Abhishek Gautam

PhD (Thermal Energy Storage)
M. Tech (Energy Engineering)
B. Tech (Mechanical Engineering)

OBJECTIVE

To align my professional knowledge and expertise with the long term objective of the organization and work towards its growth by way of constant innovation.

RESEARCH INTERERST

Solar Thermal Energy Technologies, Solar Desalination Systems, Thermodynamic and Thermo-hydraulic analysis of thermal systems, Thermal Energy Systems, Techno-economic Analysis

EDUCATIONAL QUALIFICATIONS

Doctor of Philosophy (Ph.D.) **(2017 – 2021)**

Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, India

Thesis Title: Performance investigation of packed bed solar energy storage system having sphere with pores as packing elements.

Masters of Technology (M. Tech.) **(2013 – 15)**

Energy Engineering, Department of Mechanical Engineering, Faculty of Engineering, DIT University, Dehradun, India

Thesis Title: Technical, Economical and Environmental analysis of solar water heating system refurbishment on student hostel. (**CGPA: 8.97/10**)

Bachelors of Technology (B. Tech.) **(2008 – 12)**

Mechanical Engineering, Maharishi Markandeshwar Engineering College (M.M.E.C.), Maharishi Markandeshwar University, Ambala, Haryana, India. (**CGPA: 7.82/10**)

WORK EXPERIENCE

- Currently Working as a Post-Doctorate Fellow in Department of Mechanical Engineering, Indian Institute of Technology Bombay, Bombay **(Sep 2021 – Present)**
- Served as an Assistant Professor in Tula's Institute of Engineering and Management, Dehradun. **(Aug 2016 – Nov 2017)**
- Served as a Senior Lecturer in GRD Institute, Dehradun **(Aug 2015 – July 2016)**
- Served as a Teaching Assistant in DIT University, Dehradun **(Jan 2014 – May 2014)**
- Have worked as a Lecturer in Dev Bhoomi Institute of Technology, Dehradun **(Aug 2012 – July 2013)**

JOURNAL PUBLICATIONS

1) **Gautam, A.**, Saini, R.P., (2022). Performance analysis and system parameters optimization of a packed bed solar thermal energy storage having spherical packing elements with pores, **Journal of Energy Storage** 48, 103993.

2) **Gautam, A.**, Saini, R.P., (2021). Development of correlations for Nusselt number and friction factor of packed bed solar thermal energy storage system having spheres with pores as packing elements. **Journal of Energy Storage** 36, 102362.

3) **Gautam, A.**, Saini, R.P., (2020). Thermal and hydraulic characteristics of packed bed solar energy storage system having spheres as packing element with pores. **Journal of Energy Storage** 30, 101414.

4) **Gautam, A.**, Saini, R.P., (2020). A review on sensible heat based packed bed solar thermal energy storage system for low temperature applications. **Solar Energy** 207, 937–956.

5) Singh, S., Kharkwal, H., **Gautam, A.**, Pandey, A., (2020). CFD analysis for thermo-hydraulic properties in a tubular heat exchanger using curved circular rings. **Journal of Thermal Analysis and Calorimetry** 141, 2211–2218.

6) **Gautam, A.**, Saini, R.P., (2020). Experimental investigation of heat transfer and fluid flow behavior of packed bed solar thermal energy storage system having spheres as packing element with pores. **Solar Energy** 204, 530–541.

7) **Gautam, A.**, Saini, R.P., (2020). A review on technical, applications and economic aspect of packed bed solar thermal energy storage system. **Journal of Energy Storage** 27, 101046.

8) **Gautam, A.**, Pandey, L., Singh, S., (2018). Influence of perforated triple wing vortex generator on a turbulent flow through a circular tube. **Heat and Mass Transfer** 54, 1–13.

9) Bartwal, A., **Gautam, A.**, Kumar, M., Mangrulkar, C.K., Chamoli, S., (2018). Thermal performance intensification of a circular heat exchanger tube integrated with compound circular ring–metal wire net inserts. **Chemical Engineering Processes and Process Intensification** 124, 50-70.

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

11) Singh, S.K., Kumar, M., Kumar, A., **Gautam, A.**, Chamoli, S., (2018). Thermal and friction characteristics of a circular tube fitted with perforated hollow circular cylinder inserts. **Applied Thermal Engineering**, 130, 230-241.

