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Preparation and flow resistance characteristics of novel microcapsule slurries for engine cooling system

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ABSTRACT

Due to the high heat carrier density, using microcapsule phase change material (MPCM) slurry as engine coolant instead of water was presented. To match the engine cooling temperature, a novel microcapsule was prepared based on phase change paraffin with phase transition temperature range of 78–85 °C as core and urea-formaldehyde as resin shell. To improve thermal conductivity of the microcapsule, a composite microcapsule phase change material (CMPCM) was also prepared by inlaying graphene into urea-formaldehyde resin shell. By dispersing microcapsule in water, microcapsule slurries were prepared. To analyze the feasibility in engine cooling system, an experimental study on the flow resistance characteristics of microcapsule slurries in a circular tube was conducted. The pressure drops of slurries for turbulent flow were measured and the effects of such facts as the concentration and flow velocity were discussed. According to the pressure characteristic and latent heat of the slurry, the pumping consumption rates of slurries to water under a given heat transportation quantity can be obtained. The results show that mass flow rate and pumping consumption of slurries decrease greatly compared with water, which indicate that the microcapsule slurries are promising media for engine cooling system.

1. Introduction

With the rapid development of engine performance, developing highly efficiency engines has been a major goal over the last several decades. Engine cooling system is crucial to ensure engine could operate at its optimum temperature [1]. However, conventional coolants such as water and ethylene glycol (EG) which are commonly used in engines, have poor thermal conductivity [2] and low heat carrier density. Methods for increasing the cooling rate have faced certain limitations [3]. To solve this issue, advanced coolants such as nanofluids and phase change material (PCM) slurries can be utilized.

To enhance heat transfer rate of heat removal from the engine, nanoparticles have been dispersed into conventional coolants and their performance has been acknowledged by many researchers [4]. Addition of different particles, such as Al_2O_3 [5], MWCNT [6], TiO_2 [7], CuO [8] and SiO_2 [9] has been suggested as a promising approach in engine cooling system. Although nanofluids have good heat transfer characteristics, their heat carrier density is low because they can only absorb sensible heat with the help of temperature rise at engine working temperature.

Microcapsule slurries which are produced by adding microcapsule particles to the base fluid, exhibit a higher heat carrier density when the particles undergo a phase change transition [10–15]. According to the phase change temperature range, they can be used for many fields, such as air conditioning with the phase change range of 2–7 °C [16], nocturnal radiative cooling and chilled ceiling panels with the melting temperature of around 18 °C [17,18], low-temperature solar heating system with the phase change range of 36–38 °C [19], and so on. However, there is little literature on microcapsule slurry with phase change temperature over 80 °C for engine cooling system. Compared with water and nanofluids, phase change fluids have not only high heat carrier density, but also little temperature difference when phase change occurs, which will keep the cylinder sleeve of engine at constant temperature and avoid hot cracking. In our previous work [20], we proposed an engine cooling system based on water and phase change fluid. Fig. 1 shows the schematic configuration of engine cooling system.

Fig. 1 shows that the engine cooling system retains the cooling water jacket, and the engine cooling media consists of water in cooling water jacket and phase change fluid flowing in the tube which is attached to the outer wall of the cylinder liner. When the cooling tube is stuck on the outer wall of the cylinder liner, the phase change fluid has high heat density which works with

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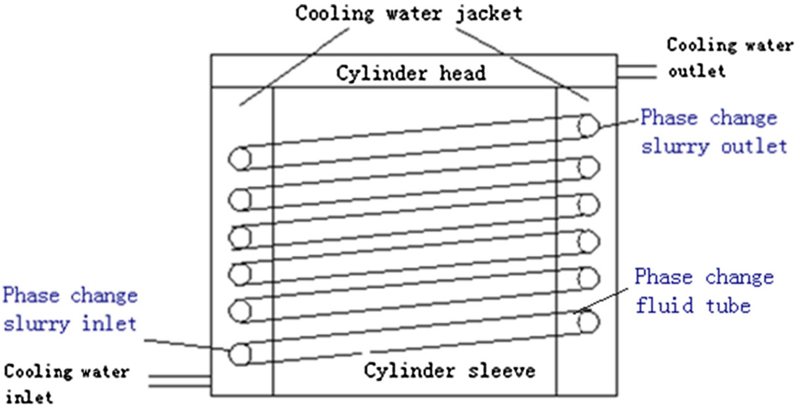

Fig. 1. Engine cooling system based on water and phase change fluid [20].

water, the cooling effect of the engine will be better. Compared with the pure phase change fluid, the phase change fluid particles are prevented from adhering to the wall surface of the engine cylinder liner, thereby affecting the heat transfer of the cylinder liner. So, it can prevent the engine from overheating.

