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Simulated Performance of Packed Bed Solar Energy Storage System having Storage Material Elements of Large Size-Part III

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Abstract: Simulated performance of packed bed solar energy storage system is reported in the present paper in continuation with Part-I and Part-II of this paper. The present part of the paper deals with system performance w.r.t. energy consumption by fan to propel air through the bed and thermal efficiency of solar collector. It is observed that energy consumption by fan and thermal efficiency of the collector are strong function of system and operating parameters.

Keywords: Packed bed, solar air heater, thermal energy storage.

1. INTRODUCTION

Packed bed system is generally used for storing heat energy in air based solar energy system. Energy stored in the packed bed may be useful to have uninterrupted supply of energy in the absence of solar radiation and also to fulfill the peak load energy demand even in the presence of solar radiation.

It is revealed from literature that the system design must be based on the methods to reduce pressure drop in the bed in order to enhance an effective use of solar energy system. Sagara and Nakahara [1] reported that large size material elements can be used for reducing pressure drop through the bed. Singh *et al*. [2] carried out an extensive experimental study to analyze effect of shape of large sized material elements and void fraction of the bed under set of operating conditions. In order to predict the performance of packed bed system, Nusselt number and friction factor correlations as a function of Reynolds number, sphericity and void fraction of the bed have been reported by Singh *et al*. [2].

With the help of mathematical simulation reported in Part-I of this paper, system performance has been reported in the present part w.r.t. energy consumption by fan to propel air through the bed and thermal efficiency of the collector. It is observed that energy consumption by fan and thermal efficiency of collector are strong function of system and operating parameters. It is observed that system parameters play a predominant role in influencing the heat transfer and fluid flow characteristics of packed bed energy storage system.

2. RESULTS AND DISCUSSION

The results obtained from the mathematical simulation w.r.t. energy consumption by fan and thermal efficiency of the collector are reported and discussed in the following sub-sections.

2.1. Energy Consumption by Fan

Energy consumption by fan is a strong function of bed parameters. It is directly proportional to flow rate of air, pressure drop in the bed and charging time. Generally with passage of charging time, temperature at outlet of the bed starts increasing, which leads to rise in mass flow rate of air due to the reason discussed in Part-I of this paper. Consequently pressure drop in the bed also increases. Fig. (**1**) shows an increase in mass flow rate of air with charging of

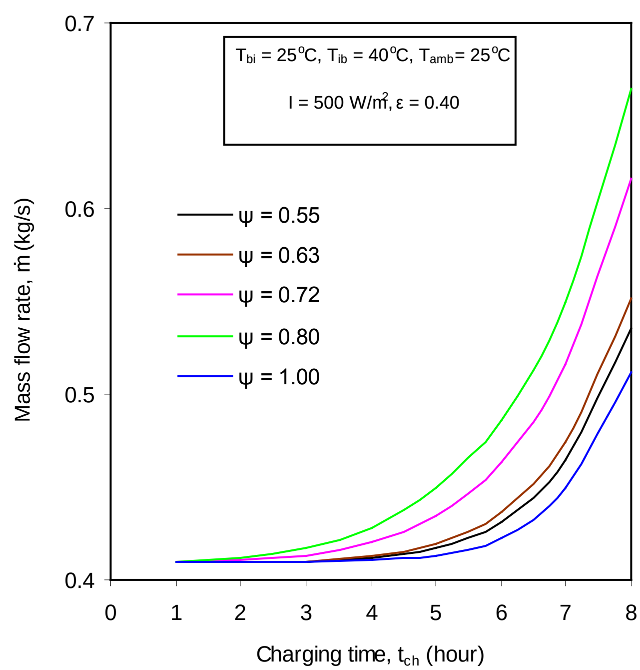

Fig. (1). Variation of mass flow rate of air with charging time for different shapes of material elements.