12) **Gautam, A.**, Chamoli, S., Kumar, A., Singh, S., (2017). A review on technical improvements, economic feasibility and world scenario of solar water heating system. **Renewable and Sustainable Energy Reviews** 68, 541–562.

WORKSHOPS/SEMINAR/CONFERENCES

- Contributed as a co-coordinator of International Workshop on Solar Thermal Energy Storage organized by Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, India on 13th-14th Dec. 2021

- Participated in 2nd Online International Workshop on Hydrokinetic Technology held on 27th - 28th Sep. 2021 at Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, India.

- Participated in Tech4Seva – A three day National Workshop on "Technology Outreach as an Enabler for Inclusive and Sustainable Development" between 10-12th Aug. 2019 at Indian Institute of Technology Delhi, India.

- Attended a Workshop on "Publishing in Academic Journals: An Authors Workshop" jointly organized by Indian Institute of Technology Roorkee and Taylor & Francis Group on 4th May 2019.

- Attended a two days Workshop on "Research Fundamentals: Innovation and Entrepreneurship" at Indian Institute of Technology Roorkee between 13th – 14th Oct. 2018.

- Attended the Workshop on "Basics of Intellectual Property Rights" conducted at Indian Institute of Technology Roorkee on 20th Jan. 2018.

- Volunteered in International Workshop on Hydrokinetic Technology help on 10th - 11th Oct. 2019 at Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, India.

- Participated in Faculty Development Programme on Computer Based Product Design & Manufacturing conducted by Indian Institute of Technology Roorkee at Tula's Institute Dehradun between 9th to 13th Dec. 2017.

- Participated in two days Entrepreneurship Development Program on Solar Energy between 10th and 11th June 2017 in Dehradun, Uttarakhand organized by National Institute for Entrepreneurship and Small Business Development in association with TRA Renewables.

- Attended two weeks GIAN course on "Advances in Renewable Energy Technologies" in National Institute of Technology Calicut during 2nd Jan. to 13th Jan 2017.

- Organized a three days Skill Development Program in collaboration with Republic Motors on Basics of Vehicle Dynamics from 20th-22th Oct. 2016 at Tula's Institute Dehradun.

ACADEMIC ACHIEVEMENTS AND SCHOLARSHIP

- Recipient of scholarship during PhD Ministry of Education, Government of India from Dec 2017 to June 2021.

EXTRA-CURRICULAR ACTIVITIES

- Participated in Tech-Mech Quiz organized by Mechanical Engineering society, M.M.E.C.
- Contributed as a player to the M.M.E.C. Cricket Team.
- Winner of Silver Medal in Discus Throw competition in sports meet held at school level.
- Certified by Helpage India for Social Service.

TECHNICAL SKILLS

- **Experimentations –** Able to Design and fabricate the experimental Set up for thermal energy systems.
- **Language -** C (basic), Python and Matlab
- **Software Expertise –** Ansys (Fluent), Open Foam, Solid Works and MS office.
- **Writing skills –** Have a good technical writing skills.

REFEREES

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PERSONAL PROFILE

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RELEVANT LINKS AND IDs

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DECLARATION

I hereby affirm that the information furnished above is true to the best of my knowledge and belief.

Place : Mumbai, India

Date : 14th Mar 2022

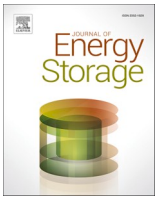
(Abhishek Gautam)

Journal of Energy Storage 48 (2022) 103993

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est



Research Papers

Performance analysis and system parameters optimization of a packed bed solar thermal energy storage having spherical packing elements with pores

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ARTICLE INFO

Keywords:
Packed bed storage system
Insolation
Thermo-hydraulic efficiency
Temperature rise parameter
Optimization

