Curriculum Vitae
Ashish Kumar, Ph.D.

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Organization Details

Position: **Research Associate**
Department: Energy Sciences and Engineering
Specialisation: Fluid and Thermal Sciences

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Personal Details

Name: Dr. Ashish Kumar
Date of Birth: 08/09/1989
Sex: Male
Nationality: Indian

Examination	University/Institute	Status	Branch/Specialisation	CPI/%
Post-Graduation	IIT Guwahati	Passed: 2013	Fluid and Thermal Sciences	7.63
Under Graduation	CSVTU/BIT Durg	Passed: 2010	Mechanical Engineering	6.99
Intermediate(12th)	K.V. Bilaspur	Passed: 2006		79.6%
Matriculation(10th)	K.V. Baikunthpur	Passed:2004		72.8%

RESEARCH BACKGROUND

Indian Institute of Technology Bombay
Ph.D.
"Design and optimization of latent heat thermal energy storage using metal matrix."
Insights:

- The objective of the work was to design an optimal latent heat thermal energy storage system(LHTES) for medium temperature applications.
- Phase change materials(PCM) are used for energy storage and thermic oil served the purpose of energy carrier.
- Numerical study of PCM embedded in porous structure is done for fluid flow and heat transfer characteristics of LHTES using **ANSYS Fluent**.
- **MATLAB** program had been developed to solve the governing equation involved in simplified model of LHTES.
- The concept of variable porosity porous structure was proposed for efficient energy storage.
- Lab-scale experiment setup was designed and fabricated for performance analysis in actual working conditions of storage system.

Indian Institute of Technology Guwahati
M.Tech
"Numerical Simulation and analysis of cryogenic ablation of tumor in a tissue."
Insights:

- The objective of the work was to destroy the tumor in tissue by thermal means

- Bio-heat equations are validated using **MATLAB** code and **FORTRAN** for 1-D,2-D geometry
- Bio-heat transfer model was applied in numerical analysis of cryogenic ablation in 3-D tissue tumor using **COMSOL**.
- It was found that helium is most suitable cryogen to ablate the tumor.
- The probe of diameter 8mm can thermally ablate the tumor of diameter 5cm.

Addition Projects:

- Developed a program in **MATLAB** for modeling and simulation of flow in Lid driven fluid cavity and validation of simulation results with standard benchmark results for various Reynolds numbers.
- A summarized report was prepared for the fluid effects; these effects were characterized along with their effects on the interface. The models available in literature were also reported.

INDUSTRIAL TRAINING

- Undergone training (in wire and rod mill) at USHA MARTIN LIMITED (Alloy and Steel Division) for duration of 40 days (2008)
- Undergone training (in mill) at URANIUM CORPARATION OF INDIA LIMITED (2009)

PUBLICATIONS

Journal Publications:

- **Kumar, Ashish, and Sandip K. Saha**. "Energy and exergy analyses of medium temperature latent heat thermal storage with high porosity metal matrix." *Applied Thermal Engineering*109 (2016): 911-923.
- **Kumar, Ashish, and Sandip K. Saha**. "Latent heat thermal storage with variable porosity metal matrix: A numerical study." *Renewable Energy* 125 (2018): 962-973.
- **Kumar, Ashish, and Sandip K. Saha**. "Experimental and Numerical Study of Latent Heat Thermal Energy Storage with High Porosity Metal Matrix under Intermitted Heat Load. Applied Energy 263, (2020)
- **Kumar, Ashish, and Sandip K. Saha**. "Performance Study of a Novel Funnel Shaped Shell and Tube Latent Heat Thermal Energy Storage System" (Under Review, Renewable Energy)
- **Kumar, Ashish, and Sandip K. Saha**. "Numerical study and optimization of integrated collector storage solar water heaters*"* (To be Submitted)

Conference Proceedings:

