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INVESTIGATION OF HEAT TRANSFER IN PACKED BED SOLAR AIR HEATER

PRASHANT TIWARI, ARVIND KUMAR & R M SARVIYA

Amarpatan - 485775, Madhya Pradesh, India

ABSTRACT

An experimental investigation has been carried out on a porous packed bed solar air heater. Investigation covers various parameters of iron chips, i.e. equivalent chip diameter 1.51 mm, and range of porosity from 0.652 & 0.816 and packing Reynolds number range from 244-975. The range of the mass flow rate used in experiment is between 0.014 and 0.036 kg/s. It is seen that heat transfer coefficient and friction factor are strong functions of geometrical parameters of the porous packed bed. The results of a packed bed solar air heater show a substantial enhancement in the thermal efficiency as compare to the conventional collector also a decrease in porosity increases the volumetric heat transfer coefficient.

KEYWORDS: Solar Air Heater, Themal Efficiency, Thermohydraulic.

INTRODUCTION

A Flat-plate solar air heater is a device used to heat air by the application of solar energy. Solar air heaters are the cheapest and widely used to deliver heated air at low to moderate temperatures for in various applications such as in drying agricultural products, water heating, cooking, and space heating and various industrial applications. Such air heaters have low thermal efficiency because of low convective heat transfer coefficient, which results in higher heat losses to the surroundings. For the purpose of minimizing the energy losses and maximum utilization of solar energy to increase the thermal performance of the solar air heater Several methods including the use of packing of porous materials like pebbles, rocks, hollow spheres, glass beads, wire mesh, cross rod matrices and slit-and-aluminum- foil matrices in the duct of solar air heater have been proposed. Also various designs of solar air heater with different configurations have been proposed to enhance thermal performance of solar air heater. Several experimental and theoretical studies have done to obtain detailed information on the heat transfer mechanism by using a porous packing in an air duct.

Kays and London (1964) have done a detailed study on heat transfer and flow friction using wire screens inside the heat exchanger tubes. Hamid and Beckman (1971) have studied the thermal behavior of air-cooled radiatively heated and randomly stacked copper wire mesh screen matrices in a bed. Chiou et al. (1965) and Chiou and El-Wakil (1966) experimentally investigated the volumetric heat transfer coefficient and friction factor for a collector duct packed with slit and expanded aluminium foil matrices and found that the volumetric heat transfer coefficient is generally higher for beds with lower porosities. Bansal et al. (1982) studied the non-porous double flow solar air system for single and double glazing system. Hasatani et al. (1985) have investigated theoretically and experimentally about the collection and storage characteristics of solar collector packed with semi-transparent material.Ong et al. (1995) developed a mathematical model to predict the mean temperature of the heated air near the inlet and the outlet of the collector.Choudhary and Garg (1993) have done an experimental study on the comparative theoretical performance analysis of solar air heater packed with different materials like cylinder, ring, sphere and crushed materials; and without packing in the flow passage Choudhury et al. (1993) carried out experimental investigation on optimization of design and operational parameters of a rock bed thermal energy storage device coupled to a two pass single cover solar air heater.Varshney and Saini (1998) carried out experimental investigations on heat transfer and fluid flow characteristics of a solar air heater having its duct packed with wire mesh screen matrices. The investigations covered a wide range of geometrical parameters of wire mesh screen matrix (wire diameter, pitch and number of layers). Yeh et al. (1999) have presented a mathematical model for the double flow solar air heaters with fin attached to the upper and lower surfaces of the absorber plate. It was shown that the proposed design has improved efficiency. Forson et al. (2000) developed a mathematical model to predict the thermal performance of SPDDSAH and concluded that increasing the top to bottom cannel ratio is a cost effective way to optimize the performance of such systems. Ho et al. (2002) studied the effect of fraction of mass flow rate in the upper or lower flow channel of the double flow device on collector performance by passing air simultaneously over and under the absorbing plate.

