DOR: 20.1001.1.24234931.1401.9.2.14.7

Review Article Volume 9, Issue 2, Autumn & Winter, p. p. 38-40

Received: 02/11/22 **Journal of Renewable and New Energy**

Accepted: 05/17/22 **jrenew.ir**

A Comprehensive review of sensible heat based packed bed solar thermal energy storage system

Reza Zaghari[1], Nasser Baharlou-Houreh[2]*

1- BSc Student, Heat Fluids and facilities, Shahid Rajaee Teacher Training University, Tehran, Iran.
2- Assistant Professor, Department of Mechanical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
* Tehran, P.O.B Box: 163-16785, nasser.baharloo@sru.ac.ir

Received: 11 February 2022 Accepted: 17 May 2022

Abstract

Packed bed storage system (PBSS) is one of the techniques to store the solar thermal energy which can be used for greenhouses heating, crop drying and space heating due to its simple mechanism and economic feasibility. In this study parameters affecting on PBSS performance and parameters which used for their performance evaluation has been explained. After that we focused on economic evaluation and some of PBSS applications. Between two types of stationary beds and fluidized beds; although the fluidized beds have higher rate of heat and mass transfer but they have more technical problems in design and construction. Between two types of radial flow and axial flow; the radial flow systems can achieve the same efficiency as axial flow system at higher cost. Among solid materials which can be used in stationary beds; cast iron has the highest level of energy density but gravel has recommended because of less refund return period than cast iron. Rectangular geometry for cross section of storage unit provides the lowest cost, but it makes high-pressure drop due to corner effects.

Keywords: Solar Thermal Storage, Sensible Thermal Energy, Packed Bed, Solar Air Heater

1. INTRODUCTION

Many industrial activities need energy all hours of the day and all days of the year. The additional solar energy from summer or day-time should be reserved for using during winter or nights. Thermal energy storage (TES) systems suggest pliable approaches which cause stability of solar energy systems. In these systems, the internal energy of materials is utilized to store thermo-chemical, latent and sensible heat. In sensible TESs, due to the change in temperature, thermal energy is stored in the material. Sensible TES is the simplest methode to store heat [1]. In sensible TES methode, materials like bricks, oil, water, soil, or sand etc is used to store heat. during the change in temperature, there is no phase change. Fig.1 shows the sensible TES methods classification.

2. Sensible TES in packed beds

Packed beds include a reservoir stuffed with a heat transfer fluid and packing material that is flows throughout the bed to recover or store heat.

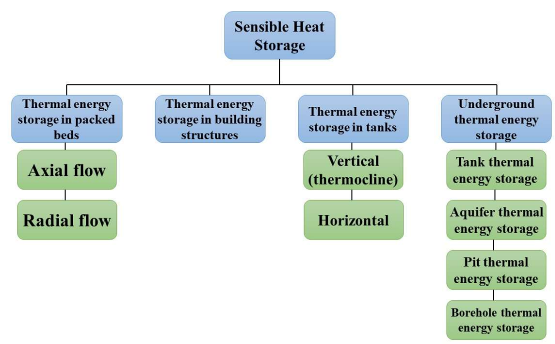

Fig. 1. Classification of sensible TES methods

The materials of packing (PMS) of packed bed storage systems (PBSS) have great specific heat, which can save the considerable amount of thermal energy by increase of temperature. Packed beds divided in two groups; fluidized beds and stationary beds. Solid materials of stationary beds such as rock [2], metals [3], pebbles [4], gravel, ceramics [5] and recycled materials [6] can be used as packing materials. Gravel has better function among others for filling [7]. Working methods of PBSSs; by circulating the heat transfer fluid (HTF) through the holes between the PBSS, the heat is extracted from and transferred to the PMS. Thermal oil and water are common heat transfer fluid.

Flow direction is another basis of classification of PBSSs which divided in two groups; axial direction and radial direction [8]. In axial flow PBSS, fluid enters parallel relative to the axial and exits parallel relative to the axial and in radial flow PBSS, fluid enters parallel relative to the axial and exits perpendicular to it. PBSSs which have radial flow can have equal efficiency as PBSSs which have axial flow but with more cost. Three different geometries of storage tank for sensible thermal energy storage according to their cross section are; cylindrical, rectangular, and truncated cone. Rectangular cross section has the lowest cost of storage unit, however it has great pressure drop because of its corner effects [9].