ABSTRACT

World energy demand is rising sharply from last few decades. Solar energy is capable to achieve this increasing energy demand as it is plenty in nature and pollution free by behavior. However, solar energy is associated with unsteady energy supply due to its intermittent nature. Therefore, solar energy systems require a storage unit for continuous supply of energy. The packed bed storage system (PBSS) is a feasible heat storage technique for solar thermal energy systems. Moreover, it is found most suitable technology for the applications of low temperature. The shape of the packing elements influences the performance of the PBSS and packed bed of spheres is found to have highest thermo-hydraulic efficiency among other shapes of packing elements investigated so far. Therefore, the influence of pores over the spherical surface on the performance of PBSS is analyzed and attempted to optimize the packing element parameters under this study. Pore depth to sphere diameter ratio, perforation index and pore to sphere diameter ratio are design parameters, whereas, temperature rise parameter and Reynolds number are considered as operating parameters under this study. The analysis is carried out in terms of thermo-hydraulic efficiency and the optimized value of investigated parameters under different operating conditions are presented. The present study may be useful for the designing of PBSS integrated with low temperature solar thermal applications.

1. Introduction

The continuous increase in energy demand and harmful effects of fossil fuels on environment emphasizing the world to switch towards the renewable sources of energy [1]. Solar energy is a globally accepted renewable energy source that can be utilized with solar photovoltaic and solar thermal systems. However, there is a need to integrate the storage units with solar energy systems due to their intermittent nature [2]. In case of solar thermal systems, storage tanks, fluidized bed, novel composite materials for thermal energy storage (TES) in buildings, packed bed, thermal comfort textiles, concrete blocks and moving bed are some common methods of energy storage [3–5]. Packed bed storage system (PBSS) to store sensible heat is a recommended technique for TES of low temperature solar thermal applications. It is therefore, PBSS is lower in cost, simple in mechanism and have higher effectiveness [6,7].

PBSS involves various modes of heat transfer, however, heat transfer through convection among storage material and heat transfer fluid (HTF) governs its thermo-hydraulic efficiency for applications having working temperature range up to 373K [8,9]. The heat transfer through convection among storage material and HTF is influenced through a number of factors such as physical features of HTF and packing elements, sphericity, void fraction, mass flow rate and surface temperature of packing elements. Authors have reported in their previous studies that the packing elements shape have significant impact on the outcome of the PBSS [10].

Willits and Chandra [11] revealed that the mass flow rate and size of packing elements significantly influence the volumetric heat transfer coefficient (HTC) of PBSS. However, design parameters such as bed porosity, size of storage particles and flow rate of air affects the pressure drop under the PBSS. This study has open up the research area to explore impact of mass flow rate of equivalent diameter of PBSS on its performance. Based on the same line, Sorour [12] revealed that the higher storage efficiency can be obtained at lesser mass flow rate with packing elements of intermediate size. Whereas, Ammar and Ghoneim [13] studied PBSS of spherical packing elements made up with Egyptian clay and recommended that 900 *kg/h*, 2.1 m and 0.019 m are the optimized values of flow rate, bed length and packing elements diameter, respectively.

The impact of large size packing elements on the thermo-hydraulic performance of PBSS is also explored by several reserachers. Sagara and Nakahara [14] carried out a study with large size U-shape gutter of

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https://doi.org/10.1016/j.est.2022.103993
Received 17 May 2021; Received in revised form 31 December 2021; Accepted 6 January 2022
Available online 13 January 2022

Journal of Energy Storage 36 (2021) 102362

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Development of correlations for Nusselt number and friction factor of packed bed solar thermal energy storage system having spheres with pores as packing elements

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ARTICLE INFO

Keywords:
Nusselt number
Friction factor
Pore depth
Pore diameter
Number of pores
Regression analysis

ABSTRACT

Solar energy is an emerging alternative of fossil fuels to fulfill the global energy demand as it is available in plenty and eco-friendly in behaviour. However, solar energy systems requires storage unit due to its intermittent nature. The packed bed storage system (PBSS) as storage unit is considered to be a feasible option for solar thermal energy systems having operating temperature range under 100°C. The heat transfer and pressure drop within PBSS are influenced by shape of packing element as convective heat transfer coefficient is a function of it. Under the current study, correlations are developed for Nusselt number as well as friction factor using the results obtained through experimental investigation for the PBSS built up of spherical shaped packing elements having pores on the surface. The developed correlations are the function of Reynolds number, ratio of pore diameter to sphere diameter (d/D), perforation index (PI) and ratio of pore depth to sphere diameter (t/D) within range of 200 to 800, 0.066 to 0.2, 0.06 to 0.22 and 0.05 to 0.2, respectively. Values obtained from the developed correlations are compared with the values obtained through experimentations and it is found that the correlations for Nusselt number and friction factor can predict the values with mean absolute deviation of 6.7% and 7.5%, respectively. These correlations may be helpful for the researchers working in the same research area and manufacturers developing the low temperature solar thermal energy systems. This study may also be useful to investigate the effect of similar shape of packing elements in latent heat based PBSSs.