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the bed at void fraction of 0.40 for different shapes of material elements. The effect of sphericity on average mass flow rate of air during charging for different shapes of the material elements is shown in Fig. (**2**). Due to the combined effect of increase in mass flow rate and pressure drop in the bed, energy consumption by the fan increases with charging time as shown in Fig. (**3**). The maximum amount of energy consumption by the fan is observed for bed packed with material elements having sphericity of 0.63 and the minimum is for bed packed with material elements having sphericity of 0.80.

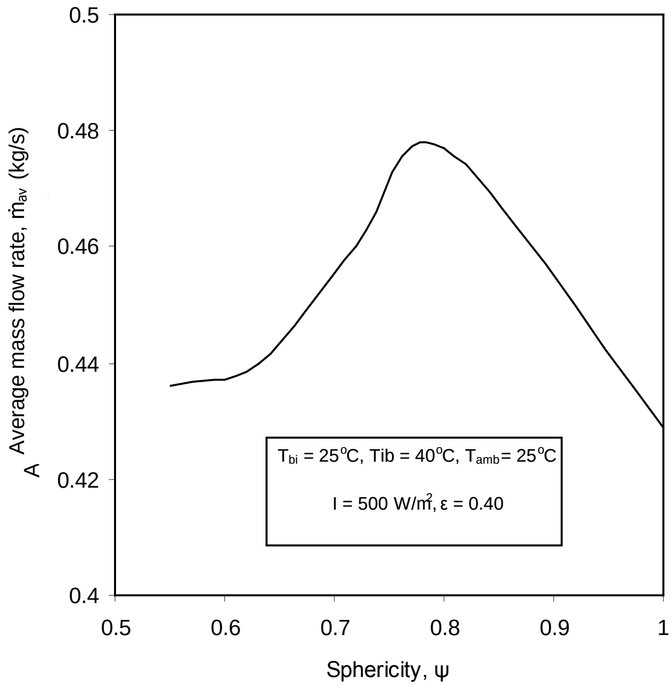

Fig. (2). Effect of sphericity of material elements on average mass flow rate of air during the charging period.

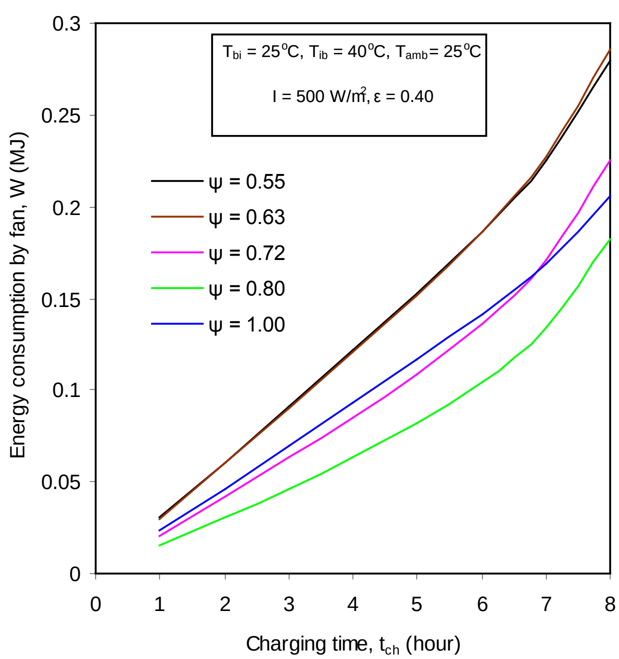

Fig. (3). Variation of energy consumption by fan with charging time for different shapes of material elements.