Thakur et al. (2003) carried out experimental investigation on a low porosity packed bed solar air heater. Investigation covers a wide range of geometrical parameters of wire screen matrix. The correlations have been developed for the Colburn j factor and friction factor for a low range of porosities from 0.667 to 0.880 and packing Reynolds number range from 182 to 1168.

Rabadi et al. (2003) conducted experimental study on enhancing solar energy collection by using curved flow technology coupled with flow in porous medium. Hegazy (2003) investigated that the channel depth-to-length ratio is an important parameter in determining the useful heat gain. And found that for variable flow operation, the optimum depth-to-length ratio should be 0.0025.

Paul and Saini (2004) carried out experimental investigation on optimization of bed parameters for packed bed solar energy collection system. Tian et al. (2004) experimentally Investigated the various configurations of copper screen meshes to identify the preferable orientation for maximizing thermal performance under steady state forced air convection Resulted that the overall heat transfer depends on porosity and surface area density but weakly on orientation.

Singh et al. (2006) carried out experimental investigation on the effect of system and operating parameters on heat transfer and pressure drop characteristics of packed bed solar energy storage system with large sized elements of storage material. Five different shapes of elements of storage material were investigated. Correlations were developed for Nusselt number and friction factor as function of Reynolds number, spherocity and void fraction. Mittal and Varshney (2006) have done a thermo-hydraulic investigation of a solar air heater packed with blackened wire screen matrices for different geometrical parameters And and a mathematical model was developed to select a matrix which would result in best thermal performance with minimum pumping power penalty. Ramadan et al. (2007) carried out experimental investigations on thermal performance of a double-pass solar air heater packed with lime stones and gravels, resulted that the thermo-hydraulic efficiency was found to increase with increasing mass flow rate until a typical value of 0.05 kg/s beyond which increase in thermo-hydraulic efficiency becomes insignificant.

Paswan and Sharma (2009) studied thermal performance of Wire-Mesh Roughened Solar Air Heaters by providing wire-screen mesh (metal) as artificial roughened on the underside of its absorber plate. El-Sebaii et al. (2011) carried out experimental investigation on double pass-finned plate solar air heater, resulted that the double pass v-corrugated plate solar air heater is 9.3–11.9% more efficient as compare to the double pass-finned plate solar air heater.

The present investigation is taken up with the objective of experimentation on packed bed solar air heater and a conventional solar air heater to collect data on heat transfer and fluid flow characteristics. Tests are conducted under identical and actual outdoor conditions in order to compare their thermal performance.

EXPERIMENTAL SET-UP

Fig. 1 shows the schematic of an experimental set-up designed as per Sukhatme (1987) and ASHRAE (1977). To collect data with respect to heat transfer and friction characteristics of a packed bed solar air heater. The set up consists of two identical ducts of length of 1.60 m, width of 0.62 m, and depth of 0.025 m and were made of softwood, both ducts are inclined at an angle of 20° to the horizontal. The Conventional duct had an absorber plate of 2 mm GI sheet. absorber plate was blackened with black board paint on the side facing solar radiation. It had a 3 mm thick glass sheet cover fixed 20 mm above the absorber plate. The sides and bottom of the duct were insulated with thermocol sheet (having thermal conductivity 0.037 W/m/K). In the packed duct the gap between GI back plate and lower glass cover is 25 mm. iron chips are placed between the 2 mm thick GI back plate and mm lower glass cover which are apart. The distance between the upper and lower glass cover is 20 mm. In the conventional solar air heater, the glass cover is placed at a distance of 25 mm above the absorber plate. All the glass covers are 3 mm thick. An exit section has been provided at the end side of the duct which is followed by a mixing section. The mixing section contains four baffles plate over 100 mm length for the purpose of mixing the heated air properly so as to obtain the uniform temperature of air at the outlet. The mixing section is connected to the flexible pipe on other side this flexible pipe is connected to the Mild Steel pipe. Orifice plate has been fitted concentric with the Mild steel pipe in both ducts to measure the air flow rate. A standard set of inlet and outlet pressure taps are provided at a distance of 25.4 mm on each side of the orifice plate. A 2.2 kW centrifugal blower has been used for drawing the air through the duct. The bed temperature As well as inlet and outlet air temperatures have been measured by calibrated copper constantan thermocouples, connected to the selector switch. A digital micro-voltmeter is connected to the selector switch to indicate the output of the thermocouples in milivolts. Pressure drop in ducts are measured by a digital micro manometer. After the fabrication of the set-up, data has been collected on both the packed bed solar air heater and on the conventional air heater for the purpose of determination of enhancement of thermal performance.

