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Parametric Optimization and Analysis of Packed Bed Regenerator for Space Heating Applications in Hilly Areas

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ABSTRACT: Solar radiations are present for limited hours. As a result it is often necessary to use a storage system to store the day time solar radiation which can be used at night for various applications. The thermal energy of solar radiations can be stored in various ways which depends upon its applications. Space heating is one of the most important demands of people living in hilly areas in winters. In winters the night temperature becomes too low below human comfort in these areas. Thermal energy storage system with a solar air heater and a rock bed storage system can be a solution to such a problem which provides comfort at night time by storing energy at day time. Space heating from rock bed needs optimization of parameters associated with the charging and discharging of rock bed. The present paper deals with the optimization of various vital thermal energy storage system parameters i.e. rock bed size, rock particle diameter, mass flow rate of air in charging of rock bed, cycle time of charging the rock bed and desired condition of human comfort inside a room, for a room heating application in hilly areas of Uttarakhand, having a volume of 64 m^3 and is occupied by 4 persons. For the analysis of rock bed parameters in charging and discharging both, a computer program in MATLAB has been made. The validation of the program is done with a previous research literature. The results show that an optimized design of a rock bed can serve the purpose of heating at night with comfort.

Keywords—Heat Bed Regenerator, Clay, Rocks Particle Diameter, Mass Flow Rate, MATLAB.