The effect of shape of material elements on total energy consumption by fan is shown in Fig. (**4**). It is observed that from sphericity of 0.55 to 0.63, energy consumption by fan increases and further it drops up to sphericity of 0.80 and again it starts increasing beyond sphericity of 0.80. Although for bed with material elements having sphericity of 1.00, flow rate at the end of charging is less than the bed with material elements having sphericity of 0.80, even then pressure drop in the bed of spheres is more due to larger surface area of spherical material elements. Therefore, high value of energy consumption by fan for bed with material elements having sphericity of 1.00 may be expected as compared to bed with material elements having sphericity of 0.80. In case of material elements having sphericity of 0.55, 0.63 and 0.72, number of sharp corners is more as compared to the material elements of sphericity 0.80. Therefore, for bed packed with these elements, large pressure drop lead to higher energy consumption as compared to the bed packed with material elements of sphericity 0.80 as has been observed in Fig. (**4**).

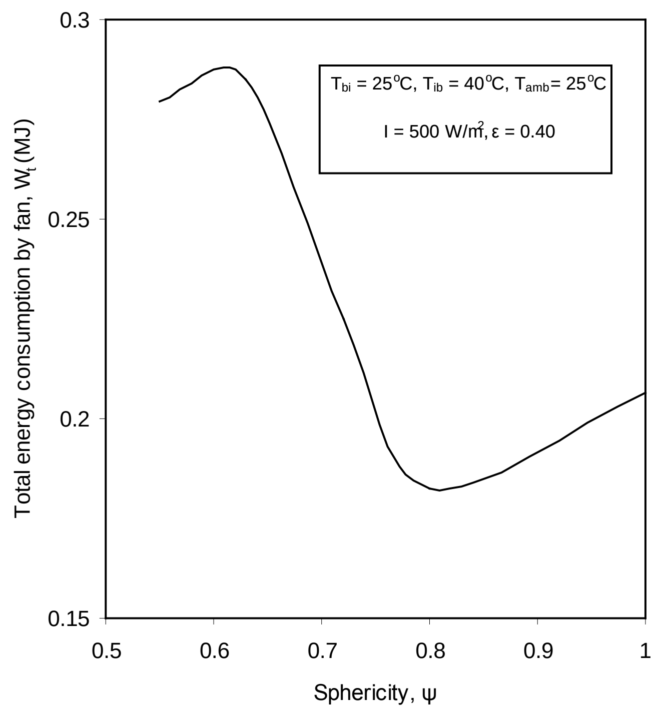

Fig. (4). Effect of sphericity of material elements on total energy consumption by fan during the charging period.

Fig. (**5**) shows an increase of energy consumption by fan with charging time at different void fraction values for a given sphericity value. The effect of void fraction on total energy consumption by fan at the end of charging is shown in Fig. (**6**). It is observed that with an increase in void fraction energy consumption decreases, attains minima and then increases. With increase in void fraction, friction factor decreases due to decrease in friction losses. However, with an increase in void fraction, temperature at the outlet of the bed also starts increasing which results into increase in flow rate of air. It is observed that with increase of void fraction upto 0.45, the effect of decrease in friction factor is more dominating as compared to the effect of increase in mass flow rate of air. With increase of void fraction beyond 0.45, an increase in mass flow rate of air is quite considerable as shown in Fig. (**7**), which results an increase in energy consumption by fan beyond void fraction of 0.45 as has been observed in Fig. (**6**).