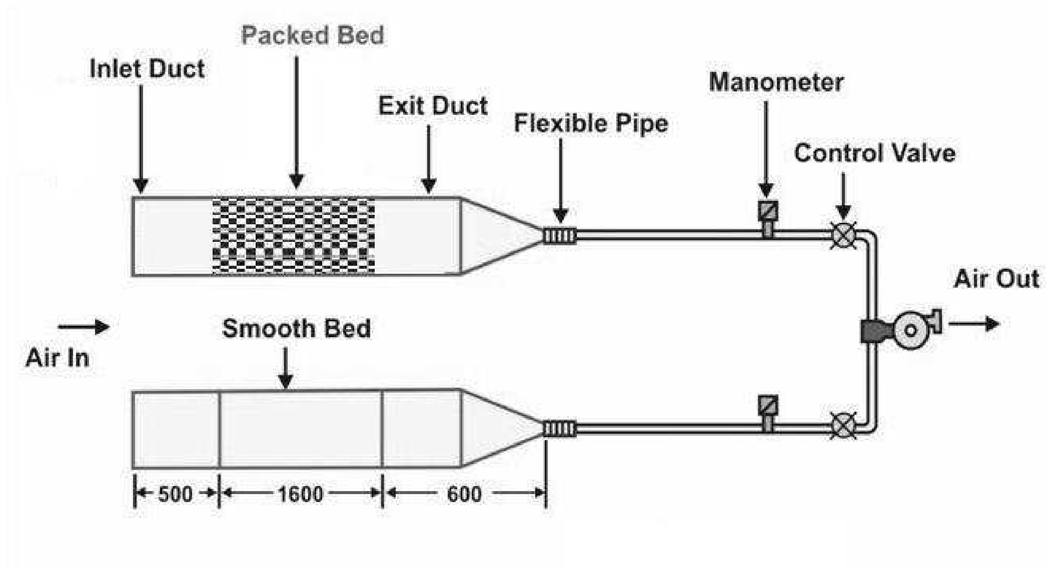

Fig. 1: Schematic diagram of the experimental set-up.

VALIDATION OF EXPERIMENTAL SET-UP

Before collecting data, from the experimental set up the system was validated by collecting data for the system with smooth duct to determine the Nusselt number and friction factor for different mass flow rates. Values of these Nusselt number and friction factor obtained experimentally were compared with predicted values of Nussselt number using Dittus and Boelter correlation and friction factor using Blasius equation . Figs. 3 and 4 show a comparison between experimental and predicted values of Nusselt number and friction factor respectively. It can be seen that Nusselt number has a maximum deviation of 5.96% from the predicted values obtained from Dittus and Boelter correlation while the friction factor has a maximum deviation of 2.73% from the predicted values by Blasius equation. This ensures that the set-up can be used for accurate data collection.