I. INTRODUCTION

Solar energy is the need of future. The use of solar energy for various applications at present shows how useful and clean energy it is. Solar energy can be utilized and stored in several forms like mechanical, electrical and thermal energy. The conversion of solar energy in to thermal energy is the simplest technique to utilize it. The intermittent and variable nature of solar radiation leads to a mismatch between obtained energy and load requirement. As a result it is often necessary to use a storage system in between. The storage unit stores energy when the collected energy is in excess of the requirement of application and discharges energy when the collected amount found to be inadequate. At night time when collected amount is zero or sun is not there then use of solar energy without storage unit can't be achieved. Solar thermal applications like space heating, crop drying etc. can be further developed with focusing on thermal storage systems. Thermal energy can be stored as chemically, latent heat form or as sensible heat. In chemical storage system the solar energy is stored in form of chemical reactions. In latent and sensible heat storage systems the temperature of the unit is increased but a phase change occurs while increasing temperature in latent heat storage which is not in case of sensible heat storage. Sensible heat storage found to be more economical method of storage as compare to rest of the two methods. In case of sensible heat storage systems, energy is stored or extracted by heating or cooling a liquid or solid which does not change its phase during the process of storing energy. A variety of substances such as water, oils, certain inorganic molten salts, and rocks, pebbles and refractories are used to store energy in sensible heat form. Sensible heat storage systems are simpler in design than latent heat or thermo chemical storage systems. However, they suffer from the disadvantage of being bigger in size. Rock storage is one of the best ways to store energy with sensible heat storage. It consists of rocks in a chamber and inlet outlet ducts, which get heated from a solar air heater during the day and it serves as a unit having energy that can be utilized at night. In operation, flow is maintained through the bed in one direction (downward) during addition of heat and in the opposite direction during removal of heat. Typically, the characteristic size of the pieces of rock used varies from 1 to 5 cm and 300 to 500 kg of rock per square meter of collector area is used for space heating. The various parameters like bed size, rock diameter, mass flow rate of air etc. has significant effect on the overall performance of rock bed along with its applications. Packed beds using rocks have many characteristics that are desirable for solar energy applications. The high heat transfer coefficient between the air and solid is one of the most important characteristic which promotes thermal stratification in bed which is desirable for a storage unit. A high degree of stratification is required as in this case the storage unit achieves a uniform temperature after a long time of charging. The cost of the storage material is low as compared to other storage materials this is also one of the advantage of using rock bed for storage. The problem of freezing and boiling which occurs in case of water storage system is also absent in rock bed storage system. These advantages of rock bed storage unit leads to a focused study of the system and to derive its various applications. Space heating in winters, especially in hilly areas where day is quite comfortable but night temperature drops below human comfort, heating of residences with rock bed storage unit seems to be a good application. Space heating from rock bed needs optimization of various parameters associated with the charging and discharging of rock bed. Heating load calculation of the room and up to what amount energy is to be stored so that it can serve as a source of heating throughout night with comfort temperature inside the room. A single rock bed of bigger size can be segmented in to number of beds according to the space availability. A number of technical if and buts associated with space heating through rock bed needs to be answered. A vast literature is available in sensible heat storage in rock bed. Different researchers have done theoretical and experimental work in this context. Schumann, 1929: [1] The heat transfer to and from a flowing fluid to a packed bed has been the subject of many theoretical and experimental investigations the first was Schumann. He studied a liquid initially at uniform temperature passes lengthwise through a right, porous prism, initially at some other uniform temperature. Furnas, 1930: [2] probably conducted the first experimental study for heat transfer from a fluid stream to a bed of broken solids. Colburn, 1931: [3] used granular materials, pebbles, porcelain balls and zinc balls of different sizes in the experimental study on heat transfer between air flowing through a filled tube with granular materials. Lof and Hawley, 1948: [4] determined the heat transfer between air and loose solids in an experimental study. Duffie and Beckman, 1974 [5], Klein, 1975 [6], Mumma and Marvin, 1976 [7] made attempts to solve the governing equations for the packed bed by finite difference methods. Hughes et al., 1976: [8] observed that the time to compute the temperature distribution in the bed might constitute a substantial fraction of computational effort of the simulation. Sowell and Curry, 1980: [9] presented an accurate and efficient model based on convolution theory for replacing finite difference method in which differentials are removed from the simulation equation. Chandra and Willits, 1981: [10] found the pressure drop to depend on rock size, bed porosity and airflow rate. Coefficient of heat transfer was dependent on rock size and flow rate only. No influences of inlet air temperature or initial rock bed temperature on coefficient of heat transfer was found. Courtier and Farber, 1982: [11] used rocks in solar system for heat storage with packed beds. They concluded that a general and reliable method was needed while designing a packed bed; particularly to determine the most critical parameters as (i) Air flow rate per unit face area of the bed, (ii) Rock equivalent diameter and (iii) Bed length and the bed face area. Saez and McCoy, 1982: [12] presented a mathematical model for simulating the dynamic response of a packed column to an arbitrary time dependent inlet air temperature. It included features like axial thermal dispersion as well as intra particle conduction that have usually been neglected but can be important in solar energy applications. Maaliou and McCoy, 1985: [13] presented a model for optimization of design parameters of a packed bed. The objective of the work was to device a method for the determination of the optimum velocity of air, column length and diameter, collection time and particle diameter, so that the packed bed yields the maximum net economic output. Choudhary et al., 1995: [14] conducted a theoretical analysis for optimization of design and operational parameters of a rock bed thermal energy storage device coupled with a two-pass single cover solar air heater. Fath, 1998: [15] conducted an extensive study on different energy storage techniques and materials used in sensible heat storage systems. Crandall and Thacher, 2004: [16] performed numerical simulations for solar energy storage with rock in stratified beds. Aldo Steinfeld et al., 2011: [17] has developed and experimentally validated a heat transfer model for a storage system consisting of a packed bed of rocks with air as heat transfer fluid. A parametric study of the packed bed dimension, fluid mass flow rate, particle diameter, and solid phase material was carried out for evaluating the charging and discharging characteristics. J.Pascal Coutier et al., 1982: [18] A general method for solving the differential equations describing the heat transfer process within a rock bed is presented. A numerical model accounting for secondary phenomena such as thermal losses and conduction effect is developed. Mahmud S. Audi, 1992: [19] A compact solar air heating unit for space heating is developed and tested using four types of Jordanian rocks in their natural forms as the heat storage medium. The collector efficiency equation, hence the system design parameters and the heat capacities of the rocks in the storage space environment are determined. The results are used in an application of heating a 220 m^2 floor area house in the Amman area. D.L. Zhao et al., 2011: [20] In this study, a solar air heating system was modeled through TRNSYS for a 3319 m2 building area. Lof et al., 1963 [21]: designed an air heating system using overlapped glass plate collectors and a rock bed for energy storage and, using these concepts, buit a residence near Denver. Experience with this system provides evidence that well designed air systems can operate reliably over many years with very little maintenance. Since 1970, many systems of space heating using rock bed have been analyzed. The potential of space heating with rock bed storage with optimization is now a day's becoming a popular subject of research.