3. Parameters affecting on PBSS performance

3.1. Particle diameter and aspect ratio

A significant parameter to obtain minimum wall effects is the ratio of reservoir diameter to the packing diameter. Based on Bruch et al. [10] this ratio should be higher than 30. Reduction in diameter of particle and increasing the aspect ratio will always cause increasing friction coefficient.

3.2. Storage materials

The material should have enough compressive strength so it will be resistant to the force of its weight. In addition to these substantial properties, materials should have some optimal properties such as low cost, chemical stability, non-toxic, low flammability, low super cooling, and having easy access.

3.3. Void fraction

It is the void of the packed bed to the bed volume ratio. The lower values of void fraction causes contact of great number of points between the packing elements. This condition causes better conduction heat transfer of the packed bed. Although, in packed bed with lower void fraction, for the circulation of HTF we need more pumping power [11].

3.4. Sphericity

Sphericity of a packed bed is the ratio of the surface area of a sphere to the surface area of packrd bed with identical volume to sphere [12].

4. The evaluation of PBSSs performance

4.1. Performance evaluation with regard to exergy analysis

The exergy analysis evaluates the PBSS performance based on energy equilibrium and the potential for producing the mechanical function will provide with it. The exergy efficiency is equal to the ratio of recovered exergy of the storage element to the total exergy of storage element. The exergy efficiency will be remarkably affected by the mass flow rate, specially at flow rates which are lower than 100 L/hour [13].

4.2. Thermo-hydraulic performance evaluation

Five different shapes thermo-hydraulic behavior has been studied by Singh et al. [14] which are standard masonry bricks, T-joint masonry tile bricks, concrete spheres, standard masonry tile bricks and concrete cubes used in PBSS. Studies showed that the sphere with the lowest void fraction achieved the highest thermo-hydraulic performance.

4.3. Performance evaluation based on storage of thermal energy

The choice of storage tank size and material are depend on the quantity of stored energy. It has been reported by Audi [15], zeolite as compared to Basalt, limestone and Tarsand, is very desirable rock for sensible TES in packed bed. The storage volume needed for a 50 m^2 collector was 3.5 m^3 of Tarsand, while it was 8.9 m^3 in case of zeolite.

5. Economic aspects of packed beds

The economic aspects are generally depend on the properties of the TES packed bed. Advanced storage material and desirable heat transfer rate can result in storage unit with lower size, which causes lower cost as result [16]. Cast iron is the best material for the sensible heat storage, as its density of energy level is higher than water [17]. Despite this, pebbles and rock piles are recommended because of their lesser payback period and lower cost than cast iron [18].

6. Solar heat storage in packed beds for solar air heaters

Period of production drying in solar air heater with pebble bed storage is lower than open solar drying. Saxena et al. [19] examined granular carbon as a TES material in a solar air heater and compared this with a simple solar air heater. Their results showed that the solar air heater with granular carbon stores heat for a longer time and leads to a maximum thermal efficiency of 73.65%.

Solar air heater having wire mesh PBSS with counter and parallel flow structure was investigated [20]. Their results showed that counter flow solar air heater with PBSS has 11% to 17% higher efficiency than parallel flow one.

7. CONCLUSION

In this work, the packed bed solar thermal storage system is introduced. In the following, the parameters affecting the performance of PBSSs and the parameters used to evaluate their performance were introduced and described. Economic evaluation and reference to some applications of PBSS are the final parts of the article. Some important results are summarized below:

- Cast iron has the highest energy density among solid materials used in stationary beds, but due to their lower payback period and lower cost than cast iron, pebbles are recommended.
- Counter flow solar air heater with PBSS has 11% to 17% higher efficiency than parallel flow one.
- The diameter of the tank to the diameter of packing ratio must be greater than 30. Reduction of particle diameter and increasing the aspect ratio always cause increasing friction coefficient.
- Storage units with Rectangular cross-section has the lowest cost, however it has graet pressure drop because of its corner effects.

8. REFERENCES

[1] V. Becattini, T. Motmans, A. Zappone, C. Madonna, A. Haselbacher, A. Steinfeld, Experimental investigation of the thermal and mechanical stability of rocks for high-temperature thermal-energy storage, *Applied Energy*, Vol. 203, pp. 373–389, 2017.

