International Journal of Heat and Mass Transfer 92 (2016) 490–496

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Study on phase change interface for erythritol with nano-copper in spherical container during heat transport

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ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form 27 August 2015
Accepted 28 August 2015
Available online 19 September 2015

Keywords:
PCM
Thermal storage system
Interface
Thermal storage
Encapsulation

ABSTRACT

Compared with the conventional portable heat transport, this paper proposes the spherical encapsulation arranged in the thermal storage tank. A new kind of PCM (0.4% nanocopper+ 99.6% erythritol) with latent heat of 362.2 kJ/kg was encapsulated in stainless steel ball. The validity of various models developed and complexity required for a given problem is not suitable for spherical encapsulation during heat transport. Take the spinning during heat transport into consideration, the heat transfer process was analyzed for an encapsulated phase change material and its theoretic model for the PCM interface was established. In order to validate the model, the experiment was conducted for the temperature distribution change. During the heat release, the solid–liquid interface moved from the spherical shell to ball center, and it was found that interface moving speed increases when the ambient temperature reduces. The research is also investigated for effect of the ball size on the interface moving, which has an equally agreement with the theoretical model.

1. Introduction

At present, a lot of materials are always selected as PCM for thermal storage system including Water and Barium hydroxide, but these thermal storage systems are limited in heat storage density, safety and phase change temperature. The organic PCM can solve the potential problem, meanwhile in order to improve its low thermal conductivity, and different kinds of metal additivities have to be added in the thermal storage material [1–14].

As organic material, erythritol provides much higher storage density and a small temperature differential between storing and releasing heat. But in order to improve its' low thermal conductivity, some metal matrix or high conductivity particle should be added. Teppei Oya developed new phase change composites using erythritol as a phase change material ,and graphite and nickel particles are added as highly thermal conductive fillers, leading to 6.4 times higher than thermal conductivity of pure erythritol [15].

Besides above, there are also numerous researches that reported the preparation and characterization of encapsulated PCMs. Agyenim reviewed the development of latent heat thermal energy storage systems, studied various phase change materials (PCM) investigated over the last three decades, and examined the geometry and configurations of PCM containers. A series of numerical and experimental tests were undertaken to assess the effects of parameters such as the inlet temperature and the mass flow rate of the heat transfer fluid [16]. Sharma et al. summarized the investigation and analysis of the available thermal energy storage systems incorporating PCMs for use in different application [17]. Zhu et al. presented an overview of the previous research work on dynamic characteristics and energy performance of buildings due to the integration of PCM [18]. Researches on thermal storage, such as the PCM encapsulated in concrete, gypsum wallboard, ceiling and floor have been ongoing for some time and were discussed by Khudhair and Farid [19]. From previous studies, it is obvious that PCM encapsulation influences significantly on the performance of a TESS. Based on the above literature, it was noticed that the survey on the effect of various initial parameters, as heat release temperature, size, shell thickness of the encapsulated PCM on the liquid–solid interface of the PCM is relatively few. At this point, the objective of the present study is to highlight the effect of initial parameters on the performance of a TESS, as well as on the interface generation during the heat release process.

During the heat transportation process, take the cost, sealing performance into consideration, the encapsulation of PCM in sphere is more suitable to reduce the initial investment, and the spherical structure can be produced in overall processing without weld joint. In addition, the heat requirement can be arranged through changing the quantity of encapsulation ball when the heat transportation tank has been designed. In terms of the PCM in

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.08.095
0017-9310/

Nomenclature

α	thermal diffusion coefficient
r	radius
k	thermal conductivity
L	latent heat
R	heat resistance
M	mass fraction
T	temperature
C	sensitive heat
t	time
Bi	Biot number
Ste	Stefan number
τ	dimensionless time'
$b(t)$	function in (18)

Subscript

l	liquid
s	solid
b	boundary
∞	environment
i	inside
e	outside
f	flow

spherical encapsulation, many scholars have considered it for improving the heat transfer efficiency. Tan et al. [20] studied the constrained melting of wax inside a spherical capsule. It was found that the waviness and excessive melting of the bottom of the PCM was shown to be underestimated by the experimental observation due to the support structure to hold the sphere. An experimental study was conducted by Amin. A suitable relationship for the effective thermal conductivity was developed as a function of the Rayleigh number. The study demonstrated the applicability of determining effective thermal conductivity relationships to represent natural convection in PCM thermal energy storage systems (TESS) [21].