- **Kumar, Ashish, and Sandip K. Saha**. "Second Law Analysis of Latent Heat Thermal Storage for ORC-based Solar Thermal Power Plant." International Conference on Advances in Energy Research 2015, December 15-17, 2015, Indian Institute of Technology Bombay, India.
- **Kumar, Ashish, and Sandip K. Saha**. "Latent Heat Thermal Storage with Variable Porosity Metal Matrix: A novel concept." Proceedings of the 24th National and 2nd International ISHMT-ASTFE Heat and Mass Transfer Conference (IHMTC-2017), December 27-30, 2017, BITS Pilani, Hyderabad, India.
- **Kumar, Ashish, Pradeep Shahi, and Sandip K. Saha**. "Experimental Study of Latent Heat Thermal Energy Storage System for Medium Temperature Solar Applications"

DOI:10.11159/htff18.152, The 4th World Congress on Mechanical, Chemical, and Material Engineering. Madrid, Spain.

- **Kumar, Ashish, and Sandip K. Saha.** "Exergy Analysis of Latent Heat Thermal Energy Storage with Variable Porosity Metal Matrix." International Conference on Energy and Sustainable Development Jointly organized by Jadavpur University and The Institution of Engineers, India February 14-15, 2020.
- **Kumar, Ashish, and Sandip K. Saha.** "Study of Shell and Tube Latent Heat Thermal Storage with Tapered Shell Wall: A novel approach" (Submitted, 8th European Thermal Sciences Conference 6-10 September, 2020, Lisbon, Portugal)

TECHNICAL SKILLS

Modelling and Simulation tools	ANSYS-FLUENT, MATLAB, COMSOL, AutoCAD, Solid Works, Tecplot, Origin, Maple
Programming languages	Fortran 95, C/C++/C#

INTERNATIONAL EVENTS

- Attended International Conference on Heat Transfer and Fluid Flow, Spain (Madrid), August, 2018
- Attended International Heat and Mass Transfer Conference, BITS Pilani, Hyderabad, India. December, 2017
- Attended International Conference on Advances in Energy Research, IIT Bombay, Mumbai. December, 2015

ASSOSIATIONS

- Associated with US-India Partnership to Advance Clean Energy-Research (PACE-R) for the Solar Energy Research Institute for India and the United States (SERIIUS)

REFEREES

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3	Prof. Rajneesh Bhardwaj	Indian Institute of Technology Bombay	rajneesh.bhardwaj@iitb.ac.in

Ashish Kumar

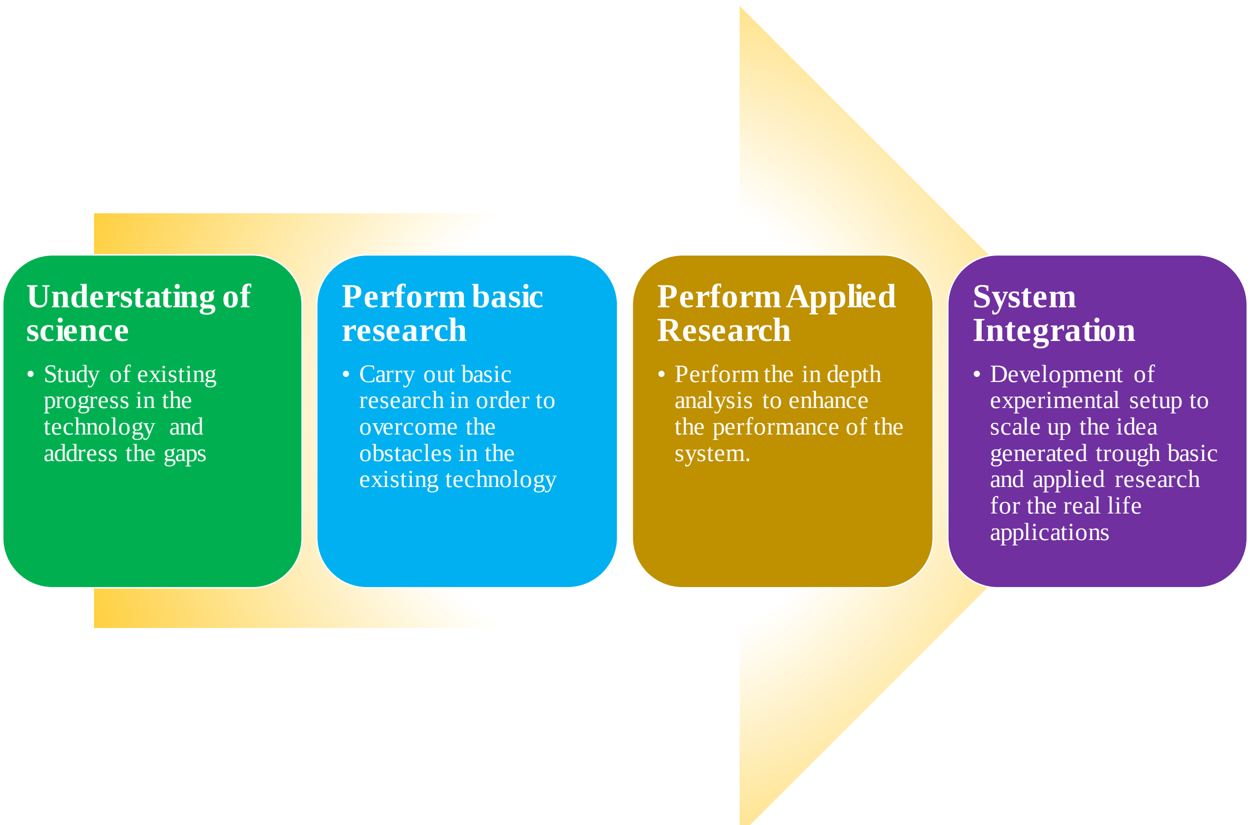
(Ashish Kumar)

