Experimental Investigation on Performance of Packed Bed Solar Energy Storage System

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Abstract - Packed bed is generally used for thermal energy storage in solar air heaters. In the present paper, an extensive experimental investigation has been carried out in order to investigate heat transfer and friction characteristics of packed bed solar energy storage system having standard masonry tile bricks and half standard masonry tile bricks as the storage material. Nusselt number and friction factor correlations have been developed by using the experimental data in order to predict thermal and hydraulic performance of such type of a system.

Keywords: Solar air heater, packed bed, Nusselt number, friction factor.

I. INTRODUCTION

Energy is closely concerned with environment and development. Energy is needed for basic human needs like cooking, heating, lighting and for other household based activities. Energy is also required to sustain and expand economic processes like agriculture, electricity production, industries, services, transport etc. In order to solve this problem, it is required to attach solar energy storage system for solar air heaters. The Packed bed is generally represents a suitable energy storage unit for air based solar energy utilization systems. A packed bed is a volume of porous media obtained by packing particles of selected material into a container. During the charging mode, heated air from solar air heater is forced into the top of the container i.e. upper plenum and then passes uniformly down through the bed heating the storage particles and passes out through the lower plenum. Air is drawn off at the bottom and returned to the collectors.

Many investigations on performance analysis of regarding design of packed beds, material used for storage, heat transfer enhancement, flow phenomenon, pressure drop through packed beds etc have been carried out by various investigations. Among earliest investigations Groton and Fraser [1] investigated the stacking of spheres in packed bed solar energy storage systems. Authors have suggested two unique arrangements of stacking the spheres on a horizontal plane i.e. square layer & rhombic layer. Lof and Hawley [2] investigated unsteady-state heat transfer between air and loose solids. Authors developed correlation for heat transfer coefficient between air and bed of common builder's gravel used for design of packed bed solar energy storage systems. Martin et al. [3] investigated pressure drop through stacked spheres and studied the effect of orientation. Authors reported that orientation of spheres have a definite effect on pressure drop through stacked spheres in packed bed. Sagara and Nakahara [4] reported that packing of large size elements of storage material could reduce the pressure drop in the bed. Authors concluded that the possibility exists for some large-sized storage materials to have almost the same performance as small-sized materials for heat pump solar systems. Singh et al. [5] reported an experimental study in order to investigate large size material elements. Based upon the experimental data, authors developed Nusselt number and friction factor correlations as a function of system and operating parameters.

Many other medium and large size material elements available in the common market still remain to be investigated as storage material for packed solar energy storage system. In the present paper, an attempt has been made in order to investigate heat transfer and friction characteristics of packed bed energy storage system having standard masonry tile bricks and half standard masonry tile bricks as storage material. Nusselt number and friction factor correlations have been developed by using the experimental data in order to predict performance of the system.

II. EXPERIMENTAL INVESTIGATION

An experimental set-up was designed and fabricated in order to collect the desired data. Schematic of experimental set-up is shown in fig.

Description: 1.Air duct with electric heater, 2.U-tube manometer, 3.Orificemeter, 4.Centrifugalfan, 5.Flow control valve, 6.Pipeline, 7.Union joint, 8.Hot air inlet to packed bed, 9.Storage tank, 10.Screen for supporting storage material elements, 11.Air outlet, 12.Taps for thermocouple wires and pressure pipes, 13.Micro-manometer.

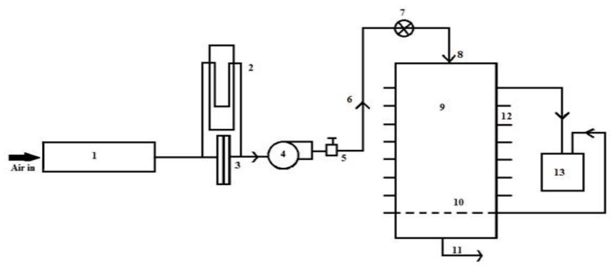

Fig. 1: Schematic of experimental set-up.

