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Performance analysis of a multi-pass solar thermal collector system under transient state assisted by porous media

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ABSTRACT

An enhanced forced convective multi-pass solar air heating collector (MPSAHC) system aided with granite pebble bed has been investigated in this present article. The air heating collector system was tested in the outdoor solar research site of Universiti Teknologi PETRONAS, Malaysia (4.385693° N and 100.979203° E). Transport pipe for movement of heated air around the system was eliminated in the design of the MPSAHC facility to minimise the thermal losses, pressure drop and the pumping cost of the hot air in the control volume. The daily ambient temperature and relative humidity range recorded during the repeated tests are 21.09–36.64 °C and 48.04–87.9%, respectively. The collector unit achieved a peak temperature of 80.29 °C while the optimum system air mass flow rate of 0.016 kgs^{-1} was applied. Despite high relative humidity of the environment, the stream of ambient air was heated to 48.53 °C, 57.75 °C and 71.19 °C at different positions in the MPSAHC which correspond to single pass, double pass and multi-pass effects, respectively. The porous matrix exhibited slow energy discharge at night time with air temperature difference of 14.27 °C at 18:00 h to 4.54 °C at 24:00 h over environmental air temperature. MPSAHC system delivered specific energy demand (SED) of 11.51 kWh kg^{-1} while the maximum thermal collector and daily average transient collector efficiencies of 72.59% and 36.38% were achieved, respectively. A good agreement has been established between reported studies and the present investigation. Although continuity of system operation at night was achieved using porous matrix but improvement is still needed to optimise the system performance.

1. Introduction

Transformation of global energy demand from hydrocarbon source to sustainable energy sources would not be an easy task except every stakeholder in renewable energy sector takes pragmatic step to mitigate environmental pollution. In addition, there is need for improvement on the performance efficiency of solar energy based appliances to gain wide acceptability. The United Nations (UN) has supported the clean energy initiative with the launching of Sustainable Development Goals (SDG), while regional efforts such as vision 20-20-20 of European Union has been conceived to assist in protecting the environment from global warming and other adverse effects of fossil fuel.

Flat plate collector has been consistently used over the years for indirect solar space heating, drying operation and industrial application. Flat absorber is still relevant due to its architecture in different forms, operating temperature, fabrication cost and wide applications. Flat collector plate may maintain flat shape, chevron, v-grooved or any other shape that does not converge the reflected solar radiation. Flat plate solar collector is often relevant for low and medium range operating temperature (Karim and Hawlader, 2006a; Naphon, 2005).

Several propositions have been made to improve the performance of solar air heater (SAH). Ho-Ming and Chii-Dong (2009) investigated the relevance of using external recycle approach to enhance the performance of a solar air heating collector. Their proposal has been based on the improvement of air mass flow rate to ease convective heat transfer and mass transfer of moisture in drying application. However, reflux ratio of recycle air must be properly managed to reduce the negative impact of recirculation on the inlet air temperature. Recycle of exit air and creation of baffles on solar absorber have been reported as a means of improving the collector efficiency (Ho et al., 2005; Mohammadi and Sabzpooshani, 2014; Ravi and Saini, 2016; Yeh, 2012). Karim and Hawlader (2006a) studied a v-grooved solar absorber to improve the thermal performance of a corrugated solar air collector. Kumar and Kim (2015) employed the vortex technique to introduce disturbance (baffles

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