FLOW AND HEAT TRANSFER STUDIES IN A DOUBLE – PASS COUNTER FLOW SOLAR AIR HEATER

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ABSTRACT

The present work deals with the experimental investigation of flow and heat transfer studies in a counter flow double pass solar air heater. To achieve the higher heat transfer from the absorber plate to the flowing air stream with an intention to increase the amount of the collected energy, and hence to improve the instantaneous efficiency, a unique double pass solar collector concept has been used in the present study. To investigate the effects of Reynolds number, tilt angle, β =20º and mass flow rate on the performance parameters of the Solar Air Heater, a detailed experimental analysis has been made. Apart from achieving higher collector performance, the present study is also important from the fundamental point of view.

Keywords: solar air heater, Absorber Plate, Instantaneous efficiency, Top loss, Mass flow rate

1. INTRODUCTION

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth surface is approximately 1.8×10^{11} MW, which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle solar energy could supply all the present and future energy needs of the world on a continuing basis. The main difficulty is capturing more and more energy from the available source and utilize for useful work.

In recent times there has been renewed interest in a non-conventional solar air systems because of its applications for achieving higher collector performance. Out of various non-conventional solar energy collectors, a double pass solar air heater may play an important role for getting higher heat transfer coefficient of air.

Drying of the agricultural products and space heating are some of the important application of solar energy. Solar air heaters normally comprise of an array of integrated solar heat collectors, with most incorporating a single pass type of forced air circulation of ambient air intake and solar heated hot air discharge to the required space.

The first ever reported work on the design modification dates back to more than five decades, when Pery[1] presented experimental results on high-velocity jets impingement perpendicular to the heat transfer surface. First of all, the useful heat transfer correlation of the jet plate solar air heater has been reported by Kercher and Tabakoff [2]. Later Chaudhary and Garg[3] reported the detailed studies on the jet plate solar air heater. Kuzay et al. [4] have reported to get substantial improvement in thermal efficiency when they did experiment on a finned solar air heater. Thombre and Sukhatme[5] have conducted extensive experiments for turbulent heat transfer in a shrouded fin arrays solar air heater and suggested Dittus-Boelter equation for finding heat transfer coefficient. Singh[6] also reported the analytical work on longitudinal fins solar air heater.

In order to reduce losses from the top, Satcunanathan and Deonarine[7] suggested the use of a double pass solar air heater in order to reduce the losses from the top. It was observed from the experiment that the outer glass cover was lowered by 2 to 5°C and as a result, the losses were reduced and the efficiency of the collector was measured to be 10 to 15% higher than the conventional single pass solar air heater. Subsequently, Wijeysundera et al.[8] studied 2-Pass concept in greater detail both analytically and experimentally. Duwairi et al.[9] have reported the influence of solar flux on the performance of solar pond. Solar pond is a system of collecting and storing solar energy. Singh[10] has numerically investigated the natural convection and surface radiation in open cavities which may be analyzed in the solar air heater.

Cucumo et al.[11] have done theoretical and experimental works for comparisons among different testing methods in quasi-dynamic conditions of flat liquid solar collectors and reported that the comparison results show a substantial agreement among all the methods. Ramani et al.[12] have predicted the results on performance studies on 2-pass solar collector.

However, a search of technical literature indicates that only a limited amount of work has been done in double pass solar air heater. The present work is motivated by a need to study and analyze the influence of the above mentioned parameters on the performance of the solar air heater.

The test runs to collect flow and heat transfer data under steady state conditions were conducted in Dhanbad, Jharkhand(India) during 7th Feb, 2010 -.17th April 2010. The following parameters were recorded (i) temperatures of the hot absorber plate (ii) temperature of the air at inlet and exit (iii) head difference across the orifice meter (iv) gap between the bottom plate and the absorber plate (v) tilt angle.

3. DATA REDUCTION

Mass flow rate of air has been determined from the manometer head difference across the orifice plate, using the following relation.