In order to supply hot air to the packed bed, solar air heater duct reported by Bhushan and Singh [6] was used. The storage tank is the main component of the experimental set-up. It is made of mild steel sheet of 2 mm thickness. It consists of three main parts i.e. upper plenum, packed bed test section and lower plenum. For uniform distribution of air in the bed, distribution vanes were provided in upper and lower plenums of the storage tank. Height and diameter of the storage tank are 1500 mm and 750 mm respectively. Height of upper and lower plenum has been fixed as 250 mm each, as per recommendations of Hollands [7]. For supply of hot air, storage tank is attached to air duct through a pipe line having diameter of 75 mm.The tank is provided with number of taps in order to take out the thermocouple wires for temperature measurement in the bed. The iron rods have been welded on the outer surface of the tank for mounting it on a stand made of mild steels .The tank can be held in hanging condition with the tilting provision in order to make it trouble-free for attaching/detaching the union joint at entry to the bed and also for easy loading/unloading of storage material. A handle made of metal rod is provided on the lower portion of the storage tank in order to tilt the same whenever required. Handles are also provided on the upper surface of the top cover of the tank for lifting and positioning the same conveniently. Rubber packing has been provided on the flange of the tank for tight fitting of the top cover with the help of nuts and bolts. Storage tank has been insulated properly with polyethylene foam in order to minimize heat loss to the environment. Above lower plenum, tank is provided with screen for supporting the storage material elements. Screen is made of mild steel sheet of thickness 2 mm and supported on mild steel angles mounted inside the tank. Diameter of the screen has been kept 0.73 m in order to put the same inside the tank conveniently. An orifice plate fitted between the flanges in the pipeline was used to measure the mass flow rate of air. U-tube manometer was fitted in the pipeline for measuring the pressure drop across the orifice plate, which is further used to measure the flow rate of air. Micro manometer was fitted with the taps at inlet and outlet of test section of the storage tank for measuring pressure drop across the bed. Temperature of air and solid elements at different locations along different cross sections in the test section of bed was measured with the help of thermocouples. Thermocouple junctions were fixed in small size grooves on the surface of material elements to be packed in the test section of packed bed. The thermocouple output was measured by a digital temperature indicator connected through a selector switch. Good physical contact between the thermocouple and storage material element was ensured by using a good quality adhesive. After checking continuity of the thermocouples properly, the top cover of storage tank was fixed tightly with nuts and bolts. The storage tank was connected to the pipeline through union joint for making supply of hot air.

In order to start the experiment, electric heater was switched ON. Fan was also switched ON just after switching ON the electric heater in order to avoid heat accumulation in the duct and to supply hot air to the bed. The desired flow rate was adjusted by using the control valve. Experimental data were collected for pressure drop in the orifice, pressure drop in test section of the bed, temperature of air and material elements after charging of the bed for one hour. The same procedure was repeated in order to collect the data for each mass flow rate of air. Range/value of system and operating parameters used in the present experimental investigation has been shown in Table1.

Table.1: Range of system and operating parameters.

Parameter	Range/Value
Mass velocity (*G*)	0.0509–0.171kg/s m²
Reynolds number (Re)	400 – 1200 (Standard masonry tile bricks) 300 – 900 (Half standard masonry tile bricks)

III. RESULT AND DISCUSSION

Heat transfer data collected in the present investigation were reduced to heat transfer coefficient and Nusselt number; pressure drop data were reduced to friction factor and mass flow rate data were reduced to mass velocity and Reynolds number as per the relationships reported by Singh et al. [5]. Variation of heat transfer coefficient with change in mass velocity of air for standard masonry tile bricks and half standard masonry tile bricks is shown in Fig. 2 It can be noted that for both type of storage material elements, heat transfer coefficient increased with increase in mass velocity of air. Increase in mass velocity causes increase in turbulence which results increase in heat transfer coefficient. It can also be noted that the heat transfer coefficient of half size standard masonry bricks has been found higher than the standard masonry bricks. This may be due the fact that by breaking standard masonry bricks element into two pieces, number of sharp corners has increased. Also one surface of each element of half size standard masonry bricks elements became more rough as compared to the surface of standard masonry tile bricks. It happened due to increase in void fraction for standard masonry tile bricks. Increase in void fraction also results decrease in heat transfer coefficient as has been reported by Singh et al. [5].