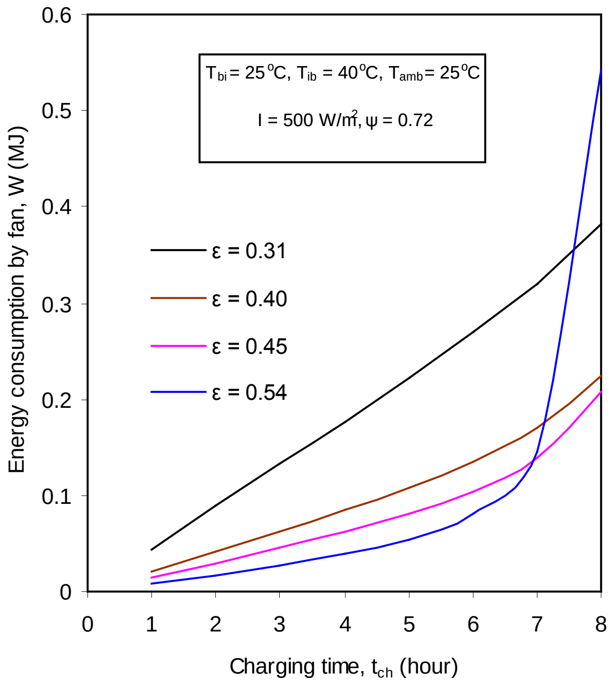

Fig. (5). Variation of energy consumption by fan with charging time at different void fractions of the bed.

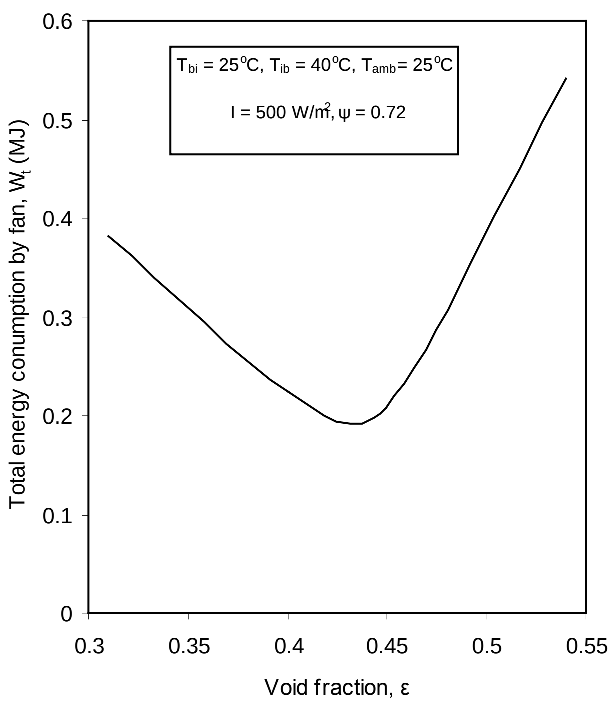

Fig. (6). Effect of void fraction of bed on total energy consumption by fan during the charging period.

2.2. Thermal Efficiency of Solar Collector

It is well known that thermal efficiency of a collector depends upon an inlet air temperature under the given

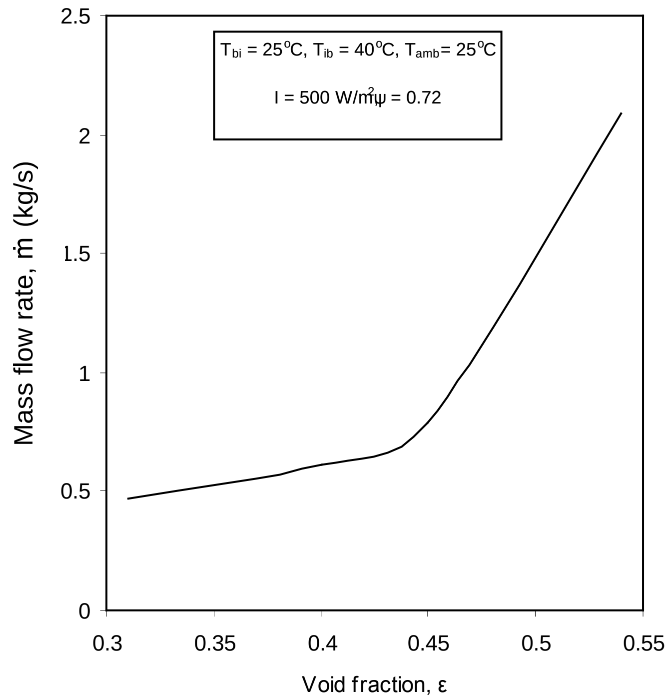

Fig. (7). Effect of void fraction of bed on mass flow rate of air at the end of charging.