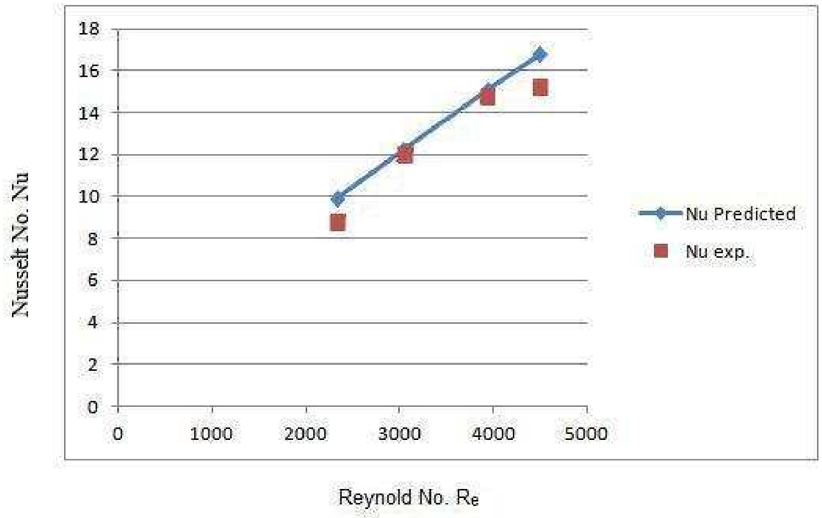

Fig.2: Comparison of experimental values of Nusselt number with values predicted by Dittus and Boelter's correlation

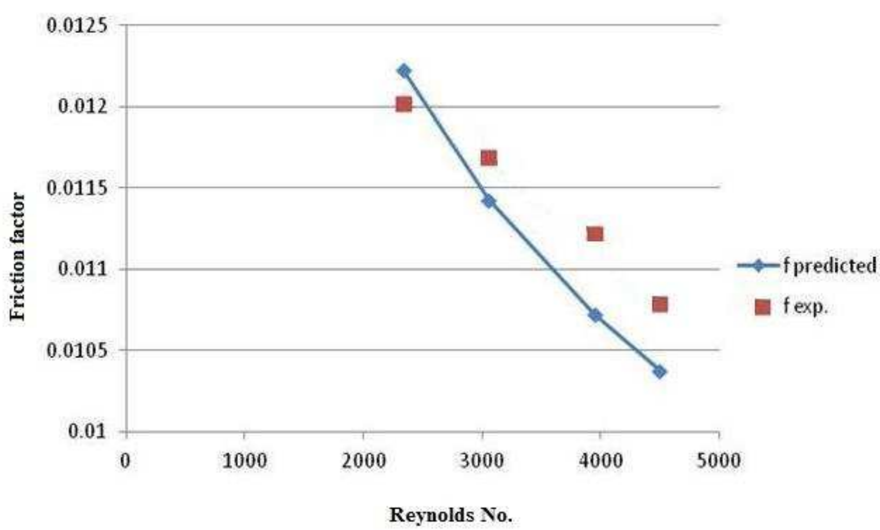

Fig. 3: Comparison of experimental values of friction factor with the values predicted by Blasius's equation for smooth collector

EXPERIMENTAL PROCEDURE

The experimental data has been collected by following the procedure described in ASHRAE Standard Handbook (1977) for testing the solar air collector operating in open loop flow mode. Data pertaining to a given mass flow rate between 11 a.m. and 2 p.m. at an interval of 1 h were taken on a clear sky day. Before starting the experiment, all the joints of duct, inlet section, mixing device and pipe fittings were examined for leakage and leakage was sealed by using glass putty. While recording the temperature, the ice-bath and lead wire for micro-voltmeter were protected from direct solar radiation. The blower was run for an hour and thereafter, the thermocouple readings for iron chips mesh temperatures at various locations and inlet and outlet air temperatures, pyranometer readings for intensity of solar radiation and manometer readings for pressure drop across the duct were recorded for a particular day. Experimental data were collected for flow rates ranging from 0.0159 to 0.0347 kg/s-m^2. First of all a low porosity iron chips mesh is used. Afterwards same iron chip mesh with high porosity is used and the above mentioned data was collected. The parameters measured are: pressure difference across the ducts and orifice meter, temperature of the absorber plate, iron chip mesh, inlet and outlet temperature of air in the ducts,

RESULTS AND DISCUSSIONS

As described above, experimental set up is designed and fabricated, and data have been collected with respect to heat transfer and fluid flow characteristics of packed bed solar air heater. The Experimental results of packed bed solar air heater are given below:

Fig. 4 shows effect of Reynolds number Rep on volumetric heat transfer coefficient. Volumetric heat transfer coefficient increased with the increase in Reynolds number.