Research Statement

Ashish Kumar, Ph.D.

1. Research Philosophy and Strategy

My idea of research is rooted down to seeking and introspecting knowledge and culminate it in a manner such that it gets to grips with the real time concerns. The idea is not only about functioning of the content but also to grow with it. As a scientist I try to see a problem statement with all possible bent besides all shortfall and uncovering the most optimized solution to it. In this position I see it as a responsibility not to hold back on my knowledge and very keenly fan it out. Following are the basic steps which defines my research strategy:



2. Research Interest

An efficient thermal energy storage system can reduce the mismatch between the demand and supply of the thermal energy from an intermittent source. Thermal energy can be stored by means of change in internal energy of a material, such as sensible heat, latent heat and thermo-chemical or combination of these. However, the latent heat thermal energy storage system (LHTES) employing phase change materials (PCM) requires less space as compared to the sensible heat energy storage system due to high volumetric storage density. Thermal energy storage (TES) utilizing phase change material (PCM) gaining focus in the area of waste heat recovery, solar thermal application, process drying etc. The phase change material stores and releases a significantly high amount of energy during the phase transition due to its high latent heat capacity.

The application of PCM manifolds when the difference between the source and sink temperature is low due to its properties of nearly isothermal phase change. According to the required operating temperature range of the thermal energy storage system, the selection of PCM is carried out. Organic and inorganic pure materials and eutectic salts are the commonly used PCM that can be used in low temperature (<100 °C), medium (< 350 °C) and high temperature (> 350 °C) thermal storage. However, the low thermal diffusivity of PCM retards the heat transfer capacity in the PCM, which in turns reduces the performance of the latent heat thermal energy storage system (LHTES). However, the low thermal diffusivity of PCM retards the heat transfer capacity in the PCM, which in turns reduces the performance of the latent heat thermal energy storage system (LHTES). Several methods are introduced to enhance heat transfer in PCM, such as dispersed mixture of high thermal conductivity composite material in PCM, extended surfaces like fin, encapsulated PCMs and metal matrix/foam saturated by PCM. The passive heat transfer enhancement technique can be carried out through altering the shape of shell and tube type storage tank. This reduces the additional effort required such as placing metal structure, using fins etc. which generally lead to the increases in the weight of the system and also adversely affect the cost. Further, for the high temperature storage system metallic PCM are the potential candidate which possess high latent heat fusion with high melting point and thermal conductivity. The use of such metallic PCM has the ability of overcome the issue of corrosion and less heat transfer in the storage system which is very prominent with organic and inorganic salts. My research interest lies in the design and development of efficient thermal energy storage system with the following research thrust:

- Storage Material: Short-term and long-term material selection based on thermal properties of the PCM; as well as the synthesis and characterization of composite PCM, fluids and thermochemical materials.
- Design and internal heat transfer concept: The recent progress in the storage device and design of efficient heat exchanger for thermal energy storage utilizing salts and metallic alloy as PCM.
- Storage Integration: Assessment of lab scale latent heat storage system followed by thermos-economic analysis.