$Q = C_d A_o (2g\Delta h_{air})^{1/2}$ (1)

$m = Q \times \rho$ (2)

Useful heat gain to the air is calculated as;

$Q_u = m C_p (T_{fo}-T_{fi})$ (3)

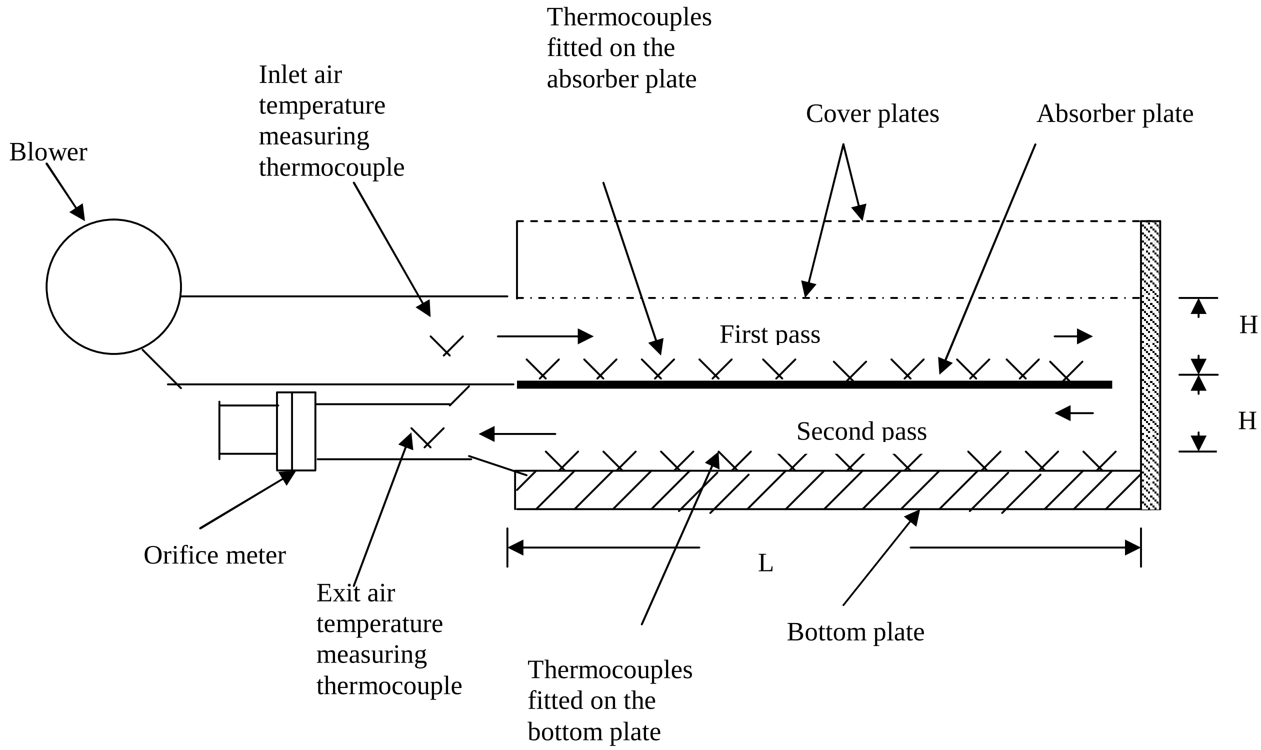

Fig. 1 Schematic sectional view of the experimental setup

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The schematic sectional view of the experimental set up is shown in Fig.1. The flow system consists of an entry section, an exit section, an orifice meter, U-tube manometer and a centrifugal blower. Ten thermocouples (K-type) are attached with upper surface of the absorber plate whereas other ten thermocouples are attached with bottom insulating plate. One thermocouple is connected to find inlet temperature and other is used for measuring exit temperature of the air. The whole solar air heater is supported on the tilting system.

The heat transfer coefficient of the air is found as;

$h = Q_u/Ap\,(T_{pm} - T_{fm})$ (4)

The heat transfer coefficient, has been used to determine the Nusselt number as

$Nu = hD_h/k_f$ (5)

Instantaneous Collector Efficiency of the solar air heater is as;

$\eta_i = Q_u/ApI_T$ (6)

$\eta_i = F_R (\tau\alpha) - U_l F_R [(T_{fm}-T_a)]/I_T$ (6a)

Friction factor is found from the following relation;

$f = 0.079\times Re^{-0.25}$ (7)