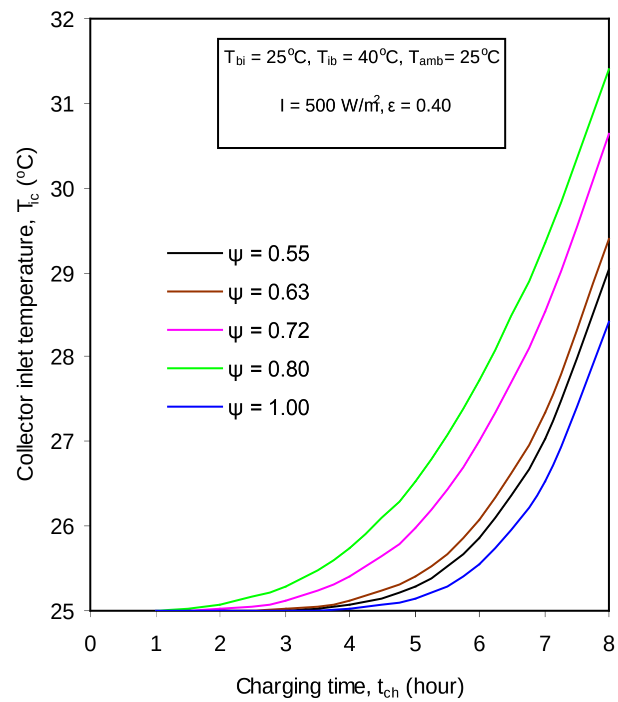

Fig. (8). Effect of charging of the bed on inlet air temperature to the collector for different shapes of material elements.

insolation and ambient conditions. The effect of shape of material elements on inlet temperature to the collector is shown in Fig. (**8**). Using the values of inlet temperature, the effect of charging time on thermal efficiency of collectors for different shapes of material elements is shown in Fig. (**9**). It is observed that thermal efficiency of collector decreases

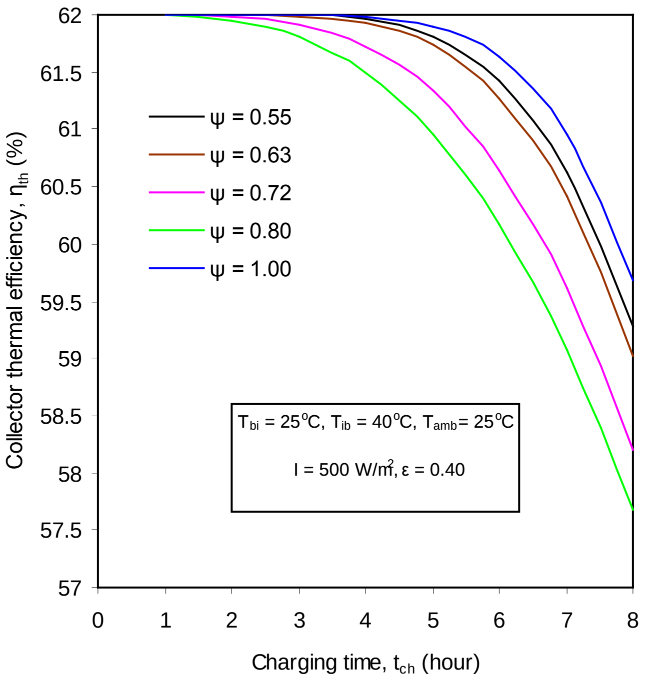

Fig. (9). Variation of thermal efficiency of collector with charging of bed for material elements of different shapes.