Variation of Nusselt number with change in Reynolds number for standard masonry tile bricks and half standard masonry tile bricks is shown in Fig. 3. It can be noted that Nusselt number increased monotonously with increase in Reynolds number as was expected based upon the experimental investigation reported by Singh et al. [5]. It can also be noted that Nusselt number values for half standard masonry tile bricks are lower than standard masonry tile bricks. It happened due to different equivalent diameter of elements. Variation of pressure drop with change in mass velocity of air for standard masonry tile bricks and half standard masonry tile bricks is shown in Fig. 4. It can be noted that pressure drop increased with increase in mass velocity of air. Increase in mass velocity of air yielded higher frictional loss and consequently the higher pressure drop in the bed. It can also be noted that pressure drop values for standard masonry tile bricks are lower than the half standard masonry tile bricks. It may have happened due to increase in void fraction for the bed of standard masonry tile bricks. Variation of friction factor with change in Reynolds number for standard masonry tile bricks and half standard masonry tile bricks is shown in Fig. 5. It can be noted that friction factor decreased with increase of Reynolds number as was expected based upon the experimental investigation reported by Singh et al. [5]. It can also be noted that friction factor values for half standard masonry tile bricks are lower than standard masonry tile bricks.

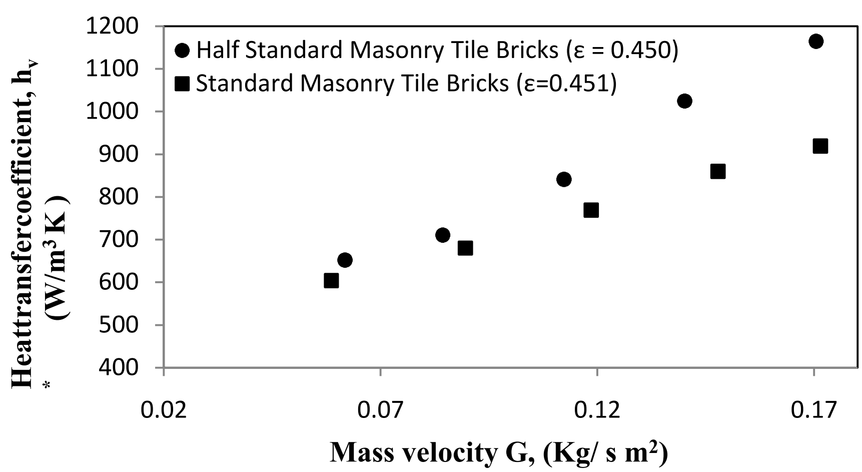

Fig. 2: Mass velocity vs. heat transfer coefficient for both types of storage material elements.

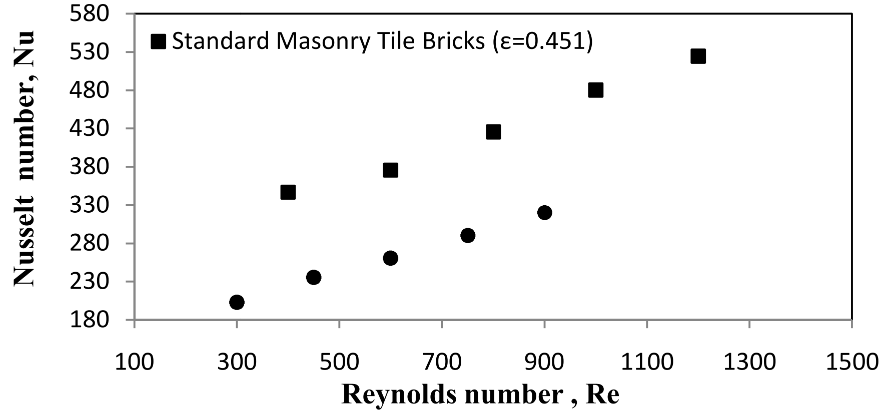

Fig. 3: Reynolds number vs. Nusselt number for both types of storage material elements