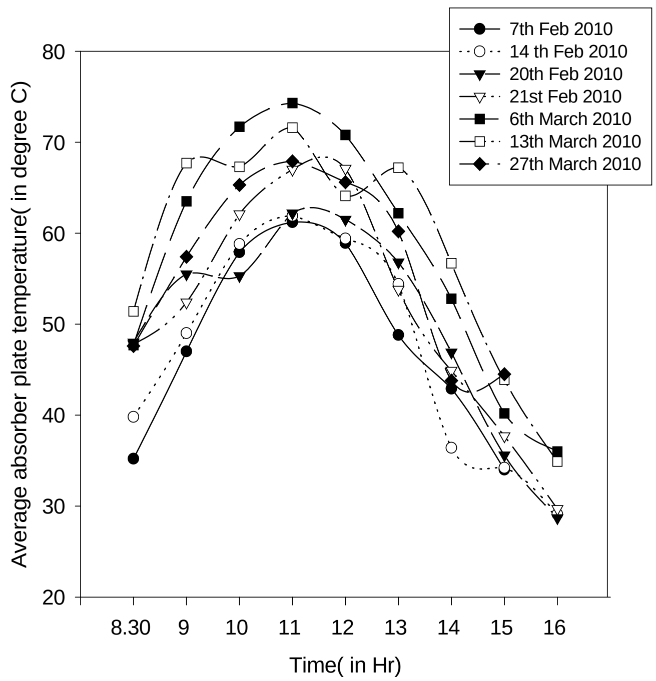

Fig. 2 Average absorber plate temperature variation with time

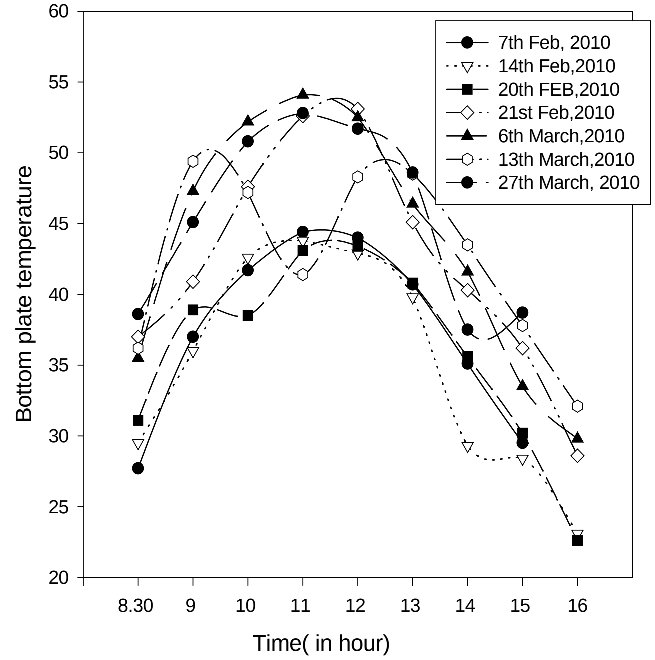

Fig. 3 Variation of average bottom plate temperature with time

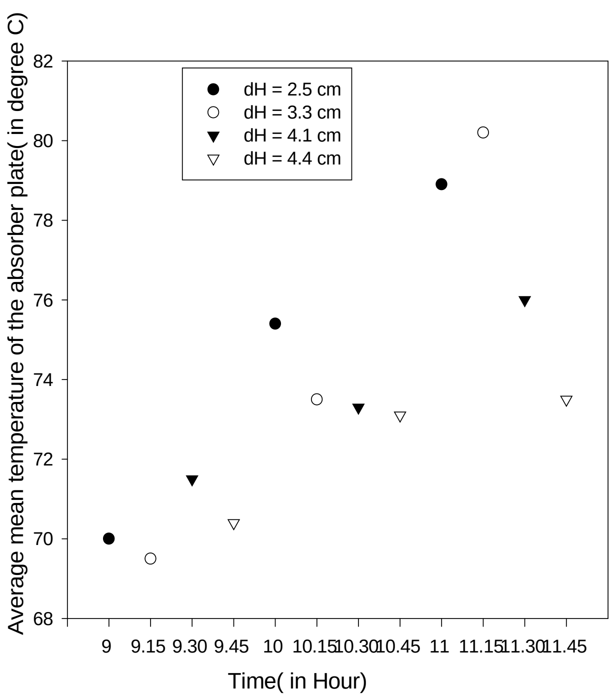

Fig. 4 Absorber plate temperature variation with time

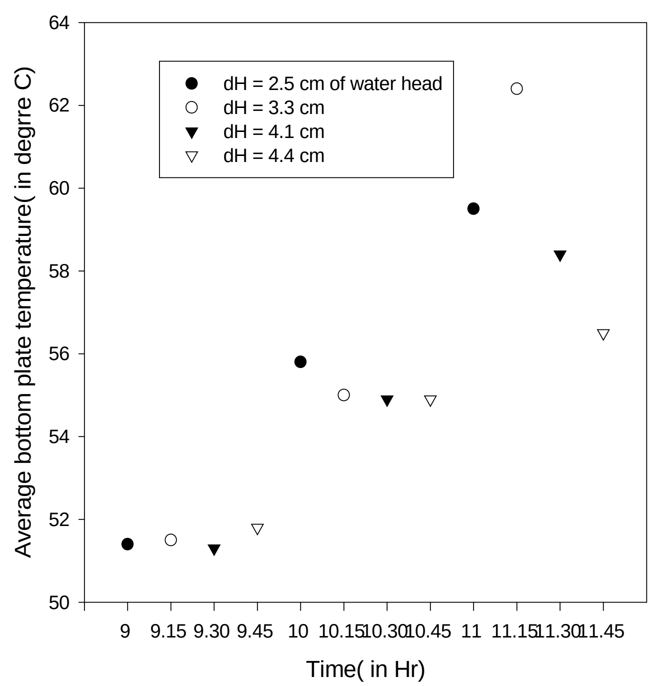

Fig. 5 Average bottom plate temperature variation with time

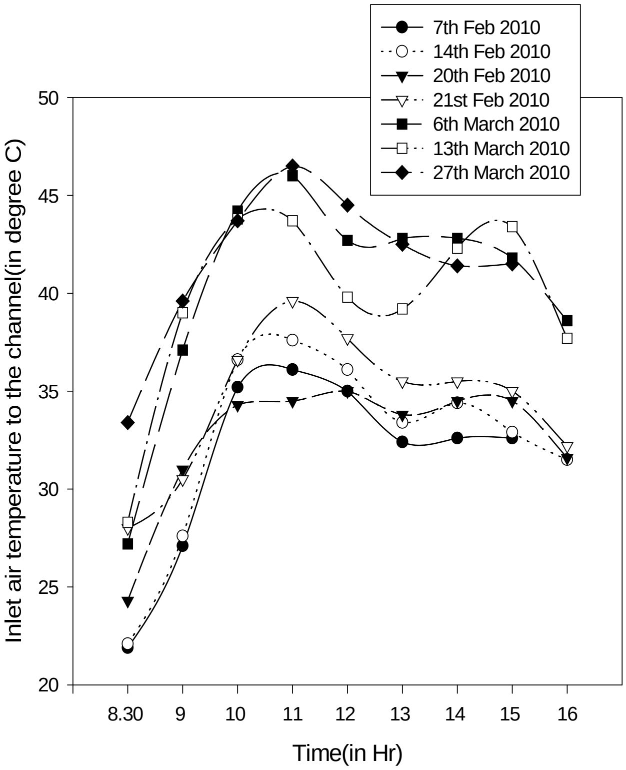

Fig.6 Inlet air temperature varaition with time

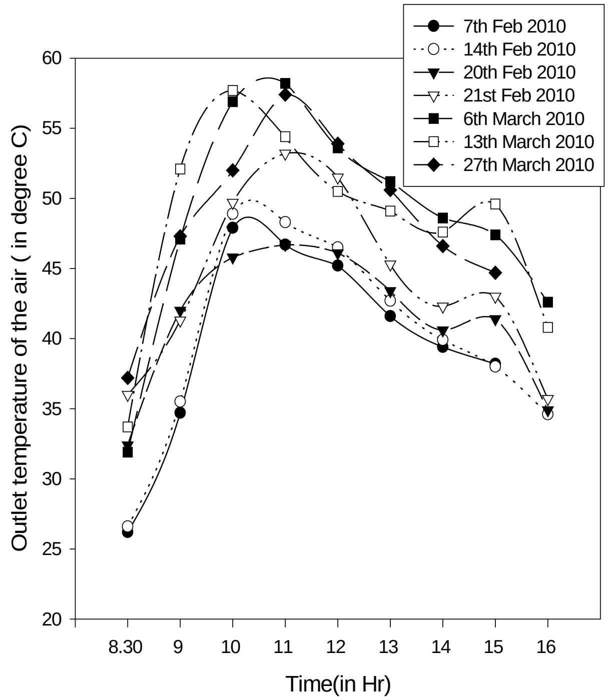

Fig.7 Outlet temperature of the air variation with time

4. RESULTS AND DISCUSSION

Figures 2 and 3 show the variations of average temperature of the absorber plate and bottom plate with time. The average temperatures of both the plates are increased with time and the same starts decreasing after 