3. Previous Research (Doctoral Degree):

3.1 Highlights:

- Numerical analysis had been performed in a shell and tube type thermal energy storage system using Phase change material (PCM). A commercial software Ansys Fluent 16.2 was used in the simulations.
- Numerical study of latent heat thermal energy storage (LHTES) with PCM embedded in porous metal structure for improving heat transfer in PCM was done and consequently performance analysis had been carried out based on fist law and second law efficiency
- The concept of variable porosity porous structure was proposed for more efficient energy storage. Various User Defined Functions (UDF) were developed based on assumptions of variable porosity and incorporated in commercial software Ansys Fluent 16.2.
- Simplified dynamic model (SDM) of LHTES with porous metal matrix was proposed for simulating continuous operation of storage system with less computational time.

Subsequently, a MATLAB program has been developed to solve the governing equation involved in simplified model of LHTES.

- A Lab-Scale experimental setup of LHTES with the implication metal matrix in the PCM is designed and installed for in-house experimental investigation.
- A novel funnel shaped LHTES was proposed followed by performance study based on first and second law of thermodynamics.

3.2 Major Results

- The latent heat storage system is more efficient than sensible heat storage system.
- The use of high porous metal matrix (0.85-0.97) as thermal conductivity enhancer improves the efficiency of latent heat storage system.
- At low porosity of metal matrix (0.85) maximum energy and exergy efficiencies can be achieved.
- The use of variable porosity metal matrix in LHTES improves the temperature distribution in the PCM.
- Reduction in the size of storage system can be done with the use of variable porosity metal matrix.
- Inlet temperature and mass flow rate of HTF directly affects the performance of LHTES.
- SDM can accurately predicts the heat transfer phenomena of the LHTES and can be used for large scale multiple cycle simulations.
- A funnel shaped LHTES is an efficient passive heat transfer technique.

4. Future Research Direction and Proposal

I would like carry forward my research in the area of thermal energy storage, especially for the high temperature operating range. Several available literatures discussed about the thermophysical properties of the metallic alloy and tests the consistency of these alloys as PCM for high temperature operation. However, the performance analysis of thermal energy storage system using metallic alloy as PCM is very rare. The net electricity generation by solar thermal power plants operating in the world is far behind that of solar photovoltaic generation. This is due to lack in development in this technology, specially related to energy storage. The storage of energy in the form of thermal energy is less costly as compared to electrical energy storage. Hence, there is a need of study and development of less costly, compact and efficient thermal energy system. There are few test facilities for the high temperature thermal energy storage system. University of South Australia and German Aerospace Center (DLR) established high temperature thermal energy storage test rig of operating temperature up to 900 °C and the PCM used was molten salt. A Sweden based company is gaining attention for successfully implementing high temperature latent heat thermal energy storage system using Al-Si alloy integrated with CSP, for commercial usage. However, the efficiency of this system is unknown. India has great potential for CSP due to the tropical weather, however there are few solar power plant operational in India and some other are under construction. India One Solar Thermal Power Plant has commissioned a solar thermal power plant which thermal energy storage technology. However, India need to travel a long path in this field.

4.1 Scope of the work

- In order to enable the opportunities related to high temperature latent heat thermal energy storage using metal alloy as PCM in large scale operation with efficient working. There is need for prototype testing facility which can be programed to the full range of flow and temperature conditions and can simulate the field operational conditions. There are only handful of such system present in the world as detailed above and none of them used metal alloy as working PCM.