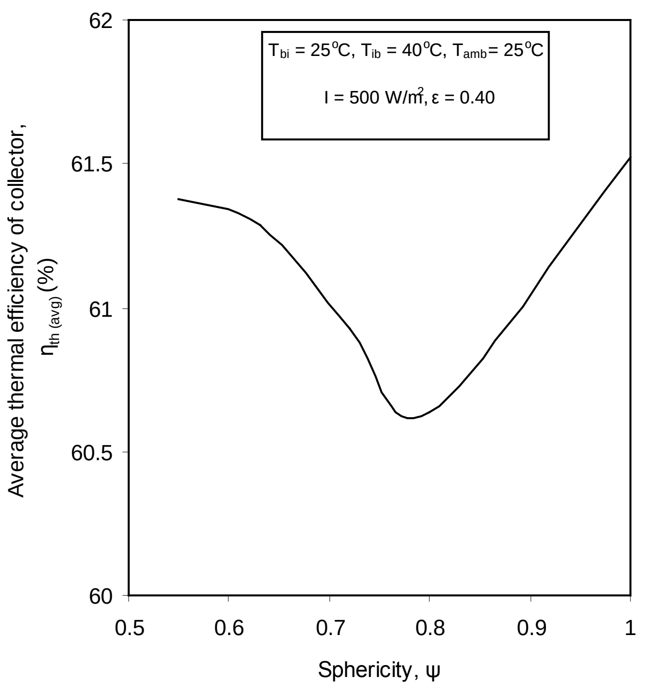

Fig. (10). Effect of sphericity of material elements on average thermal efficiency of collector during the charging period.

during charging of the bed. The amount of decrease depends upon the increase in inlet air temperature to the collector. The effect of material shape on average thermal efficiency of the collector during charging of the bed is shown in Fig. (**10**). The variations are found to be in line with the variation of heat transfer coefficient as a function of sphericity. The minima is obtained for the collector attached with packed bed containing material elements of cubical shape (ψ = 0.8), in which heat transfer coefficient is minimum.

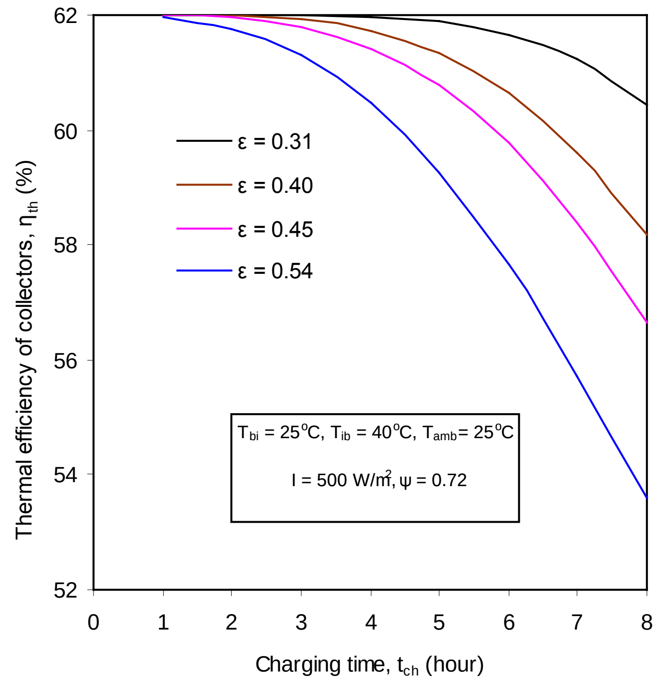

Fig. (11). Variation of thermal efficiency of collector with charging of bed at different void fractions.