12 hr. The maximum temperature of the absorber plate and the bottom plates are observed as 75ºC on 27th March, 2010 and 55ºC on 6th March,2010 respectively due to radiation and convection heating.

Figures 4 and 5 show the variation of average temperature with time for variable flow rates of air. As the flow rate increases the average temperatures of the absorber and bottom plates decrease. In case of the absorber plate, it is seen as shown in Fig. 4 that the minimum temperature is achieved for

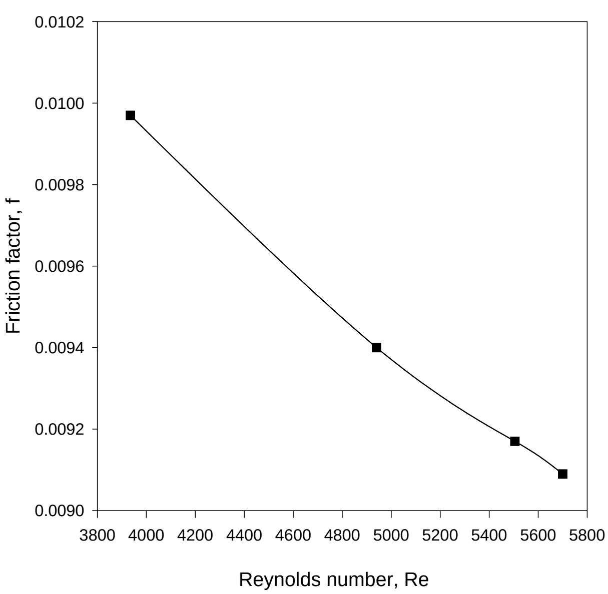

Fig. 8 Friction factor variation with Re

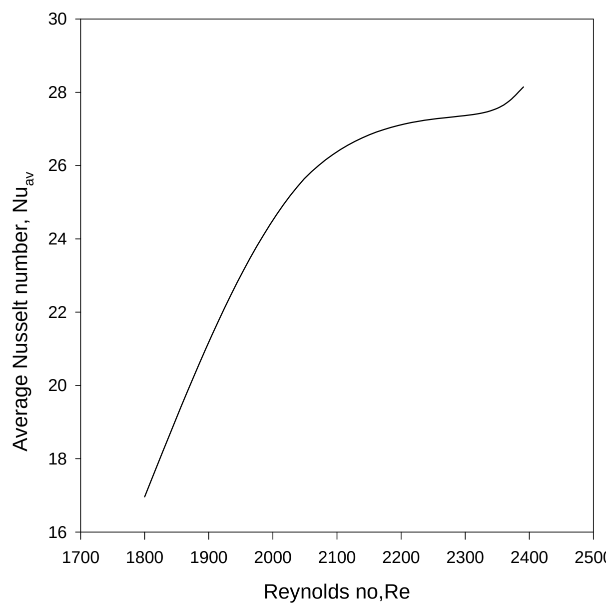

Fig.9 Nusselt number variation with Re

maximum ΔH and the same pattern is observed for the bottom plate as shown in Fig.5. It signifies that more heat gain is possible at the higher flow rate.

Figure 6 shows the variation of inlet temperature of the air in the solar air heater channel with time. The maximum temperature of the inlet air is seen at approx. 12 noon on 27th March, 2010. The outlet temperature of the air after taking heat from the absorber plate in the solar air heater also varies similar like earlier one. In this case, the maximum temperature is observed as approx. 58ºC as shown in Fig.7. The outlet temperature starts decreasing after 12 noon

Figure 8 shows the variation of friction factor in the flow channel. It clearly shows that friction factor decreases as Reynolds number increases. It signifies that at high speed of the air, friction head loss will be less. It means that less pumping power is required by the blower. At high speed, heat transfer rate increases as heat transfer coefficient is a function of velocity.