Fig 5 shows effect of mass flow rate Go on heat transfer coefficient h. It is seen that the heat transfer coefficient increases with a decrease in porosity and with an increase of mass flow rate

Fig 6 shows effect of packing number Re_p on friction factor f_p for packed bed solar air heater. It can be seen that friction factor decreases with an increase of Re_p and decrease of porosity.

Fig 7 shows effect of mass flow rate Go on efficiency. It is seen that the efficiency increases with a decrease in porosity and with an increase of mass flow rate.

Fig 8 shows effect of Reynolds number on efficiency. It is seen that the efficiency increases with a decrease in porosity and with an increase of Reynolds no.

Fig. 9 Shows colburn J_h factor as a function of Reynolds number. It is seen that colburn J_h factor decreases with an increase of Re_p and increases with an increase of porosity.

Fig. 10 Shows colburn J_h factor as a function of relative ms flow rate Go. It is seen that colburn J_h factor decreases with an increase of Go and porosity

Fig. 11 Shows colburn J_h factor as a function of efficiency. It is seen that colburn J_h factor decreases with an increase of efficiency and porosity.

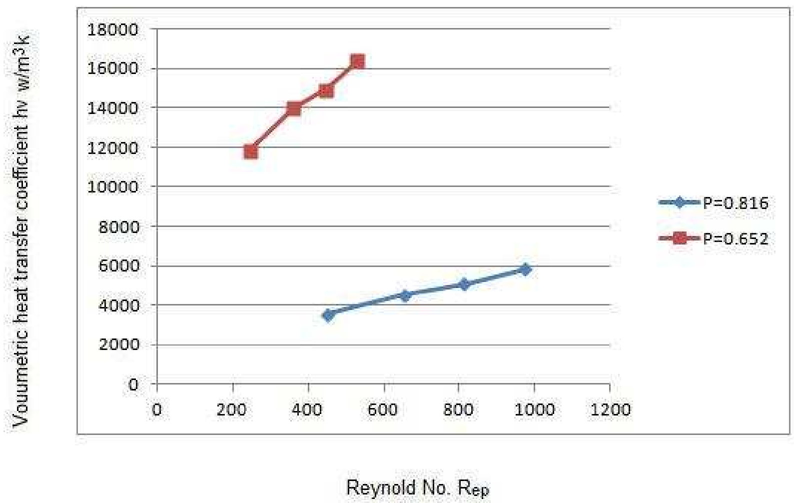

Fig. 4: Effect of Reynolds number & porosity on volumetric heat transfer coefficient

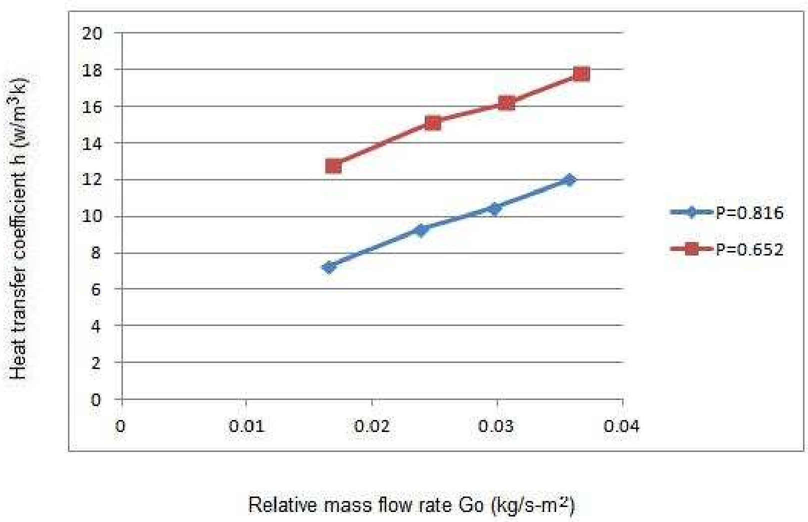

Fig. 5: Effect of relative mass flow rate and porosity on heat transfer coefficient