1. INTRODUCTION

Energy security plays a major contribution in the progress, modernization and sustainability of every nation [1]. It is also a crucial sector for the economic development of every nation. The fossil fuels are the major sources to fulfill the global energy demand [2]. However, their limited quantity and negative impact on environment emphasizes to switch towards the renewable energy resources in order to achieve sustainable socio-economic systems [3]. Renewable energy resources are the most reliable resources to deal with the global energy demand and climate change. The solar energy is one of the dominating source of energy as it is available everywhere and free from environment related issues [4,5]. Solar photovoltaic, solar water heater [6], solar pond [7], solar air heater [8], solar still [9] are some common applications of solar energy. However, the intermittent nature of the solar energy is its major drawback [10,11]. In order to overcome this issue, storage units are required to be integrated with solar powered applications [12]. For thermal systems based on solar energy, packed bed storage system (PBSS) is the appropriate approach compared to rest thermal energy storage (TES) technologies due to its simple mechanism and economic feasibility [13].

The PBSS can be used with low temperature as well as high temperature solar thermal energy systems [14]. Based on the operating temperature range of the applications, storage materials and heat transfer fluid (HTF) are selected [15]. The PCM are associated with the advantage of high energy storage density [16], whereas, sensible heat storage materials are preferable due to their easy availability and economic benefits. The thermal properties of the storage material and HTF significantly influence the performance of the PBSS [17,18]. Various studies are reported on the thermal properties of the storage materials and HTF [19–22]. Similarly, the thermal performance of the PBSS are affected by the parameters that influence heat transfer within the packed bed [23,24].

There are various mode of heat transfer involved under the packed bed. However, convective heat transfer amid packing element and HTF

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https://doi.org/10.1016/j.est.2021.102362
Received 17 July 2020; Received in revised form 1 December 2020; Accepted 26 January 2021
Available online 7 February 2021

Solar Energy 207 (2020) 937–956

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

A review on sensible heat based packed bed solar thermal energy storage system for low temperature applications

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ARTICLE INFO

Keywords:
Packed bed
Storage element
Stratification
Thermal Performance
Pressure drop

ABSTRACT

Solar thermal energy is one of the categories of renewable energy source and it is quantitative abundant and qualitative superior. It is capable to fulfil the global thermal energy demand and it emerges as a competitive option with the conventional equipment's if these systems are incorporated with storage units. The solar thermal storage unit can also improve the equipment performance in terms of a smooth supply of energy with fluctuated solar energy collection as solar radiation varies throughout a day. Packed bed storage system is one of the feasible techniques to store the solar thermal energy which can be assembled with various solar thermal applications of low temperature as well as high temperature. The present review covers the sensible heat based packed bed solar thermal energy storage systems for low temperature applications. It includes a brief discussion about packed bed, its thermodynamic background, temperature distribution within packed bed, various design parameters affecting its performance and its analysis based on the energy as well as exergy efficiency. Various experimental and numerical investigations for performance analysis of PBSS have also been reported. The economic feasibility of the PBSS and comparison of sensible heat based PBSS with latent heat based PBSS has also been discussed in detail.

1. Introduction

Energy is an essential segment for the advancement of industry, public service and transport (Gautam et al., 2018). It is the prime mover for the monetary benefit and advancement of every nation. Its demand is consistently expanding because of the worldwide population growth and rising living standards. As per a report of world energy outlook 2017, although the current rate of escalation in energy demand is quite low as compared to the past few years, it is still expected to expand by 30% between 2017 and 2040 which is nearly equivalent to adding a new China and India in current demand (Energy Information Administration, 2011). In such scenario, renewable energy resources are the assets, specially solar energy and its modernization have chances to provide solutions of constantly increasing energy related being faced by various countries (Rawea and Urooj, 2018).