II. OBJECTIVE OF PRESENT STUDY

The objective for present work is as follows:

- ❖ Study of Rock bed charging and discharging characteristics with MATLAB.
- ❖ To determine the optimum mass flow rate of hot air, coming from solar air heater so that heating of rock bed happens at lower pumping cost with bed get fully charged in day period.
- ❖ Heating load calculation of a room to be heated by rock bed at night. A typical hill area residential room occupied by four persons is taken for studies.
- ❖ To determine the supply air temperature and mass flow rate throughout the night for comfort inside the room.
- ❖ Parametric studies of rock bed parameters such as length of the bed, diameter of the bed, porosity, rock particle diameter, number of beds, mass of rocks etc.

III. MATERIAL AND METHEDOLOGY

Space heating of residences with sensible heat storage system or rock bed is the easiest, cheapest and non-polluting technique. This technique needs various parameters of rock bed and space heating to be determined and optimize, in charging (day time) and then utilizing of charged storage system (night time) in space heating application. Charging of rock bed is obtained by heating rock bed in day time by a solar air heater when solar isolation is available. The heated air from air heater enters in to the rock bed and supplies heat energy to storage material i.e. in rocks. Discharging of rock bed is done with cold air from atmosphere. The atmospheric air at night gets heated while passing through the bed. This heated air is passed to space to be heated.

A. Rock Bed: Regenerator

Rock-beds generally represent the most suitable storage units for air-based solar heating systems. Storage in rock bed is accomplished by heating the rock with hot air with the help of solar air heater when solar insolation is available (day) and then utilizing it as a source of heating when solar isolation is absent (night). Rock bed acts as a regenerator in charging and discharging processes. A schematic of rock bed storage technique is as shown in Fig. 3.1 In order to design this storage unit, a general and reliable method is needed, particularly to determine the following four most "critical" parameters as suggested by **Coutier and Farber [1982]**. These are:

- Air flow rate per unit of face area
- Rock equivalent diameter
- Bed length
- Bed face area

These four critical parameters have to be determined for any applications especially in space heating. The volume of space to be heated and temperature to be maintained inside are the key factors in determining these critical parameters.

B. Components of rock bed:

Rock bed storage system consists of following components:

- Solar air heater
- Rock bed chamber
- Rocks
- Flow circulation unit
- Ducts/Pipes

1- Solar air heater

Solar air heater is the principle source of energy in rock bed storage system. When solar isolation is incident on a solar air heater it absorbs the thermal energy and if a cold fluid is passed through it the result is elevated temperature of fluid at exit. This hot fluid is the medium by which rock bed gets charged. A heat transfer mechanism in solar air heater is as shown in **Fig.3.2.**

2- Rock bed chamber

Rock bed chamber is meant for holding the storage rock particles; the chamber is to be well insulated so as to minimize the thermal losses from storage.

3- Rocks

Rocks are used for storing thermal energy in rock bed storage systems. Different kinds of rocks are available for thermal energy storage. Some of the rocks and their properties are shown in Table 3.1.

4- Ducts/Pipes

Ducts and pipes are the essential part of rock bed storage system as they provide passage to air in charging and discharging of rock bed. The ducts and pipes should have high insulation so as to minimize the thermal losses while transfer of heat from one place to other.

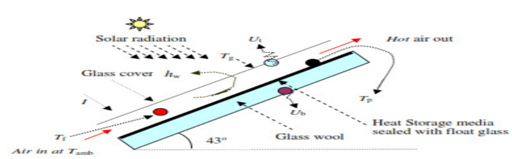

Fig. 3.2 Heat transfer mechanism in solar air heater

Table 3.1 Properties of different rocks

S.No.	Rocks	Density kg/m^3	Specific heat J/kg-K	Thermal conductivity W/m-K
1	Stone, Marble	2600	800	2.07 – 2.94
2	Stone, Granite	2640	820	1.73 – 3.98
3	Stone, Limestone	2500	900	1.26 – 1.33
4	Stone, Sandstone	2200	710	1.83
5	Clay	2650	1381	0.15 - 1.8(dry) 0.6 - 2.25 (saturated)
6	Waste plastic and Hard rubber	940	1600	0.03 - 0.1

5- Flow circulation unit

Flow circulation unit or fans are used for the forced circulation of air in heating or charging and cooling or discharging of rock bed.