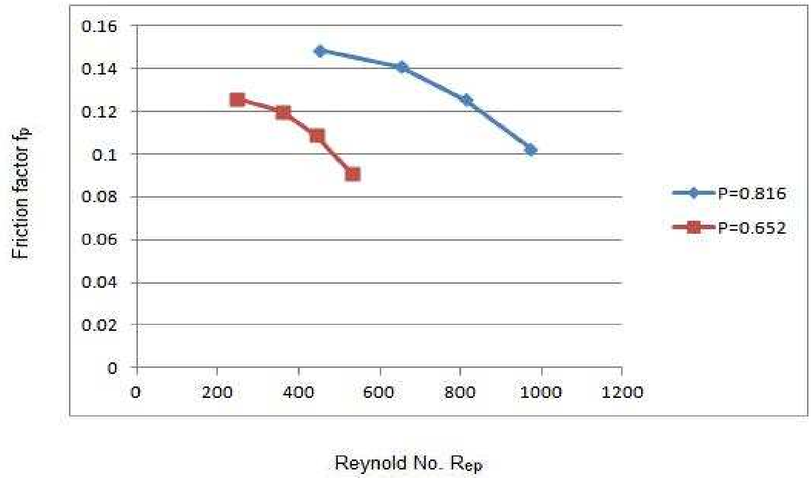

Fig. 6: Effect of Reynolds number & porosity on friction factor

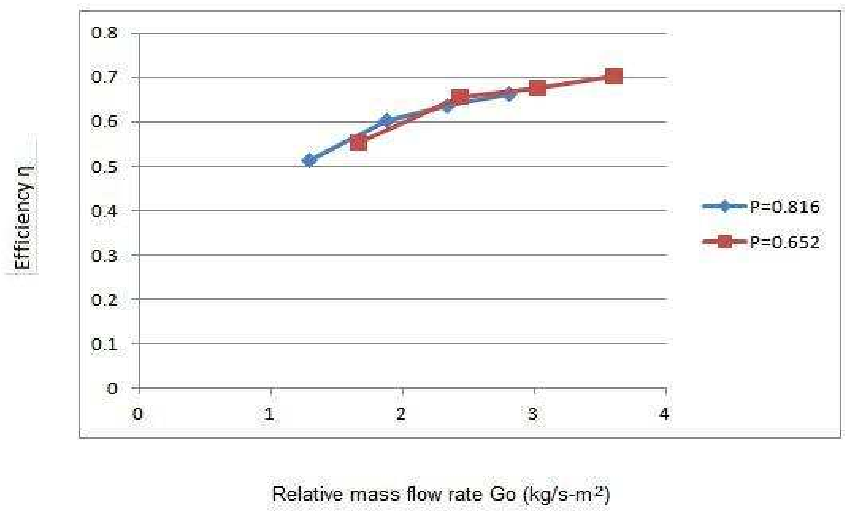

Fig. 7: Effect of Relative mass flow rate & porosity on efficiency

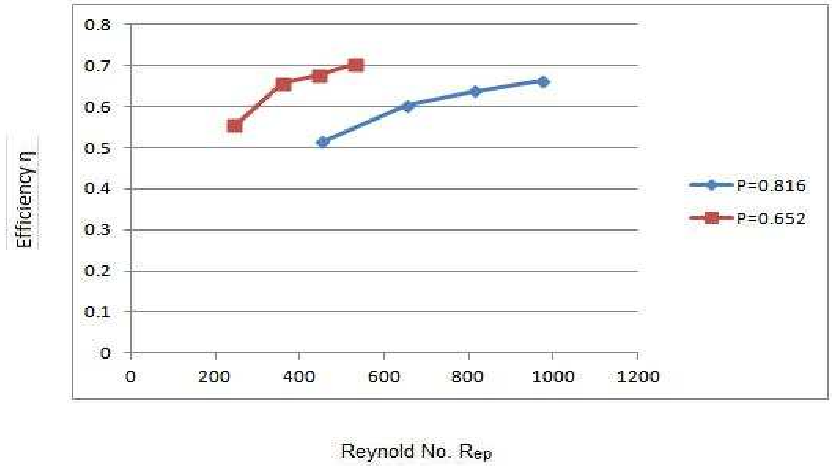

Fig. 8: Effect of Reynolds number & porosity on efficiency

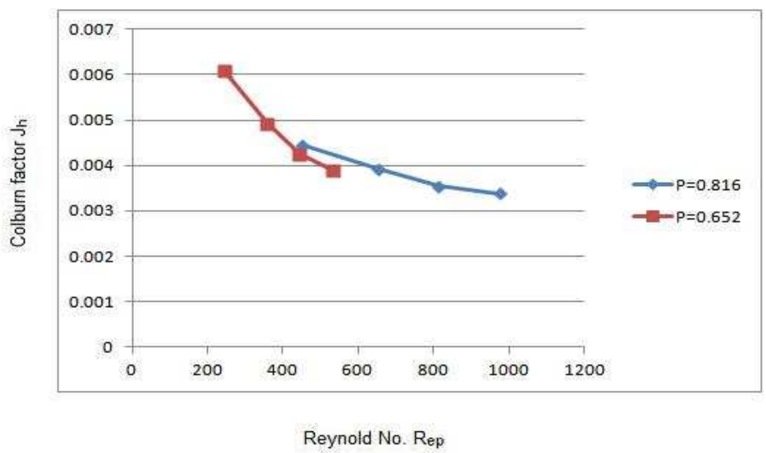

