WIND INDUCED HEAT LOSSES FROM OUTER COVER OF SOLAR COLLECTORS

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Abstract—The top cover of a flat plate solar collector is generally exposed to wind. In indoor experiments it is necessary to simulate this wind. Correlations have been developed for the wind heat transfer coefficient over flat horizontal surfaces exposed to forced air flow, produced by industrial fans in indoor experiments.

1. INTRODUCTION

In order to predict the thermal performance of a flat plate solar collector, it is necessary to estimate the convective heat transfer coefficient due to wind on the outer cover of the collector. McAdams [1] provided the correlation relating the convective coefficient to wind speed on the basis of the data of Jurges for a 0.5 m square surface. The dimensional equation is given as

$$h_w = 5.7 + 3.8\, V_w, \tag{1}$$

where V_w is the wind speed in m/s and h_w is the convective heat transfer coefficient in $\mathrm{W/m^{2\circ}C}$. Sparrow *et al.* [2] obtained similar results while carrying out wind tunnel studies on rectangular plates at various orientations. Kowalski *et al.* [3] observed that the average convective heat transfer coefficients on spheres in a naturally turbulent outdoor environment were up to 2.2 times greater than the coefficient obtained in standard low turbulence intensity wind tunnel experiments. Recently, Test *et al.* [4] carried out a detailed experimental investigation to determine convective heat transfer coefficient on the upper surface of a rectangular plate of size 122.0 cm × 81.3 cm and obtained results similar to Kowalski *et al.* [3]. They concluded that the methods based on low turbulence intensity wind tunnel tests, significantly underestimate the heat transfer due to wind flow in the natural environment. They proposed the following correlation, on the basis of experimental observations:

$$h_w = (8.55 \pm 0.26) + (2.56 \pm 0.32)\, V_w. \tag{2}$$

Presently, research work on the thermal modelling of solar collectors, box-type solar cooker and basin-type solar still is being carried out by our group [5–7]. Experimental validation is also carried out by indoor tests using electric heaters to simulate solar heating and large industrial fans to simulate the wind. So, it is imperative to carry out indoor experimental studies using such fans to determine the wind heat transfer coefficient for the outer cover of such devices. Experiments have been performed on a flat horizontal square surface, corresponding to the outer glass cover of a box-type solar cooker. Experiments have also been carried out on a basin-type solar still and the wind heat transfer coefficient has been obtained (although the main objective was thermal modelling of the solar still). All forced convection heat transfer coefficients reported are corrected values, that is after accounting for radiative heat transfer.

2. EXPERIMENTAL ARRANGEMENT

The experimental arrangement used for simulating the air flow over the top cover of a box-type solar cooker consists of a 4 mm thick aluminum plate of size 0.368 m^2. Five flat plate type electric heaters of size 0.05 m × 0.37 m each were fixed below the square plate to provide uniform heating to the plate through a servo-stabilized electric power supply. The power input was measured by a calibrated wattmeter. To reduce the bottom heat losses from the plate to a negligibly small value, the plate plus heater combination was placed over 0.16 m thick glasswool insulation in a wooden box. Thus, the depth of the box was similar to that of a box-type solar cooker. A bright aluminum foil was pasted carefully onto the outer surface of the aluminum plate to reduce radiative heat transfer to the surroundings. With this arrangement, radiative heat loss is between 2.3 and 4.0% of total heat losses (depending on the surface temperature, wind speed, etc.). Different values of surface temperatures were obtained by adjusting input power supply to the electric heaters using a variac. A one H.P. tube-axial flow fan was used to produce a forced air flow over the surface. Different wind speeds were obtained by controlling the air supply on the suction side of the fan. A 3-cup anemometer, using a chopper type sensor, was used for the measurement of wind speed. The experiments on the solar still are described in the Appendix.