- The outlet temperature of the heat transfer fluid (HTF) which transfers heat to the PCM charging process in LHTES is ever increasing and asymptotically approaches the HTF inlet temperature. If the rate of change in the HTF outlet temperature is can be somehow reduced, the heat transfer between HTF to PCM will be higher. This can be achieved by cascading of multiple metal alloy PCM which decreasing melting point which lead to higher energy storage capacity of the LHTES. Additionally, due to uniform temperature distribution in cascaded system as compared to the single PCM setup less entropy generation of the LHTES can be achieved. The arrangement of PCM and the quantification of the effect can be a scope of study. Thermophysical properties of metal alloy PCM given by several researches lacks in consistency, thus a standard test must be carried out before using any metal alloy PCM in the LHTES.

- The thermal conductivity of the metallic PCM is very high which leads to enhanced heat transfer. In this condition the thermal conductivity of the heat transfer fluid is the limiting factor for heat transfer between HTF and PCM. Liquid Sodium, Liquid NAK are some metallic HTF which can be used for high temperature application and have high thermal conductivity. However, these are highly reactive with moister and a small leak can cause accidents. Huge fire was reported in experimental solar tower in Spain where eutectic NAK was used as HTF. On the other hand, molten salt can also sustain high temperature and can be used as HTF. However, the melting point of these salts are high (~200 °C) which causes inconvenience in the operation below their freezing point. Hence, there is a scope for selection of best suited HTF for high temperature operation and at the same time thermal enhancement techniques can be explored in the HTF tube while using less conductive and less hazardous high temperature HTF.

- Metallic alloy PCM are good conductor of electricity as compared to molten salt and organic PCM. Hence, the convection heat transfer occurs during melting and solidification of PCM can be influenced by external magnetic field. With the implementation of magnetic field on the PCM the rate of solidification and melting can be controlled. Hence a study of magneto hydrodynamics (MHD) on metallic PCM can be carried out as a part of future scope.

4.2 Work Plan

Storage Material: It is also evident that aluminum is very abundant can also be extracted from the recycled products. Hence, it is a wise choice to use alloys of aluminum as thermal energy storage material. Several, literatures discussed about the thermophysical properties of the metallic alloy and tests the consistency of these alloys as PCM for high temperature operation. However, the discrepancy in the thermophysical properties of metallic PCM is one of the major reason which restrict its commercial usage. Hence, determination of the thermophysical properties will be carried for the alloys of metallic PCM with melting point > 500 °C. This can be carried out instruments such as; Differential scanning calorimeter, Hydrometer, thermal conductivity meters etc.

Test Facility: The establishment of a world class high temperature thermal storage test facility with a heat supply capacity of 50 kW for storage temperatures > 500 °C be carried out. Following are the components which need to be designed:

- Heater assembly- The heater capacity is determined by the required latent heat capacity of LHTES. A series of U-tubes immersion heaters make the heater assembly. Considering the mass flow rate of HTF and the power needed for heating the HTF to desired temperature from the ambient temperature of 30 °C in one pass will be estimated. It is worth to mention here that a series of heaters is used because we cannot switch on all immersion heaters at a time, as these may cause local heating of the HTF, and as a result, the temperature of HTF may go above its flash point.
- Storage tank: A shell and tube type storage tank is one of the widely used storage tank due to its high heat transfer area and compact design. The design parameters and dimensions of the storage tank will be studied before the fabrication.
- Cooler: Design of heat exchanger for cooling of HTF will be carried out for extraction of thermal energy from the PCM during discharging process.
- Pump: Selection of pump will be carried out for continuous circulation of HTF in the test facility.

4.3 Numerical Analysis: In this part of the work a detailed numerical model will be developed for high temperature LHTES. The model will be first validated with the results of the experiments to ensure the correctness. The purpose of the mathematical model is to analyze the performance of the LHTES with other operating parameters that cannot be applied in the experimental investigations. Further, a cascaded high temperature PCM system will be analyzed numerically in order to enhance the efficacy of the storage system.