C. Terminologies in Present Study:

The terminologies used in present study are as following:

- **Porosity, □**

  Porosity is associated with the packing of bed and it is defined as the ratio of packed volume to the total volume of bed. Mathematically it is represented as:

$$\epsilon = \frac{\textbf{Solid Volume in the bed}}{\textbf{Total volume of the bed}}$$

  For a rock bed with solid spherical rocks the porosity have range from 0.38 - 0.41 as mentioned in open literatures. In present study ε=0.4 is assumed for the analysis of rock bed.

- **Specific area, a_s**

  It is mathematically defined as:

$$a_s = \frac{6 * (1 - \epsilon)}{\mathbf{dp}}$$

- **Bed length, L_b**

  The length of the chamber is known as length of bed. Length of bed is an important parameter in deciding the amount of pressure drop and heat stored in the rock bed. For the present work it is taken as 1.6 m.

- **Bed diameter, D_b**

  The diameter of chamber is called bed diameter. In present work D_b is calculated in section 3.6.2.

- **Cross sectional area of bed, A_c**

  The cross sectional area of bed is determined as:

$$A_c = \frac{\pi * (D_b{}^2)}{4}$$

- **Rock properties**

For the present study limestone rocks are used which having density (ρ_s)= 2500 kg/m^3 & Specific heat (C_{ps})=900 J/kg-K

- **Rock particle diameter, d_p**

The rock particles which are storage medium assumed to be spherical. The studies were carried out on these particle diameters i.e. 0.001 m, 0.02 m, 0.025 m and 0.050 m.

- **Heating space volume**

The volume of the space where heating is to be done by rock bed is known as heating space volume. For the present study 4x4x4m^3 space volumes is taken.

- **Charging air temperature**

The exit temperature of air from solar air heater during charging of rock bed is termed as charging temperature. Here in this study it is assumed that a constant 40 ^{0}C temperature of air is coming out of the solar air heater during charging period.

- **Discharging air temperature**

In utilizing the bed in space heating the inlet temperature of air to bed is termed as discharging air temperature. Here in this study it is assumed that air at constant temperature of 10 ^{0}C is discharging the bed during the complete discharging operation.

- **Air properties in charging and discharging**

The air properties are density (ρ_g), dynamic viscosity (μ) and specific heat (C_{pg}) are taken at the bulk mean temperature at any instant of operation. The bulk temperature, T_b is defined as the mean of air and solid temperature at any instant.

$$T_b = \frac{\mathbf{Tsolid + Tair}}{2}$$

The properties of air at T_b is taken from Heat and Mass Transfer by **Yunus A. Cengel [2011]**

- **Mass velocity, G**

  Mass velocity is defined as the mass flow rate per unit area of bed.

- **Volumetric heat transfer coefficient, h_v**

  For calculating the value for the volumetric convective heat transfer coefficient expression suggested by **Coutier and Farber [1982]** is used which is as:

$$h_v = 700 * \left(\frac{G}{dp}\right)^{0.76}$$

  With G in kg/m^2-s, dp in m, h_v in W/m^3-^{0}C

- **Air velocity, v**

The air velocity in bed is calculated as:

$$v = \frac{G}{\rho_g * (1 - \epsilon)}$$

- **Charging time**

The time when rock bed is at cold state i.e. 10 ^{0}C and till it achieves the temperature of hot air i.e. 40 ^{0}C is called the charging time of bed.

- **Discharging time**

The time till the discharged air from rock bed becomes equal to supply temperature, is known as discharging time.

- **Overall building heat transfer coefficient, U_{wall} & U_{roof}**

The combined phenomenon of conduction and convection leads to an overall heat transfer coefficient which is known as overall building heat transfer coefficient.

- **Supply air temperature**

To compensate all the heat losses from heating space and to maintain comfort temperature inside the space, the temperature of air by which heating is to be done is known as supply temperature.

- **cmm**

It is quantity of air flow rate in cubic meter cube per minute also known as cmm.

- **Space heating load**

Space to be heated by rock bed has following loads:

1-Ventilation load

It is the amount of fresh air required per person to maintain air quality healthy and comfort. 0.56 cmm/person ventilation is required as per the book **Refrigeration and Air conditioning** by **Arora, P.C. [2000]**. For present work this value is used in evaluating this load this much ventilating air is mixed with hot air from bed in discharging process.

2-Sensible heat gain

In present study it is assumed that a person inside the room doing nominal work and the metabolism rate is 90 W/person, standard taken from **Arora, P.C. [2000]**. The electric appliances load is assumed to be 200 W.