Fig. 9: Effect of Colburn factor & porosity on Reynolds number

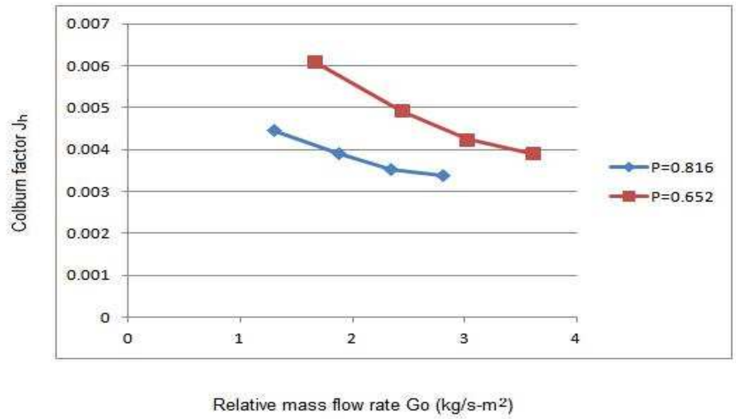

Fig. 10: Effect of Colburn factor & porosity on Relative mass flow rate

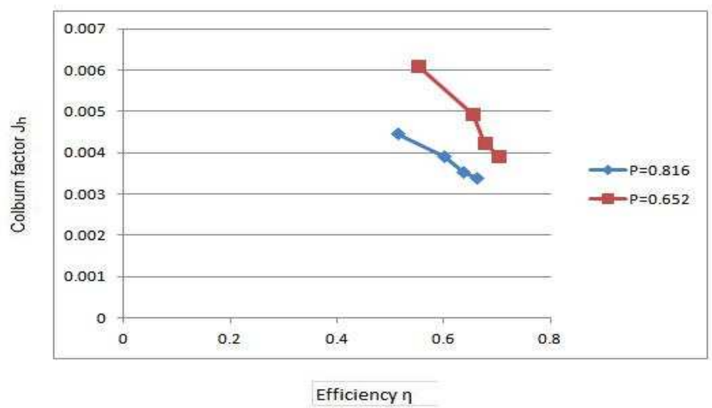

Fig. 11: Effect of Colburn factor & porosity on Efficiency

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