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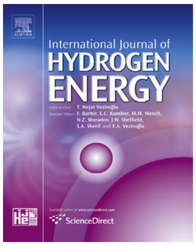

Performance enhancement of finned heat pipe assisted latent heat thermal energy storage system in the presence of nano-enhanced H_2O as phase change material

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ABSTRACT

In this research, Latent Heat Thermal Energy Storage Systems (LHTESS) containing Nano-Enhanced Phase Change Material (NEPCM) in the presence of novel shape finned heat pipe is numerically investigated from the viewpoint of discharging process. In recent years, LHTESS have been used to establish a balance between energy supply and demand. Since conventional PCMs are characterized with high latent heat and low thermal conductivity, these systems are capable of storing large amount of energy, but storage and retrieval processes cannot be achieved in the desired time duration. In this paper, CFD simulation and multi-objective Response Surface Method (RSM) optimization is used simultaneously to find the optimum configuration of novel shaped fin, which is then attached to a heat pipe and immersed into the LHTESS. The performance of finned heat pipe assisted LHTESS is compared to the LHTESS containing NEPCM, and LHTESS with other common fin structures. Since the immersion of finned heat pipe into the system decreases the amount of employed PCM, the maximum energy storage capacity of the LHTESS drops subsequently. Thus, energy storage capacity, as one of the objectives of optimization procedure of this research is studied quantitatively, which is proposed as the novelty here. Results indicate that employing maximum energy storage capacity as an evaluation parameter, leads to efficient design of LHTESS. Also it is inferred that immersing finned heat pipe into LHTESS as a heat transfer enhancement technique is superior to nanoparticles dispersion.

Introduction

In recent years, because of several problems caused by fossil fuels energy, different alternatives have been proposed and attracted attentions throughout the world including solar energy [1–3], fuel cell energy [4–11] and different types of batteries [12–14]. In several applications including photovoltaic systems, supplementary systems are required in order to fill the large gap between energy supply and demand. Latent

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Nomenclature

a	specified points in two-dimensional solution domain in (r, z)
C_p	heat capacity, m^{2}kg/s^{2}K
D_{cond}	diameter of heat pipe condenser, mm
D_{eva}	diameter of heat pipe evaporator, mm
g	acceleration of gravity, m/s^2
h	enthalpy, J/kg
K	thermal conductivity, w/mK
L	fin length, cm
L_f	latent heat of fusion, J/kg
P	pressure, N/m^2
S	solid fraction
T	time, s
T_m	solid–liquid phase change temperature, K
T_0	solid–liquid phase change interval
T_w	wall temperature, K
u	velocity, m/s
V	volume, m^3
w	fin thickness, mm
x	spatial coordinates components

Greek

α	thermal diffusivity, m^2/s
β	fin branch direction, Rad
β_e	thermal expansion coefficient
ρ	density, kg/m^3
ϕ	nanoparticles volume fraction
μ	viscosity, Pa·s
γ	liquid fraction

Subscripts

cond	condenser
eva	evaporator
f	fusion
m	melt
nf	nanofluid
bf	base fluid
p	nanoparticles
eff	effective
ref	reference

Heat Thermal Energy Storage System (LHTESS) and Sensible Heat Thermal Energy Storage System (SHTESS) are conventional systems used for energy storage applications. The main difference between these systems is that in SHTESS, energy is stored during temperature change rather than phase change. Whereas in LHTESS energy is stored during solid–liquid phase change. That energy storage-retrieval density during phase change is greater than that of SHTESS, and this feature makes it suitable for designing energy storage systems with high energy density [15]. Because of this feature, LHTESS are widely used in several applications, such as solar [16], HVAC [17] and electronic chip cooling systems [18]. LHTESS containing PCMs are capable of storage and retrieval of large amount of energy during solid–liquid phase change of the PCM but the main restriction of these systems is weak thermal conductivity of conventional PCMs. This feature weakens heat transfer mechanisms during solid–liquid phase change of PCMs, as a result of which, energy storage-retrieval is not accomplished in the desired time duration. Therefore, several enhancement techniques have been used in LHTESS in order to achieve uniform and accelerated solid–liquid phase change. Over the past few decades, the examination of heat transfer enhancement techniques has been the subject of growing attention in experimental and numerical researches. These techniques are divided into active and passive types. The latter involves applying rough, treated and extended surfaces whereas the former includes surface vibration, fluid vibration and electrostatic fields [19]. Xuan and Lee [20] in their experimental investigation on nanofluid heat transfer enhancement reported that the nanofluid had great potential in enhancing the heat transfer process, especially due to remarkable increase in the thermal conductivity of nanofluid caused by the presence of suspended ultrafine particles. For instance, for the Cu-water nanofluid, the ratio of thermal conductivity of nanofluid to that of base liquid varies from 1.24 to 1.78 while the volume fraction of ultrafine particles rises from 2.5% to 7.5%. Jourabian et al. [21] performed a numerical analysis of the effect of adding nanoparticles to PCM in latent heat storage unit during melting process using Lattice Boltzmann Method. They investigated the effect of hot inner cylinder position and nanoparticles volume fraction on the melting process of PCM reporting that when the hot inner cylinder moved upward, the melting rate enhancement obtained by the addition of nanoparticle was significant, because in this case, natural convection heat transfer was suppressed and the conduction heat transfer left a remarkable effect on melting process. Mohammad [22] studied the mysterious behaviour of fluid flow in the presence of nanoparticles reporting that consideration of simple physics in the study of nanofluid flow and heat transfer, would slightly enhances heat transfer rate but, the addition of nanoparticles to a system caused several problems in the system including suppression of natural and forced convection heat transfer due to viscosity increment by the increase of nanoparticles volume fraction. Fan and Khodadadi [23] experimentally investigated heat transfer enhancement during solidification process of NEPCM. They studied the unidirectional solidification process of PCM in the presence of different volume fractions of nanoparticles. Their results indicated that with an increase of nanoparticles volume fraction from 0.0 to 0.5%, a significant enhancement of heat transfer was observed but further addition of nanoparticles led to the reduced enhancement rate. Additionally, solid particles sedimentation is especially significant in high values of volume fractions. Therefore, finding a suitable heat transfer enhancement technique for LHTESS, without changing thermophysical properties of PCMs or causing problems such as sedimentation has gained growing attention in recent studies. Applying external electric-magnetic field to the system, immersing fin, metal matrix and heat pipe into the LHTESS and PCM microencapsulation are some of the techniques proposed to control the performance of these systems during melting and solidification processes. Charmchi et al. [24] experimentally and numerically investigated the behaviour of pure gallium melting in the presence of magnetic field