the subject of the PhD thesis of K. R. Randall. The abstract of this thesis is document C00-2971-5.

4. Natural Convection Characteristics of Compound Parabolic Concentrators.

The natural convection characteristics of CPC collectors with a flat absorber surface are under study. The heat transfer coefficients will be evaluated over concentration ratios of 2 to 4, tilt angles of 45 to 90 F, and a Grashof number range representative of actual operation. The local and average Nusselt numbers will be determined experimentally, and compared to analysis. Correlations useful for the design and analysis of thermal performance of CPC's will be developed.

This project is the on-going PhD thesis topic of B. A. Meyer. It will be completed in 1980.