3-Transmission load

Due to temperature gradient inside heated space and surrounding there will be transmission losses. Combined conduction and convection losses from walls of the space under study are considered. Standard values of overall heat transfer coefficient and material and thickness of walls and roofs are taken from **Arora, P.C. [2000]**.

- **Occupancy**

  While evaluating heating load in space it is assumed that a family of 4 persons is residing in space to be heated.

D. Methodology

Parametric study and optimization of rock bed and its application in space heating is done with following steps:

- Fixing the input and desired parameters
- Calculation of heating load
- Development of computer program
- Run the program with different inputs
- Plotting charging and discharging characteristics
- Optimization criteria
- Selection of best suited parameters: Optimization

III. RESULT AND DISCUSSION

The mathematical model used in present work is discussed in previous chapter. This mathematical model is studied, solved and validated using a MATLAB programme in the present work. Human comfort condition is the utmost priority of any space heating applications. In present work, analysis is carried out for the heating of a room at night with 4×4×4 m^3 volume and occupied by 4 persons. Heating source for the space heating was taken a rock bed which got charged at day time with the help of a solar air heater, from which a constant 40°C air is assumed to be coming at exit during the whole charging period. Heating load calculation of room at night time was done where ambient temperature of night is assumed to be 10°C throughout. Present work also includes parametric study of rock bed in charging and discharging mode and obtaining charging and discharging characteristics of rock bed with different particle diameter, mass velocity in charging and discharging and pressure drop in charging period across the bed. In general the availability of solar radiations is for 3 to 4 hours in a day. The optimization of bed is done on the basis of space heating with minimum charging time (4 hours), maximum discharging time (> 8 hours). Pumping power is to be minimum for low cost and power saving. So, charging of rock bed with least pressure drop across the bed in charging is taken as one another criteria for optimization.

Table 4.1 Variation of temperatures at different column length of previous work and present work.

Distance (m)	Time (s)	Aldo Steinfeld *et al.* Solid Temperature (K)	Present Work Solid Temperature (K)	Variation %
0.0	1200	790	752	4.81
0.2	1200	410	359	12.43
0.4	1200	310	297	4.19
0.6	1200	293	293	0
0.8	1200	293	293	0
1.0	1200	293	293	0
1.2	1200	293	293	0

As discussed above, 1.6 m length and diameter of 1.12 m of three rock beds are taken for the space heating in present work. The other parameters have to be calculated in order to optimize the complete system. Following sections describes the parametric study and the optimization of the system.

E. Effect of Rock Particle Diameter on Temperature Gradient in Charging of Rock Bed

Fig. 4.1 shows three different gradients of temperature in charging of rock bed with different particle diameter keeping all other parameters i.e. length of the bed, diameter of the bed and mass velocity same. Similar trends of charging profile with varying particle diameter is obtained in previous work of Aldo Stienfeld [2011]. Thus Fig. 4.1 is validated. As the rock particle diameter, d_p is decreasing the temperature gradient across bed is increasing. This is due to increased surface area for smaller rock particle. Lower the value of particle diameter higher will be the surface area and bed get heated uniformly and in relatively shorter time as compare to bigger particle diameter.

1-Charging Profiles of Rock Bed (G=0.450 kg/m^2-s):

Fig. 4.2 shows the temperature profiles of rock bed in charging with particle diameter of 0.001 m, 0.01 m, 0.02 m, 0.0250 m, 0.050 m and mass velocity of 0.450 kg/m^2-s. It is clear from the figures that charging time, when bed obtains the maximum temperature, is reduced as compare to charging with 0.225 kg/m^2-s mass velocity.

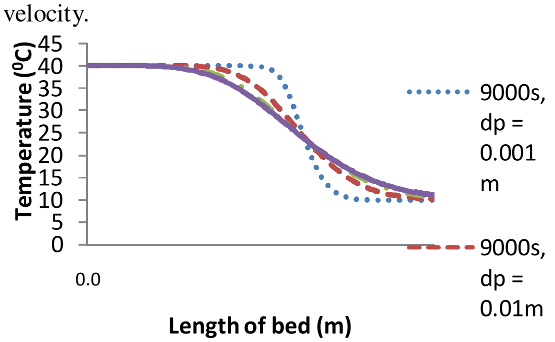

Fig. 4.1 Variation of temperature profiles at 9000 seconds (2.5 hours) with different particle diameters with G=0.225 kg/m^2-s, D_b=1.12 m, L=1.6 m