From the last few decades, solar energy is emerging as a feasible alternative, especially for the thermal applications. However, due to intermittent nature of solar energy, the solar thermal systems require a storage unit for their efficient utilization. Reduced energy cost, redistributed energy, reduced initial and maintenance cost, diminished size and most efficient usage of the equipment's are the characteristics expected from the storage unit in order to make it a competitive approach to its conventional counterparts (Lefebvre and Tezel, 2017). The solar thermal energy can be store in the form of sensible heat, latent heat and thermo-chemical energy. The scope of this review is limited to sensible heat based TES systems for low temperature applications. Greenhouse heating, solar drying, solar air heaters and space heating are some applications falls under this category whose working temperature range is up to 100 °C.

Storage tank (Brosseau et al., 2004), fluidized bed system (Almendros-Ibáñez et al., 2018), packed bed storage system (PBSS) and concrete blocks (Girardi et al., 2017) are the sensible heat storage methods generally integrated with low temperature solar thermal applications. PBSS is the suitable method for TES due to its simple mechanism and economic feasibility (Kuravi et al., 2013). The required characteristics of an efficient PBSS for low temperature applications are given in Fig. 1.

A typical PBSS incorporate an insulated tank, storage material, a screen whose role is to support the bed of packing elements, some supporting arrangement for the screen, inlet and outlet ducts as shown in Fig. 2 (Duffie and William, 2013). The insulated tank contains storage elements in the form of fixed bed and utilized as the primary heat storage medium in which the thermal energy can be stored by raising the temperature of the material. Thermal stratification is desirable in an efficient PBSS, therefore the use of packing elements with having high

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https://doi.org/10.1016/j.solener.2020.07.027
Received 20 November 2018; Received in revised form 6 July 2020; Accepted 9 July 2020
Available online 20 July 2020

Journal of Energy Storage 30 (2020) 101414

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Thermal and hydraulic characteristics of packed bed solar energy storage system having spheres as packing element with pores

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ARTICLE INFO

Keywords:
Solar thermal energy
Nusselt number
Friction factor
Thermo-hydraulic parameter
Flow separation
Heat transfer enhancement

ABSTRACT

The thermal performance of packed bed storage system can be improved by increasing the heat transfer coefficient between the packing element and heat transfer fluid. The shape of the packing element is one of the factors that influences the heat transfer coefficient. The present experimental investigation is carried out to obtain the influence of spheres having pores as packing element in packed bed storage system. The effects of pore diameter, pore depth, number of pores and mass flow rate is discussed and presented in the present paper. In order to investigate the performance, non-dimensional parameters such as pore to sphere diameter ratio (d/D), pore depth to sphere diameter ratio (t/D), perforation index (PI) and Reynolds number (Re) are considered. The experimentations are carried out for d/D, t/D, PI and Re for the range of 0.066 to 0.20, 0.05 to 0.20, 0.06 to 0.22 and 200 to 800, respectively. The maximum value of thermo-hydraulic parameter is obtained as 0.245 correspond to d/D of 0.20, t/D of 0.06, PI of 0.18 and Re of 800 within the considered range of the investigated parameters. On the basis of the experimental investigation, it is found that the use of sphere with pores as packing element improves the thermal and hydraulic performance of the packed bed storage system.

1. Introduction

The utilization of renewable energy resources all over the world in large scale can be a milestone to achieve the commitment made by various nations in Paris climate agreement, 2015 [1]. It is due to the capability of these resources to accomplish the global energy demand and reforming the natural balance [2]. The solar energy is expected to lead the renewable energy resources due to its abundant availability and eco-friendly behavior [3]. However, its intermittent nature is a challenge on which researchers are working and proposing to incorporate storage units with solar energy systems [4]. In case of solar thermal energy systems, there are many thermal energy storage (TES) methods out of which packed bed storage system (PBSS) is reported as the credible technique with comparatively low investment cost and capable to operate up to 800 °C [5].

For low temperature applications, the use of economic solid materials as packing element to store solar thermal energy in the form of sensible heat with air as heat transfer fluid (HTF) is recommended [6]. The selection of packing element and HTF is the main issue as the thermal and hydraulic performance of the PBSS depend on them [7]. Heat transfer in packed bed includes convection between packing elements and HTF, convection between wall and HTF, conduction between packing elements and conduction between packing elements and wall [8].