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Experimental and numerical study of latent heat thermal energy storage with high porosity metal matrix under intermittent heat loads

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HIGHLIGHTS

- Experimental study of shell and tube latent heat storage with high porosity metal matrix.
- Metal matrix is embedded in phase change material and fin is inserted in heat transfer fluid.
- A two-energy equation thermal non-equilibrium simplified numerical model is developed.
- Discharging inlet temperature of heat transfer fluid affects the efficiency maximum by 116%.
- Lowest fluctuation in heat transfer fluid outlet temperature is found for porosity of 0.85.

ARTICLE INFO

Keywords:
Phase change material
Metal matrix
Thermal storage
Dynamic model
Interfacial heat transfer coefficient
Effective thermal conductivity

ABSTRACT

The potential mismatch between the ever-increasing demand for usable energy and characteristically intermittent supply from the renewable energy sources can be effectively reduced by latent heat thermal energy storage system (LHTES) using phase change material (PCM). The low thermal conductivity of PCM leads to thermal stratification in LHTES. In the present study, a lab-scale shell and tube LHTES with the metal matrix as thermal conductivity enhancer is designed for medium temperature solar applications (~200 °C) and the thermal performance of LHTES is evaluated for different operating conditions. A commercial-grade organic PCM and metal matrix are placed in the annulus, while a commercially available thermic oil used as a heat transfer fluid (HTF), flows through the finned internal tube. A simplified dynamic numerical model comprising of two energy equations is developed considering the absence of local thermal equilibrium between PCM and HTF. A newly developed correlation for interfacial heat transfer coefficient and the effective thermal conductivity of PCM and metal matrix are introduced in the model, which is validated against the experiment. The model is extended to study the effect of porosity of metal matrix on the dynamic performance of LHTES under several cycles of charging and discharging operations. It is found that at a porosity of 0.85, the fluctuation in HTF outlet temperature is less with an improvement in cumulative energy fraction. A significant saving of computational time can be achieved for large scale simulations of LHTES with metal matrix using the simplified dynamic model with reasonable accuracy.

1. Introduction

The renewable energy sources are clean and sustainable alternatives for conventional energy sources, such as fossil fuels, and have lower carbon footprint; however, renewable energy sources, especially the solar and wind, are intermittent. Stable operation of power plants requires that the load loop performance remain unfazed by the variability of the load and intermittency of the renewable sources [1–3]. Hence, with a view to minimising the effect of source unreliability, a substantial amount of effort has been invested towards finding the efficient ways of storing the energy received from renewable sources. An efficient thermal energy storage system stores the excess amount of energy upon availability and releases the same as per the demand of the load loop, thereby minimising the inconsistency between demand and supply [4–6]. Sensible heat energy storage and latent heat energy storage are the two widely used thermal energy storage technologies for meeting the load loop demand. However, the latent heat thermal energy storage system (LHTES) employing phase change materials (PCM)

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Latent heat thermal storage with variable porosity metal matrix: A numerical study

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ABSTRACT

In this paper, a novel design of multitube shell and tube latent heat thermal energy storage system (LHTES) with variable porosity metal matrix in PCM is presented. The shell side of the LHTES contains a phase change material, whereas heat transfer fluid (HTF) flows through seven tubes with internal fins. Metal matrix, as a thermal conductivity enhancer (TCE), is used to augment heat transfer in PCM, however the temperature distribution in PCM is found to be non-uniform along the length of the storage system for constant porosity metal matrix in PCM, which affects the thermal performance of the LHTES. A numerical model is developed to investigate the fluid flow and heat transfer characteristics using the momentum equation and the two-temperature non-equilibrium energy equation coupled with the enthalpy method to account for phase change in PCM. The numerical model is first validated with the experimental results and further extended to identify the effects of geometrical parameters on the temperature distribution in PCM. A relationship between porosity and ratio of length to annular diameter of the storage system is developed for porosity varying from 0.95 to 0.85. It is found that the size of LHTES with variable metal matrix porosity can be reduced for the same effectiveness.