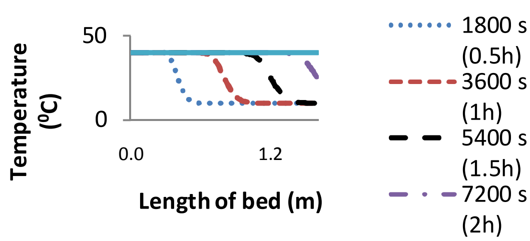

Fig. 4.2 Temperature profile of charging rock bed with 0.450 kg/m^2-s mass velocity, L=1.6 m, D_b=1.12 m, ϵ =0.40, dp=0.025 m

2-Discharging Profiles of Rock Bed

Fig. 4.3 shows the discharging temperature profiles with mass velocity 0.225 kg/m^2-s with different particle diameters. For the space to be heated throughout the night, discharging time should be maximum. So the rock bed is discharged with half of the charging mass velocity (0.225 kg/m^2-s). If it is discharged with same mass velocity in charging (0.450 kg/m^2-s) either number of beds has to be increased or larger beds has to be used.

F. Effect of Mass Velocity of Air in Charging of Rock Bed

Fig. 4.4 shows the effect of mass velocity in charging profile of rock bed. A similar trend of charging profile and mass velocity is obtained in the previous literature of Aldo Steinfeld [2011]. Thus Fig 4.4 is validated with Aldo Stienfeld [2011]. As the mass velocity is increased the charging temperature profile of rock bed gets straighter. This is due to increased particle heat transfer coefficient. This implies that if we charge the bed with higher mass velocity it takes less time to saturate the bed with uniform temperature of charging air. If a charging time of 4 hours is to be considered as maximum solar insolation is available in the period of 11:00 AM to 3:00 PM, then charging mass velocity of 0.450 kg/m^2-s is best suited for space heating of present study.

G. Effect of Rock Particle Diameter on Pressure Drop across Bed in Charging of Rock Bed

Pressure drop is a measure of pumping power. Higher the pressure drop higher will be the power of pumping. Fig. 4.5 shows pressure drop across bed in charging with particle diameter of 0.001 m, 0.01 m, 0.02 m, 0.025 m, 0.050 m and mass velocity of 0.450 kg/m^2-s. As pressure drop is decreasing with increasing particle diameter, so it can be said that in present study where space heating is to be done at minimum pressure drop, minimum particle diameter is best suited.

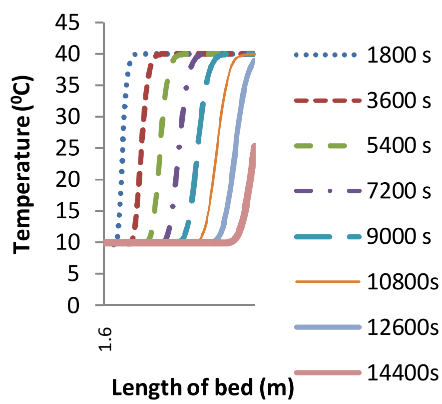

Fig. 4.3 Temperature profiles of discharging air with G=0.225 kg/m^2-s, D_b=1.12 m, L=1.6 m, dp = 0.001 m, ϵ =0.40.

H. Parameters of Rock bed: Charging

The above plots of charging can be summarized as shown in Table 4.2. For the optimization of parameters the criteria mentioned are:

(1) Charging of rock bed in 14400s (4h)
(2) Lowest pressure drop.

I. Parameters of Rock bed: Discharging

The plots of discharging can be summarized as shown in Table 4.3. For the optimization of parameters in discharging similar criteria as in case of charging is taken.