The heat transfer through convection between packing element and HTF is more dominating compared to the other modes of heat transfer in PBSS [9]. The convective heat transfer in PBSS can be influenced by a number of factors and shape of the packing element is one of them [10]. Few researchers have reported studies on various shapes and parameters related to shape of the packing element such as sphericity, void fraction, aspect ratio. These studies reported the effect of various shapes and design parameters on thermal and hydraulic behavior of PBSS.

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https://doi.org/10.1016/j.est.2020.101414
Received 22 January 2020; Received in revised form 17 March 2020; Accepted 29 March 2020
Available online 20 May 2020

Solar Energy 204 (2020) 530–541

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Experimental investigation of heat transfer and fluid flow behavior of packed bed solar thermal energy storage system having spheres as packing element with pores

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ARTICLE INFO

Keywords:
Solar thermal energy
Packed bed storage system
Insolation
Packing element
Pore depth
Pore diameter

ABSTRACT

Packed bed storage system is one of the viable options of solar thermal energy storage which can be utilized in various applications of wide temperature range. The enhancement in heat transfer coefficient between heat transfer fluid and packing element results in improved thermal performance of it. The heat transfer coefficient is also a function of shape of packing elements. From the literature review, it was found that the solid spheres as packing element comes out with best thermo-hydraulic performance in category of large size packing elements. In this paper, an experimental study has been conducted to investigate the heat transfer and fluid flow characteristics of packed bed solar thermal energy storage system. The outcomes of the experimental investigation are carried out on using large size spherical shaped packing element having pores of various diameters and depths on their surface in packed bed solar thermal energy storage system for low temperature applications. The experimentations are performed for different values of sphere diameter to pore diameter ratio (D/d) from 5 to 15, sphere diameter to pore depth ratio (D/t) from 5 to 20 and Reynolds number from 200 to 800. For the range of parameters investigated, the maximum value of thermo-hydraulic parameter has been obtained as 0.241 correspond to D/d of 5, D/t of 15 and Reynolds number of 800. Based on experimental results it is found that using spheres having pores on the surface as packing elements improve the thermal performance and momentum transport in packed bed solar thermal energy storage system.

1. Introduction

Solar energy is emerging as an admissible alternative of fossil fuels to fulfill the global energy demand and to resolve the environment related issues. However, for its sustainable development, there is a need to overcome few technical obstacles like low efficiency, instability in energy supply and monetary impediment. In order to manage instability in energy supply, the solar energy systems require an effective energy storage technology to store the energy during availability and deliver it on requirement. For solar thermal applications, the energy is required to store in the form of thermal energy (low grade energy) (Denholm et al., 2012). The packed bed storage system (PBSS) is an effective thermal energy storage (TES) technology as it has simple mechanism and can be integrated with solar thermal applications of all temperature range (Kuravi et al., 2013).

The PBSSs can store thermal energy in the various forms. However, it is recommended to store in the form of sensible heat for low temperature applications due to lesser storage cost (Suresh and Saini, 2020). The PBSS involves various modes of energy transfer, however its thermal performance is majorly dependent on the convective heat transfer between heat transfer fluid (HTF) and packing elements. The convective heat transfer rate between HTF and packing elements is a function of the physical properties of HTF and packing elements, local temperature at surface of packing element, various characteristics of packed bed such as void fraction, packing arrangement, shape of the packing elements and mass flow rate of HTF (Gautam and Saini, 2020).

The shape of the packing elements affect the flow pattern and influence the mixing of flowing streams by developing eddies under the complex set of flow passages (Singh et al., 2009). A number of researchers reported that the shape of packing element is responsible for disturbance in the flowing fluid within the PBSS and ultimately affects the convective heat transfer rate between packing element and HTF. It is therefore, shape of the packing element is considered one of the important parameter which affects the heat transfer coefficient (HTC) and hence the convective heat transfer rate.

Sagara and Nakahara (1991) investigated the effect of large size

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https://doi.org/10.1016/j.solener.2020.05.024
Received 30 July 2019; Received in revised form 12 March 2020; Accepted 6 May 2020
Available online 15 May 2020