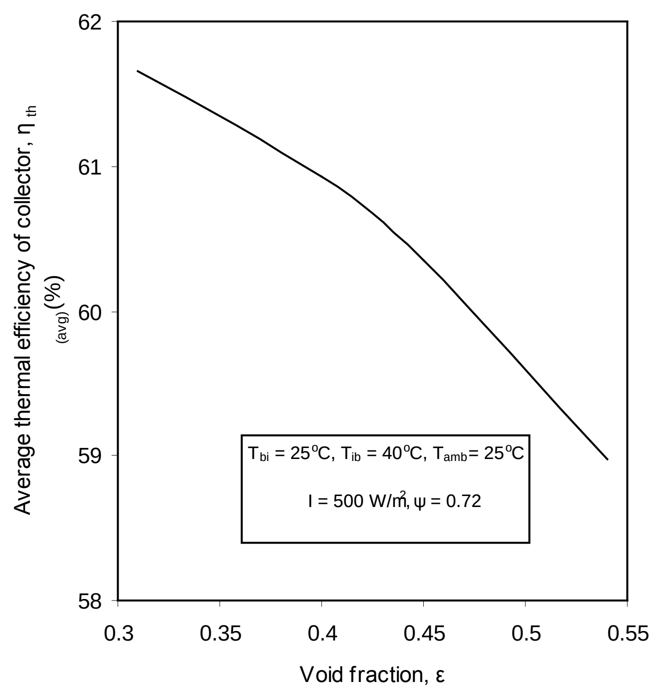

Fig. (12). Effect of void fraction of bed on average thermal efficiency of collector during the charging period.

Variation of air temperature at inlet to the collector during charging phase as a function of void fraction is shown in Fig. (**11**). The effect of void fraction of bed on thermal efficiency of the collector is shown in Fig. (**12**). It is observed that with an increase of void fraction, variation in thermal efficiency decreases. The variation of average thermal efficiency of collector with change of void fraction is shown in Fig. (**13**). It is similar to the variation of heat transfer coefficient with increase in void fraction of the bed.

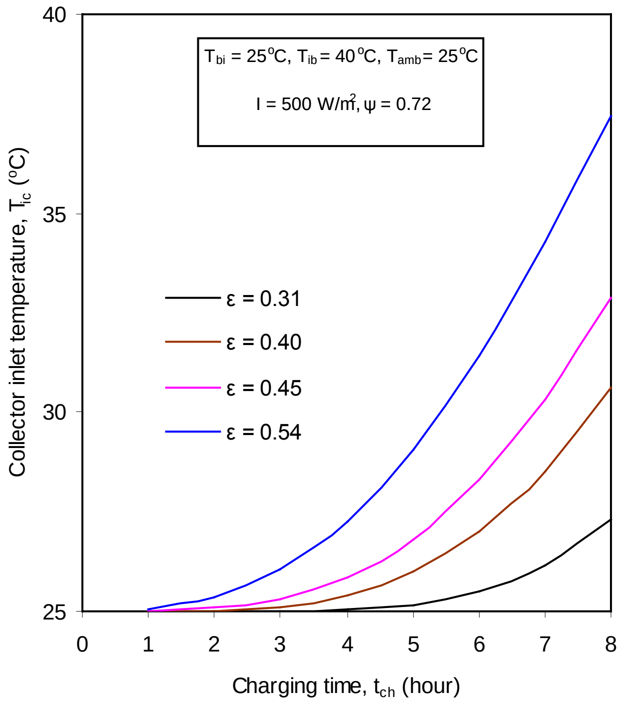

Fig. (13). Effect of charging of the bed on inlet air temperature to the collector at different void fractions of the bed.

3. CONCLUSIONS

In the present paper, an attempt has been made to report and discuss the simulated performance of a packed bed solar energy storage system w.r.t. energy consumption by fan to propel air through the bed and thermal efficiency of the collector. It is observed that energy consumption by fan and thermal efficiency of the collector are strong functions of system and operating parameters.

4. NOMENCLATURE

I	=	Insolation (Wm^{-2})
T_{bi}	=	Initial temperature of the bed (°C, K)
T_{ib}	=	Air temperature at inlet to bed (°C, K)
T_{amb}	=	Ambient temperature (°C, K)
ψ	=	Sphericity (dimensionless)
ε	=	Void fraction of bed (dimensionless)

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