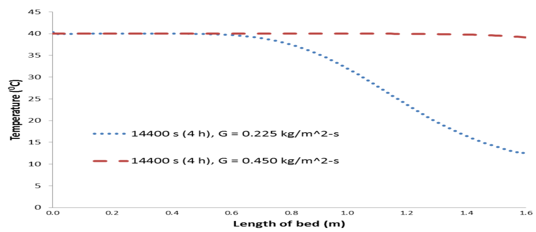

Fig. 4.4 Temperature profile of rock bed charging at different mass velocities (G) at 14400 s (4 hours) with dp=0.025 m, D_b=1.12 m, L=1.6 m

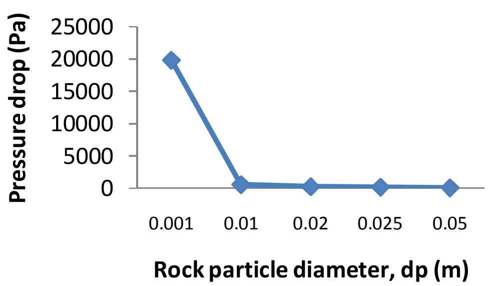

Fig. 4.5 Pressure drop across bed with different particle diameter, G=0.450 kg/m^2-s

Table 4.2 Different sets of rock bed charging parameters.

S.No.	Mass velocity, G, kg/m^2-s	Particle dia. d_p, m	Pressure loss, ΔP per bed, Pa	Charging time, t_c, Hours
1	0.225	0.001	8785	8
2	0.225	0.01	188	8
3	0.225	0.02	75	8
4	0.225	0.025	57	8
5	0.450	0.001	19810	2.5
6	0.450	0.01	601	4
7	0.450	0.02	262	4
8	0.450	0.025	203	4
9	0.450	0.050	96	5

Table 4.3 Different sets of rock bed discharging parameters.

S.No.	Mass velocity, G, kg/m^2-s	Particle dia. d_p, m	Discharging time, t_d*3, Hours
1	0.225	0.001	10.5
2	0.225	0.01	7.5
3	0.225	0.02	9
4	0.225	0.025	10.5

J. Optimization

Fig 4.6 represents the charging time of bed and pressure drop across bed. From this Figure it is clear that point at which mass velocity is 0.450 kg/m^2-s and particle diameter is 0.025 m in horizontal axis is the only point where both the optimization criteria described earlier are fulfilled. This is shown by a vertical line in this Figure.

1-Optimized Bed Parameters:

The optimized parameters in present work for air in charging the bed at 40^0C (constant) and discharging the bed at 10^0C (constant) are as follows:

- Length of bed = 1.6 m
- Diameter of bed = 1.12 m
- Number of beds = 3
- Mass velocity of hot air = 0.450 kg/m^2-s (Charging)
- Mass velocity of cold air = 0.225 kg/m^2-s (Discharging)
- Particle diameter = 0.025 m

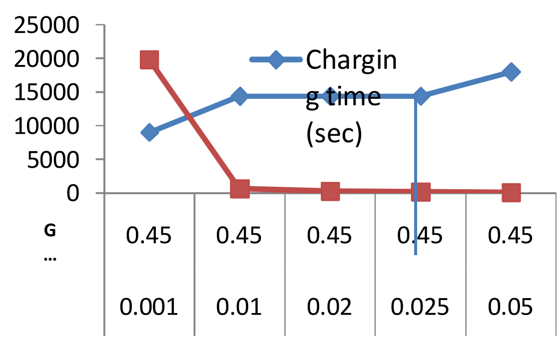

Fig. 4.6 Optimization of particle diameter and mass velocity.

IV. CONCLUSION

Parametric study of rock bed is done and optimized bed parameters were evaluated for space heating of a room of 4x4x4 m^3. The results shows that if space, in winters, is to be heated with minimum power requirement and human comfort temperature throughout the night then the optimized bed parameters evaluated in this study can be used. In the present study it is assumed that constant temperature of air in charging and discharging modes are going to charge and discharge the bed. In actual practice this is not the case as solar radiations in charging will not be constant so as the charging air. Similarly in discharging temperature of atmosphere will vary as night progresses. Inclusion of this varying temperature is a future scope of this present study. The following loads are as follows: Ventilation load is 506.58 W, Transmission load is 2838.8 W, Internal heat gain is 560 W, Net heating load is 2.785 kW and Supply air temperature is 0.1437 kg/s. These values are based on mass velocity (G), length of bed (L), diameter of bed (D_b) which is mentioned above are used to plot the temperature profiles in charging and discharging of bed with different particle diameters i.e. 0.001 m, 0.01 m, 0.02 m, 0.025 m, 0.050 m. The optimum solution for particle diameter is 0.025m, and for mass flow rate 0.450kg/m^2-s for charging and 0.225kg/m^2-s for discharging.

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