One of the main disadvantages of microcapsule slurry is its low thermal conductivity due to the low thermal conductivity of microcapsule. There are some studies [21–23] aimed at the improvement of thermal conductivity of microcapsules. Moreover, to improve the thermal conductivity of microcapsule slurries, Zhang and Zhao [24] prepared a novel heat transfer fluid, which is water based containing microencapsulated phase change material and multi-walled carbon nano-tubes. It is found that the addition of MWCNTs into microencapsulated phase change material slurry can effectively improve the thermal conductivity of the slurries. Unfortunately, both of these types of advanced coolants increase the necessary pumping power of the system because of their higher viscosity. To estimate the difference in pumping between microcapsule slurry and pure water, pressure drop and pumping power were widely studied [25]. Wang et al. [26] have conducted experiments to investigate the hydrodynamic of a latent thermal fluid, which consisted of water and well dispersed microcapsule particles, flowing in parallel microchannels. It is suggested that microcapsule particles induces much higher pressure drop, with only 1% particle volume fraction, there's an obvious increase of pressure loss due to much larger slurry viscosity. It increases around 1.8 times as that of pure water at Re 500. Hasan [27] has numerically investigated the microcapsules constructed from n-octadecane as a phase change material and the shell material is polymethylmethacrylate. These microcapsules are suspended in water in a concentration of (0–20)%. The results showed that using microcapsule slurries as cooling fluids had improved the thermal performance but it also lead to higher pressure drop. Wang et al. [28] have been experimentally investigated the flow and convective heat transfer behaviors of microcapsule slurries in a horizontal circular tube. The slurry consisted of microencapsulated 1-bromohexadecane ($C_{16}H_{33}Br$) and water. The pressure drop were measured and the results of pressure drop measurements showed a distinct transition when slurry flow change from laminar to turbulent, and the friction factors in turbulent flow fitted well with the classical model based on Hagen–Poiseuille flow. Therefore, there is always a tradeoff between the flow and cooling performance of the cooling systems utilizing advanced coolants [29]. Moreover, there are some discrepancies in the reported findings, especially in the optimum concentration and velocity. If microcapsule slurries are used as coolants in engine cooling system, a number of properties have to be taken into account for evaluating their overall cooling efficiency, namely thermal conductivity, heat carrier density, viscosity and flow resistance characteristics.

In this paper, to match the engine cooling temperature, a novel microcapsule phase change material (MPCM) was prepared based on phase change paraffin with phase transition temperature range of 78–85 °C as core and urea-formaldehyde resin as shell. To improve the heat transfer of the slurries and avoid increasing the viscosity in large caused by adding nanoparticles in slurry directly, a composite microcapsule phase change material (CMPCM) was also prepared by inlaying graphene into urea-formaldehyde resin shell. An experimental study on the flow resistance characteristics of slurries in a horizontal circular tube was conducted. The influence of the temperature, the concentration and the flow rate parameters on the flow resistance and the pumping consumption were analyzed.

2. Experimental

2.1. Sample preparation and physical measurement

The phase change temperature and the latent heat of phase change paraffin were measured by differential scanning calorimeter (DSC). By DSC test, a type of paraffin (commercial grade) was chosen as the core material (Fig. 2).

Fig. 2 shows that the paraffin has the melting peak temperature of 82.5 °C, latent heat of fusion of 196.5 J/g, melting temperature range of 78.2–85.3 °C, freezing peak temperature of 79.5 °C, latent heat of freezing of 195.4 J/g and freezing temperature range of 69.0–82.5 °C. When engine works, the phase change particle can absorb heat and melt flowing in the tube. So, the melting temper-

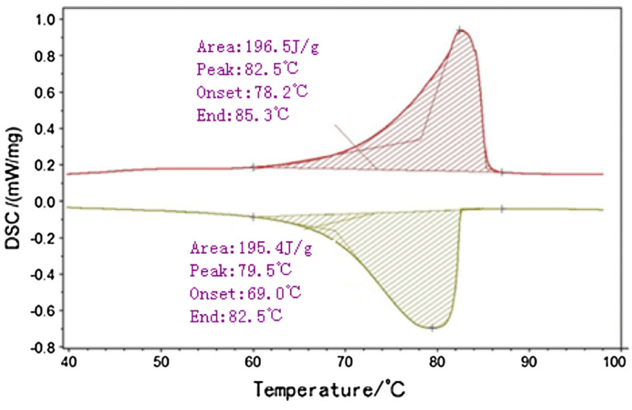

Fig. 2. DSC curve of paraffin.