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Exploratory investigation of a new thermal energy storage system with different phase change materials having distinct melting temperatures

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ABSTRACT

This paper presents the experimental investigation of the new thermal energy storage system comprising of different PCMs. Three PCMs having different melting temperatures are used to investigate the performance of the system and water is used as a heat transfer fluid (HTF). Spherical AISI 304 L capsules of 55 mm diameter were used to encapsulate the phase-change material. The whole system was operated between different temperature ranges, and HTF (heat transfer fluid) flow was varied from 2 liters/min to 6 liters/min. The temperature inside the bed was continuously monitored using LABVIEW express during the charging and discharging procedures. The effect of inlet temperature and HTF flow rate on the performance of the system was also assessed in the experimental work. The study demonstrates that there is a decrease in the charging time of the packed bed from 28% to 14% when flow rate is increased from 2 liters/min to 6 liters/min. Moreover, the energy efficiency also increases by the increase in mass flow rate. It was also found that there is a decrease in exergy efficiency with the increase in mass flow rate.

1. Introduction

Today thermal energy storage (TES) plays an important role in every aspect of life. The researchers around the world are developing new technologies to encounter the problem of energy storage. Because of high energy storage density, latent heat thermal energy storage (LHTES) systems have achieved more importance form the past decades as compared to other storage technologies. These days, thermal energy storage in phase change materials (PCM) has become the first choice of the researchers all around the globe. In this system, energy storage takes place during the phase change of the materials (solid to liquid) also called as charging process and then retrieving the same energy from the materials in the process stated as discharging process. Without making a large change in temperatures phase change materials can be easily used for heat supply or it can be extracted from them. In this way, PCMs can be used to adjust the temperature in an application.

Abhat [1] provided a detailed classification of the substances utilized for different Thermal Energy Storage Systems. Kaygusuz et al. [2] concluded that the capacity thickness in the latent heat storage system is 5–10 times higher than sensible heat storage systems. Sharma et al. [3] provides a brief introduction and analysis on the available thermal storage systems which can be used in various applications. There are huge numbers of PCMs which are present in the marketplace that melts and solidifies at the desired limits of temperatures, making them alluring in various applications for heat storage. Singh et al. [4] did a comprehensive reassessment of various packed bed storage system including design construction of packed beds, different materials used for heat storage, heat transmit properties, flow phenomenon and pressure drop via packed beds.

Alam et al. [5] used a laboratory scale prototype packed-bed storage (TES) system for their experimental study. They used high-temperature sodium nitrate as a PCM with melting temperature of 306 °C and air as HTF. A more detailed review was provided by Fleischer et al. [6] for the utilization of micro encapsulated PCMs in various construction materials. In this study the use of PCM in roofing materials was also examined. A detailed survey was provided by Zalba et al. [7] of the historical backdrop of a thermal energy storage framework with solid–liquid phase transformation. Mainly few viewpoints were the concentration of this audit: materials used as PCMs, heat transfer properties and its applications. The problem of encapsulation of materials and their long-term stability was also discussed. The study contains recorded more than 150 different materials used in examination as PCMs, and around 45 commercially accessible PCMs. Mathematical modeling of multiple PCM was done and compared with single PCM in heat storage system by Aldos and Rahman [8].

Agyenim et al. [9] also did a detailed review work on the latest advancements in latent heat thermal energy storage framework, comprising various PCMs. Along with this, heat transfer phenomenon and

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Nomenclature

Dp	PCM Capsule diameter, mm
ε	Void fraction
L	length of the bed, cm
H	Height of bed, cm
ΔT	Thickness of bed, cm
V	Volume of packed bed
T_{ins}	Wall Insulation thickness
ΔP	Pressure drop, Pa
ρ	Density, kg/m3
μDynamicViscosity	N.s. /m2
Re_p	Particle Reynolds Number
T	Temperature, ˚C
t	time, min
h	height
r	radius
Tin	Temperature values of the water entering the TES system
Tout	Temperature values of the water leaving the TES system
To	Ambient room temperature
T_{melt}	Melting temperature of the PCM
E_{in}	Heat absorbed by the PCM
E_{out}	Heat gained by the PCM from water
$\dot{m}$	mass flow rate
C_{HTF}	Specific heat of the heat transfer fluid
X_{in}	Exergy inlet
X_{out}	Exergy outlet
X_{stored}	Exergy stored in the system

Subscripts

PCM	phase change material
TES	thermal energy storage
PC	phase Change
HTF	heat transfer fluid

enhancement techniques of TES systems which were employed by different researchers were also examined. Iten and Liu [10] published a detailed technique to model an efficient short term thermal energy storage (TES) system utilizing different PCMs. Tatsidjodoung et al. [11] published a detailed review of past studies on latent heat storage and gives an understanding to current endeavors of using PCMs in energy storage. This employment outlines the examination and investigation of the accessible thermal energy storage frameworks consolidating PCMs. Furthermore, takes a gander at the condition of art of thermal energy storage systems, using PCM working with little temperature differences, for example, numerous paraffin waxes, which are modest and have direct storage density. Application of PCM in domestic hot water and heating purposes were detailed reviewed by Sharif et al. [12] Different aspects like PCM materials, encapsulation and applications were focused in the study by farid et al. [13]. Korti et al. [14] performed experimental study using three different types of PCMs. Gasia et al. [15] used the technique of recirculating the liquid PCM in the course of the melting operation in order to improve the overall heat transfer

Fig. 1. Complete experimental set-up.