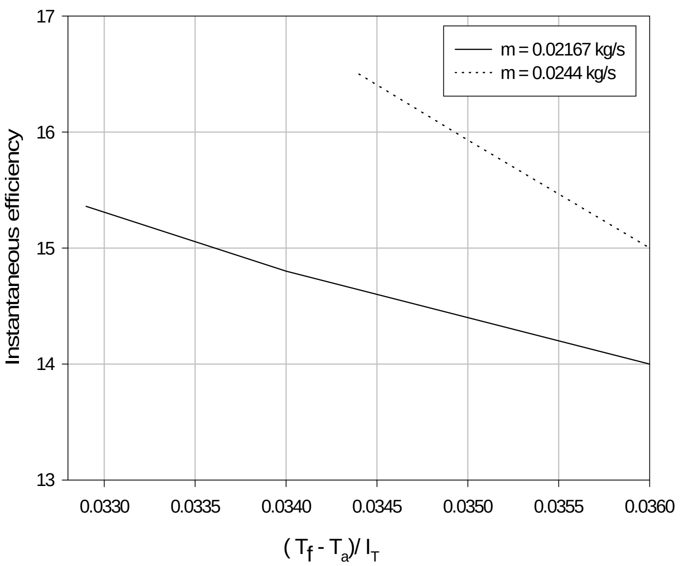

Fig. 10 Variation of Instantaneous efficiency with (T_f-T_a)/I_T and mass flow rate(m)

Figure 9 shows the variation of Nusselt number with Reynolds number. The solar air heating is based on forced convection and so the higher Nusselt number is observed at higher Reynolds number.

Figure 10 shows the variation of instantaneous efficiency with instantaneous solar flux, mass flow rate and ambient temperature. As the factor (T_f –T_a)/I_T increases, the value of instantaneous efficiency decreases. It signifies that the useful heat gain by the absorber plate is increased by either increasing the instantaneous flux or increasing the value of mass flow rate of the air. It can be seen that, when the flow rate (or velocity) of the air flowing through the collector channel increases, the efficiency also increases. The relationship (between η_i and velocity) is of great importance to the designer of a solar air system in order to achieve the best compromise between collector output and fan power.

The results show that as the temperature of the air entering the collector increases above the ambient temperature, the heat losses from the collector become larger and the useful energy collected becomes less.

5. CONCLUSIONS

The double-Pass solar air heater concept studied experimentally and analyzed in the present work shows the temperature of the absorber plate and outlet temperature of the air of the solar air heater is time dependent. Lowest friction factor is obtained at highest Reynolds number. Heat transfer in non-dimensional form increases with Reynolds number. Instantaneous efficiency is higher at higher I_T. The results show that as the temperature of the air entering the collector increases above the ambient temperature, the heat losses from the collector become larger and the useful energy collected becomes less.

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7. NOMENCLATURE

A_c Cross-sectional area of the channel, (W×H)
A_o Orifice meter area, $(\pi/4)\ d^2$
A_P Absorber plate area, (L× W)
C_d Coefficient of discharge of the air
C_P Specific heat of the air, k J/kg-K
D_h Hydraulic diameter, 4Ac/P
f Friction factor
F_R Heat removal factor
g Acceleration due to gravity, m^2/s
h Heat transfer coefficient of air, W/m^2-K
H Height of each channel
I_T Instantaneous flux incident on top cover collecor
k_f Thermal conductivity of the air, W/m-K
L Length of the channel,m
m Mass flow rate, kg/s
Nu Nusselt number
Q Volumetric flow, m^3/s
Q_u Useful heat gain,W
Re Reynolds number, VD_h/ν
T_a Ambient Temperature, ºc
T_{fi} Inlet air temperature,ºc
T_{fm} Average mean fluid temperature
T_{fo} Outlet fluid temperature,ºc
T_{pm} Average plate temperature,ºc
U_l Overall total loss coefficient
V Velocity of the air, m/s
W Width of the channel

Greek symbols

η_i Instantaneous efficiency
ν Kinematic viscosity, m^2/s
ρ Density of air, kg/m^3
Δh Manometer head difference,
$\tau\alpha$ Transmittivity and absorptivity Product