[2] G. Zanganeh, A. Pedretti, S. Zavattoni, M. Barbato, A. Steinfeld, Packed-bed thermal storage for concentrated solar power – Pilot-scale demonstration and industrial-scale design, *Solar Energy*, Vol. 86, No. 10, pp. 3084–3098, 2012.

[3] R. Anderson, S. Shiri, H. Bindra, J. F. Morris, Experimental results and modeling of energy storage and recovery in a packed bed of alumina particles, *Applied Energy*, Vol. 119, pp. 521–529, 2014.

[4] S. A. Zavattoni, M. C. Barbato, A. Pedretti, G. Zanganeh, CFD simulations of a pebble-bed Thermal Energy Storage system accounting for porosity variations effects, *Solar PACES*, 2011.

[5] S. Zunft, M. Hänel, M. Krüger, V. Dreißigacker, F. Göhring, E. Wahl, Jülich solar power tower—experimental evaluation of the storage subsystem and performance calculation, *Journal of Solar Energy Engineering*, Vol. 133, No. 3, 2011.

[6] M. E. Navarro, M Martínez, A Gil, AI Fernández, Selection and characterization of recycled materials for sensible thermal energy storage, *Solar Energy Materials and Solar Cells*, Vol. 107, pp. 131–135, 2012.

[7] A. A. El-Sebaii, S. Aboul-Enein, M. R. I. Ramadan, and E. El-Bialy, Year round performance of double pass solar air heater with packed bed, *Energy Conversion and Management*, Vol. 48, No. 3, pp. 990–1003, 2007.

[8] L. Chai, L. Wang, J. Liu, L. Yang, H. Chen, C. Tan, Performance study of a packed bed in a closed loop thermal energy storage system, *Energy*, Vol. 77, pp. 871–879, 2014.

[9] A. Gautam and R. P. Saini, A review on technical, applications and economic aspect of packed bed solar thermal energy storage system, *Journal of Energy Storage*, Vol. 27, p. 101046, 2020.

[10] A. Bruch, J. F. Fourmigué, and R. Couturier, Experimental and numerical investigation of a pilot-scale thermal oil packed bed thermal storage system for CSP power plant, *Solar Energy*, Vol. 105, pp. 116–125, 2014.

[11] H. W. Zhang, Q. Zhou, H. L. Xing and H. Muhlhaus, A DEM study on the effective thermal conductivity of granular assemblies, *Powder Technology*, Vol. 205, No. 1–3, pp. 172–183, 2011.

[12] H. Wadell, Volume, Shape, and Roundness of Quartz Particles, *The Journal of Geology*, Vol. 43, No. 3, pp. 250–280, 1935.

[13] X. Cheng and X. Zhai, Thermal performance analysis and optimization of a cascaded packed bed cool thermal energy storage unit using multiple phase change materials, *Applied Energy*, Vol. 215, pp. 566–576, 2018.

[14] R. Singh, R. P. Saini, and J. S. Saini, Nusselt number and friction factor correlations for packed bed solar energy storage system having large sized elements of different shapes, *Solar Energy*, Vol. 80, No. 7, pp. 760–771, 2006.

[15] M. S. Audi, Experimental study of a solar space heating model using Jordanian rocks for storage, *Energy Conversion and Management*, Vol. 33, No. 9, pp. 833–842, 1992.

[16] P. Agrawal, A. Gautam, A. Kunwar, M. Kumar and S. Chamoli, Performance assessment of heat transfer and friction characteristics of a packed bed heat storage system embedded with internal grooved cylinders, *Solar Energy*, Vol. 161, pp. 148–158, 2018.

[17] S. M. Hasnain, Review on sustainable thermal energy storage technologies, Part II: cool thermal storage, Energy Conversion and Management, Vol. 39, No. 11, pp. 1139–1153, 1998.

[18] S. M. Hasnain, Review on sustainable thermal energy storage technologies part I: Heat storage materials and techniques, *Energy Conversion and Management*, Vol. 39, No. 11, pp. 1127–1138, 1998.

[19] A. Saxena, N. Agarwal, and G. Srivastava, Design and performance of a solar air heater with long term heat storage, *International Journal of Heat and Mass Transfer*, Vol. 60, No. 1, pp. 8–16, 2013.

[20] P. Dhiman, N. S. Thakur, and S. R. Chauhan, Thermal and thermohydraulic performance of counter and parallel flow packed bed solar air heaters, *Renewable Energy*, Vol. 46, pp. 259–268, 2012.