1. Introduction

Solar radiation is one of the abundant renewable sources of energy that can be utilized to generate electricity for small scale (~0.1 MW) solar thermal applications. The major issue with the solar based systems is the inability to generate electricity continuously due to the intermittent nature of sun radiation. A thermal energy storage can fill the gap between demand and supply of the energy. Energy can be stored in the form of sensible heat and latent heat. Latent heat thermal energy storage system uses phase change materials (PCM) which has advantages over sensible heat storage system, as it can exchange heat within a small temperature difference and also it has high latent heat of melting that makes the storage more compact. However, a major drawback with PCM is its low thermal conductivity which often reduces the effectiveness of the storage system. Enhancement of heat transfer in PCM can be achieved by either increasing heat transfer on internal heat transfer surface or exchanging heat storage medium [1]. Some of the commonly used techniques to argument the heat transfer in PCM are embedding PCM in metal matrix [2–4], random packing of carbon fibre in PCM [5,6], using composite such as graphite in PCM [7], metallic dispersion in PCM [8,9], encapsulation [10–13], addition of fins [14–17], ring and bubble agitation in PCM [18].

The shell and tube type heat exchanger is widely used configuration to study latent heat thermal storage system (LHTES). In this paper, shell and tube type latent heat thermal storage system based on solid-liquid phase change is analyzed. The phase change material is packed in the annulus of the heat exchanger and heat transfer fluid (HTF) flows though the tubes inside the shell. Metal matrix is inserted in PCM as thermal conductivity enhancer (TCE) to improve heat transfer in PCM. Several studies have been carried out to understand the effect of metal matrix as TCE on thermal storage system. In a numerical study carried out by Mesalhy [4] on LHTES, heat transfer in PCM is found to increase by inserting high porosity metal matrix in PCM. The melting of PCM with metal matrix shows significant difference as compared to PCM without any thermal conductivity enhancer. PCM with metallic porous matrix is numerical analyzed by Bejan [19] considering thermal equilibrium between metal matrix and PCM. The results showed that heat transfer and melting rates are significantly affected by the liquid Stefan number. Thermal equilibrium model between metal matrix

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Research Paper

Energy and exergy analyses of medium temperature latent heat thermal storage with high porosity metal matrix

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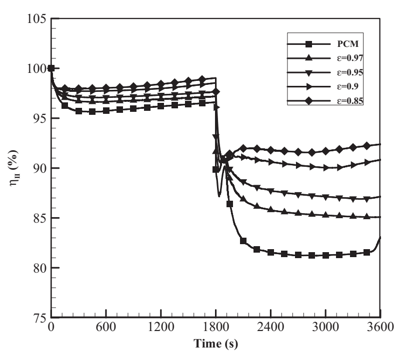
[b] Department of Mechanical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

GRAPHICAL ABSTRACT

I. Metal matrix is used as the thermal conductivity enhancers (TCE) in PCM-based TES. II. Time evolution second law analysis is evaluated for different porosities and pore diameters. III. Reduction in fluctuation in HTF temperature is significantly affected by the change in porosity (ε) shown in figure. IV. Maximum energy and exergy efficiencies are obtained for porosity of 0.85. V. Effect of pore diameter on first law and second law efficiencies is found to be marginal.



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Keywords:
Latent heat thermal storage
PCM
Metal matrix
Second law
First law
Efficiency

ABSTRACT

Thermal energy storage system in a concentrating solar plant (CSP) reduces the gap between energy demand and supply caused by the intermittent behaviour of solar radiation. In this paper, detailed exergy and energy analyses of shell and tube type latent heat thermal storage system (LHTES) for medium temperature solar thermal power plant (~200 °C) are performed to estimate the net useful energy during the charging and discharging period in a cycle. A commercial-grade organic phase change material (PCM) is stored inside the annular space of the shell and the heat transfer fluid (HTF) flows through the tubes. Thermal conductivity enhancer (TCE) in the form of metal matrix is embedded in PCM to augment heat transfer. A numerical model is developed to investigate the fluid flow and heat transfer characteristics using the momentum equation and the two-temperature non-equilibrium energy equation coupled with the enthalpy method to account for phase change in PCM. The effects of storage material, porosity and pore-diameter on the net useful energy that can be stored and released during a cycle, are studied. It is found that the first law efficiency of sensible heat storage system is less compared to LHTES. With the decrease in porosity, the first law and second law efficiencies of LHTES increase for both the charging

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