In the experiments, each data point was finalized after allowing a number of hours to get a very good steady state. On reaching the steady state condition, temperatures of the outer cover surface and ambient air temperature, input power supply and wind speed were recorded. The wind heat transfer coefficient was calculated using the relation:

$$h_w = \frac{W}{A(T_{\text{cover}} - T_a)} - h_r - U_{\text{bottom}}, \tag{3}$$

where W is the input power supply (Watts), A is the surface area of the outer cover (m^2), T_{cover} and T_a are the outer cover and ambient temperatures (°C), respectively, h_r is the radiative heat transfer coefficient and U_{bottom} is the heat transfer coefficient for conduction through the glasswool below.

3. CORRELATION FOR WIND HEAT TRANSFER COEFFICIENT, h_w

The experiments were carried out at several different air speeds and surface temperatures. The bottom conduction losses were very small and so these were estimated by standard

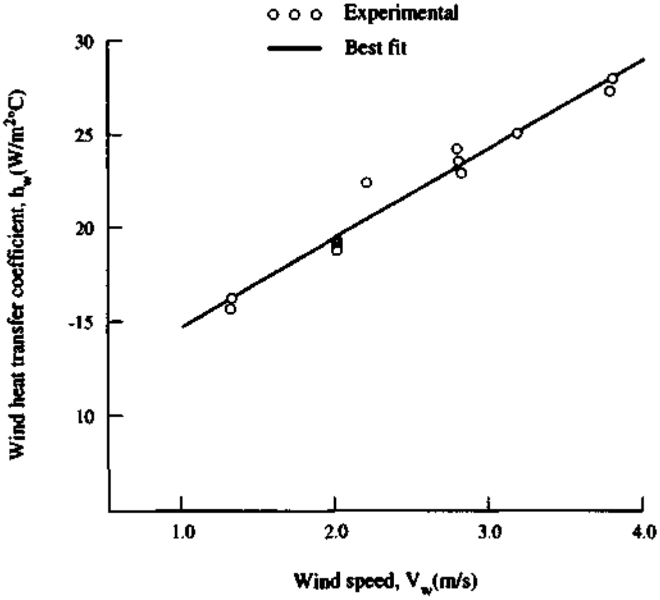

Fig. 1. Variation of h_w with wind speed for a square surface.

calculation procedures. Radiation correction was also applied (in fact the room ceiling temperatures were measured using thermocouple as an additional precaution). Figure 1 depicts the results for wind heat transfer coefficients for different wind speeds. The following linear correlation for h_w is obtained by regression of the experimental data,

$$h_w = 10.03 + 4.687\,V_w. \tag{4}$$

Correlation (4) fits the experimental values of h_w within r.m.s. error of 3.25%. The correlation obtained by experiments on a solar still is given in the Appendix.

4. RESULTS AND DISCUSSION

On comparing the results reported by McAdams [1] with those obtained using correlations (4) and (5), it is observed that the values of the wind heat transfer coefficient, h_w, obtained with industrial fans are higher than those of McAdams. The values of h_w obtained by wind-tunnel tests would have been underestimations for our experiments on thermal modelling. It is therefore suggested that the values of h_w obtained by wind tunnel tests should not be employed under other conditions. In our experimental studies of solar collectors, cookers and stills, h_w is determined under the same conditions as in the experiments on the equipment under study.

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APPENDIX: EXPERIMENTS ON A BASIN-TYPE SOLAR STILL

Experiments have also been carried out on a basin-type solar still with the main objective of thermal modelling. The prototype of the basin-type solar still used for experimentation consists of a galvanized iron metallic tray of size 1.30 m × 0.88 m × 0.20 m, fixed with six large area flat strip heating plates for heating from below the tray. Window glass of thickness 4 mm was used as the outer cover of the still. The bottom and sides of the still were insulated with glass wool insulation of thickness 0.20 m and 0.10 m, respectively. A calibrated copper–constantan thermocouple was imbedded in the centre of the glass cover (by cutting a suitable groove) to measure its temperature. An industrial man-cooler fan of 1 H.P. was employed for producing forced air flow over the glass cover of the solar still. Each data point was finalized after allowing 8–10 h to get a good steady-state. Experimental values of the wind heat transfer coefficient are correlated as

$$h_w = 12.2 + 6.548\, V_w, \tag{A1}$$

with r.m.s. error 11.56%.