Numerical analysis on flat-plate solar collector

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Abstract

Solar thermal collectors is a type of heat exchanger that intercepts solar radiation, converts into heat and transfers to the air medium. Solar collectors plays a major role in many engineering low temperature thermal applications thereby reducing the extensive usage of conventional fossil fuels. The applications of solar air heaters includes space heating, process heat, drying, night cooling and ventilation applications. The prime aim of this study is to analyze the theoretical performance of solar flat plate collector.

1. Introduction

Solar energy is the most abundant form of renewable energy that has enormous potential, not only in electricity generation but also for many industrial thermal applications. Solar energy improves our energy security by reducing the usage of expensive fossil fuels for applications like water heating, space heating, thermal electricity generation and industrial process heating systems [1-3]. Among many industrial thermal applications, drying food materials is an energy substantial process which consume almost 10-15% of nation’s industrial energy consumption. The primary aim of this research work is to design, develop and study the thermal performance of indirect solar dryer with flat plate collectors. In this present paper the efficiency of the solar dryer is studied through numerical analysis.

2. Modelling solar air heater

Solar matrix air heaters are highly suitable for high temperature applications than flat plate, vee corrugated and finned type air heaters. The matrix air heaters achieves higher efficiencies than other solar air heaters due to increased contact area between the air medium and wire mesh. Matrix air heaters are usually made of porous wire mesh [4-6]. The efficiency depends on the mesh size and porosity of the wire mesh. The heat exchanger mechanism depends on the packing of matrix wire mesh. The geometrical modelling is performed using radiative, top and bottom loss and convective heat transfer coefficients and various temperatures like absorber, glass, air inlet and outlet [7,8]. Numerical simulation on thermal performance is executed by assuming the following steady state conditions,

i. Thermo-physical properties of absorber and air is stable over the collector area and do not vary with temperature.

ii. Radiation and convection losses occurs from air heater top and bottom surface.

iii. Heat transfer and air flow are one dimensional.

The energy balance equation for absorber and fluid is represented by following equations for air flowing parallel to the absorber.

\[ s = h_v D (t_b - t_f) + U_L (t_b - t_a) \]

\[ h_v A (t_b - t_f) = \dot{m} C_p \frac{dt_f}{dx} \]

The collector efficiency (F’) and collector total loss coefficient (U_L) is given by the following expressions,
The top loss and back loss coefficient is given by

\[ F' = \frac{H + h_2 U_t}{(U_t + h_r + h_1)(U_b + h_r + h_2) - h_r^2} \]

\[ U_l = \frac{H(U_b + U_t) + U_b U_t(h_1 + h_2)}{H + h_2 U_t} \]

\[ H = h_1 h_r + h_2 h_r + h_1 h_2 \]

\[ h_r = \frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{1 + \frac{1}{\varepsilon_c} + \frac{1}{\varepsilon_p} - 1} \]

The top loss and back loss coefficient is given by

\[ U_t = h_w + h_{r,g-ciel} \]

\[ h_w = 2.8 + 3 v_{vent} \]

\[ h_{r,g-ciel} = \epsilon_c \sigma (T_g^2 + T_{ciel}^2)(T_g + T_{ciel}) \]

\[ U_b = \frac{T_{ciel} = 0.0552T_a^{1.5}}{h_{r,p-b} + h_{c,p-b} + \frac{e_{is}}{x_{is}} + \frac{e_{caisson}}{x_{caisson} + h_w}} \]

The radiative and convective heat transfer coefficient are determined by the expression given below,

\[ h_{r,p-b} = h_{r,p-g} \]

\[ h_{c,p-b} = 0.61 \left[ \frac{(T_p - T_a)}{L^2} \right]^{1/5} + 1.42 \left[ \frac{(T_p - T_a)}{L} \right]^{1/4} \]

According to Hottel-Whillier-Bliss the collector heat removal factor \( (F_R) \) and efficiency \( (\eta) \) is defined by,

\[ F_R = \frac{\dot{m}C_p}{A_c U_L} \left[ 1 - \exp \left( -\frac{A_c U_L F'}{\dot{m}C_p} \right) \right] \]

\[ \eta = \frac{q_u}{I} = F_R \left[ (\tau \alpha) - U_L \left( \frac{T_p - T_a}{I} \right) \right] \]

**Conclusion**

Solar collectors with different designs have different efficiencies therefore it becomes necessary to numerical studies on various design parameters before design and fabrication. The present work is composed of numerical analysis of solar flat-plate collector.

**References**