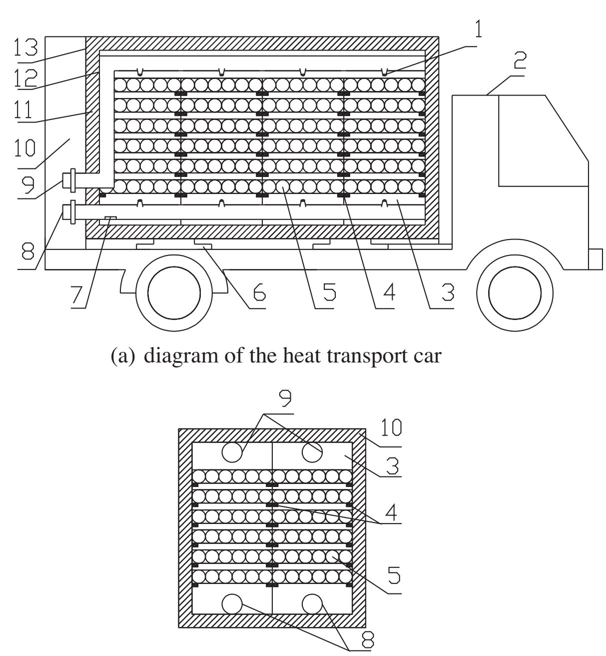
For the mobile heat transport, the research on the spherical encapsulation arranged in the heat storage tank is relatively few. Wang designed a set of phase change heat transport system which combined heat storage and heat provision unit. Water as thermal fluid are filled with 90% volume of heat storage tank, and PCM are stuffed in pipeline, which are arranged in the thermal tank [22]. The direct contact type heat transport system was proposed by Kaizawa. The system merely consisted of two inlet pipes, two outlet pipes and a heat storage tank. The heat storage and release property was changed through the fluid temperature and mass flow variation [23]. In this study, phase change interface for erythritol with nano-copper in spherical container during heat transport has been studied. One of the objectives of this study was to propose a new kind of PCM (0.4% nano-copper+ 99.6% erythritol) which enhanced the thermal conductivity up to 3.3 times, compared with pure erythritol, and arranged the establish a novel heat transport system to arrange the spherical encapsulation in the thermal storage tank. Another objective was to study the influence of ambient temperature, the radius of the phase change ball on the interface of phase change. This study verified later model proposed and taken spinning and movement during heat transfer into consideration A third objective was to build a novel heat transport system which combine a mathematical model for the heat transfer of PCM sealed in sphere during heat transport is built. Currently, universal theoretical model for single encapsulated sphere in terms of the spinning and move during heat transport is still waiting to be explored according to existing research, and most of the current models constructed based on classical theory are totally different from the truth. Hence, more experimental researches on them are needed to reveal.

2. Experimental procedure

As is shown in Fig.1, the size of the heat transport car out tank is 4.1 m × 2 m × 1.25 m, and that of the inner tank is 3.6 m × 1.8 m × 1.1 m. The thermal insulation layer is filled between the out tank and inner tank. The heat storage unit was separated by groove in each floor, where five phase change balls are arranged. The thermal oil spurted from nozzle 1 flows in from the inlet 9, and out from outlet 8. The flow rate is adjusted according to the temperature variation measured by temperature sensor 7.

At first, the phase change ball was filled with PCM. The composite (0.4% nano-copper+ 99.6% erythritol) is very stable in structure and high in thermal conductivity, so as to be chosen for an ideal PCM, Compared to pure erythritol, the thermal conductivity of the composite PCM increased 2.8 and 3.3 times, respectively in solid phase or liquid phase, although latent heat decreased about 0.3% [24]. The thermophysical parameters of the selected PCM are listed in Table1.

The experimental set up includes two thermostatic oil baths for heating and cooling the encapsulated PCM, as well as the Agilent data collection system. The encapsulation of PCM is in a spherical



(a) diagram of the heat transport car

(b) diagram of the heat storage tank

Fig. 1. Diagram of heat transport system. 1-nozzle 2-heat transport car 3-conduction oil 4-groove 5-phase change ball 6-holder 7-temperature sensor 8-outlet of conduction oil 9-inlet of conduction oil 10-trunk 11-thermal insulation layer 12-inner tank 13-outer tank.