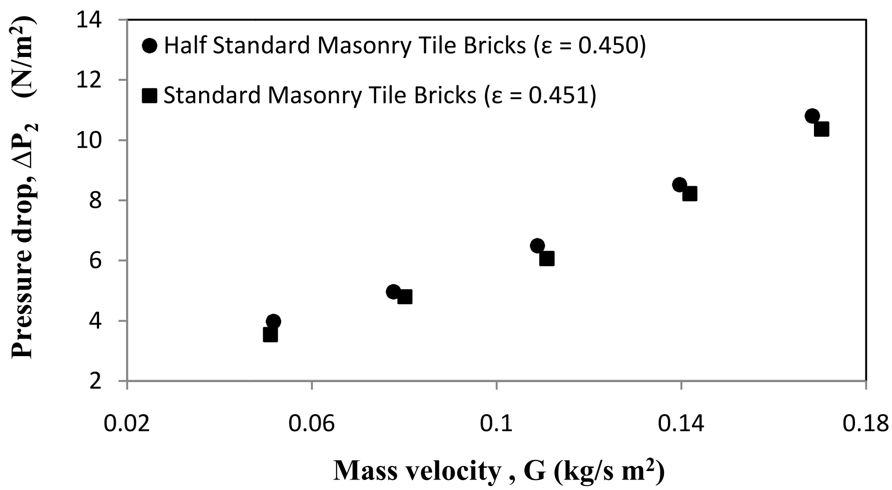

Fig. 4: Mass velocity vs. pressure drop for both type of storage material elements.

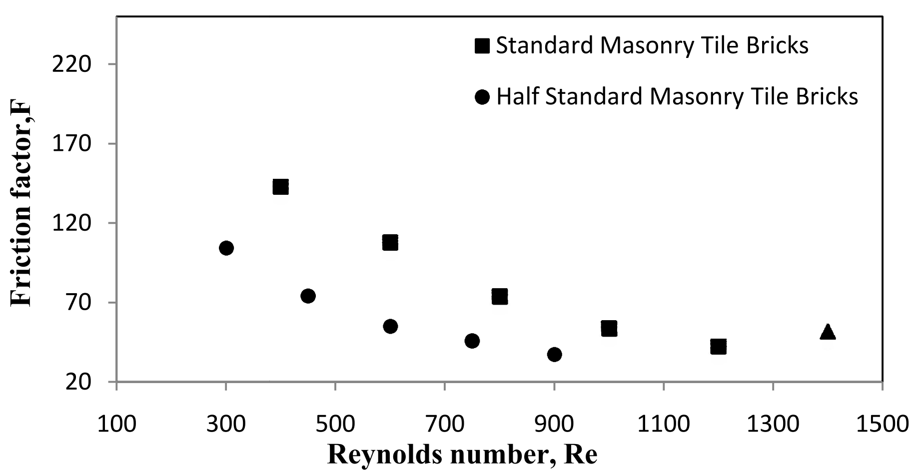

Fig. 5: Reynolds number vs. friction factor for both types of storage material elements.

IV. DEVELOPMENT OF NUSSELT NUMBER AND FRICTION FACTOR CORRELATIONS

It has been observed from experimental data that Nusselt number and friction factor are strong function of Reynolds number. Therefore, development of Nusselt number and friction factor correlations shown in table 2 have been developed based upon the procedure reported by Singh et al. [5].

Table 2: Nusselt number and friction factor correlations.

S. No.	Type of storage material	Correlations	
		Nusselt number	Friction factor
1.	Standard masonry tile bricks	$Nu = 75.68\ (Re)^{0.25}$	$f = 86198.55\ (Re)^{-1.06}$
2.	Half standard masonry tile bricks	$Nu = 8.72\ (Re)^{0.56}$	$f = 186.33\ (Re)^{-0.90}$

V. CONCLUSION

An experimental investigation on performance of packed bed energy storage system having standard masonry tile bricks and half standard masonry tile bricks as storage material has been reported in the present paper. By using the experimental data, Nusselt number and friction factor correlations have been developed in order to predict performance of the system. Experimental data and predicted data from the developed Nusselt number and friction factor correlations have been found in good agreement.

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