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Ultrasonication assisted co-dispersion of nanostructured magnesium-lined paraffin wax and magnesium oxide in a heat transfer fluid for energy related applications

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Magnesium-lined paraffin wax nanoparticles were prepared through probe ultrasonication, utilization of Tween 80 as surfactant and ionic interactions. These were co-dispersed with nanostructured magnesium oxide (0.6–2 vol%) in aqueous propylene glycol solution to obtain hybrid nanofluids. Magnesium-lined paraffin wax present in hybrid nanofluids underwent solid-liquid/liquid-solid transition between 45 °C and 62 °C during which thermal energy was absorbed/released, thereby increasing hybrid nanofluids' specific heat. The presence of magnesium oxide contributed to thermal conductivity enhancement of hybrid nanofluids, with a maximum of 20% for the one containing 2 vol% nanostructured magnesium oxide, attributable predominantly to the aggregation of primary nanoparticles as flower-like structure. Our data indicates augmentation of overall heat transfer coefficient with the utilization of hybrid nanofluid.

1. Introduction

Heat transfer fluids are essential for ensuring the performance of systems that deal with energy conversion, storage and generation. For instance, power plants that generate electrical energy from steam produced through utilization of fossil fuel, nuclear fuel or solar thermal energy require spent steam to discard heat to a coolant (heat transfer fluid) in a condenser. Fuel cells and batteries need thermal management systems involving heat transfer fluid and an appropriate heat sink to ensure that the temperature runaway is prevented [1,2]. Hence any improvement in characteristics of heat transfer fluid will influence their performance positively.

Nanofluids have achieved greater attention by virtue of their improved thermal conductivity. Several experimental investigations continue to be reported with respect to benefits of nanofluids such as improvement in thermal conductivity [3–7], reduction in viscosity [8–15], improvement in heat transfer performance [9,11,12,16–24] and solar energy collection [8,19,25–30]. There are number of recent reviews in the area of nanofluids [31–38]. While thermal conductivity and to a relatively lower extent viscosity were provided considerable importance during the formulation of nanofluid compositions, little attention is generally paid to specific heat. While using a heat transfer fluid as the coolant, its specific heat determines the magnitude of temperature rise for a given heat load and subsequently influences the driving force. The dispersion of commonly used nanomaterials such as metals, metal oxides, carbon nanotube, etc. in coolants generally results in reduction of specific heat [39].

The addition of a material that undergoes solid-liquid transition within the range of operating temperature of the heat transfer fluid improves its specific heat. Accordingly, phase change emulsions have been proposed as storage media and as an alternative to liquid coolants [40–43]. While emulsions containing phase change material with dimensions in the micrometer range suffer from poor colloidal stability leading to creaming, those with the dispersed phase in nanometer dimensions can be expected to have better colloidal stability.

When a phase change material and an inorganic material, both with characteristic dimensions in the nanometer are dispersed together in a heat transfer fluid, the specific heat can be augmented due to the former and thermal conductivity can be enhanced due to the later [44]. The presence of charged species on the surface of dispersed organic phase change material may prevent its aggregation.

This manuscript reports the ultrasonication-assisted preparation, characterization and performance of a hybrid nanofluid containing magnesium-lined paraffin wax (in nanoscale dimension) and nanostructured magnesium oxide in propylene glycol-water mixture. Magnesium oxide has lower density [15,17] and is easy to disperse in propylene glycol [15]. Hence magnesium oxide was chosen as the inorganic nanomaterial. Paraffin wax undergoes melting and freezing in the temperature range generally encountered by heat transfer fluid used in flat plate solar collectors. Magnesium lining formed on paraffin wax by self-assembly is aimed to prevent leakage of paraffin wax and improve colloidal stability also. This is the first experimental work on hybrid

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Nomenclature

%pw	Mass percentage of paraffin wax in hybrid nanofluid (%)
c_p	Specific heat (J/kgK)
MOPGNF	MgO-propylene glycol nanofluid
x	Mass fraction (or) mass percentage of paraffin wax (−) or (%)
dT	Temperature interval for phase change
k	Thermal conductivity (W/mK)
μ	Viscosity (cP)
γ	Shear rate (s^{-1})
ϕ	Nanoparticle volume fraction (or) percentage (−) or (%)

Subscripts

m	Melting
pw	Paraffin wax
pws	Surfactant encapsulated paraffin wax
pwm	Magnesium-lined paraffin wax
hnf	Hybrid nanofluids
f	Freezing
MgO	Magnesium Oxide
PGW	Aqueous propylene glycol
r	Ratio

nanofluids containing simultaneous dispersion of metal-lined paraffin wax nanoparticles and nanostructured magnesium oxide in an aqueous solution of propylene glycol. Such hybrid nanofluids can be used as heat transfer fluid for energy related applications. This work is different from our earlier publications on hybrid nanofluids [44,45] in the context of (i) use of different metal oxide nanoparticle (MgO) as against ZnO and sand nanoparticles in earlier publications; (ii) use of metal-lined paraffin wax, as against surfactant encapsulated paraffin wax in earlier publications and (iii) higher thermal conductivity enhancement (20%) with no reduction in specific heat, as against only lower thermal conductivity enhancement without compromising specific heat, in earlier publications.

2. Materials and methods

2.1. Materials

Paraffin wax of solid phase density 900 kg/m^3 and solid phase specific heat 2500 J/kgK was used. Propylene glycol with volumetric specific heat and density of 2.6 MJ/m^3 K and 1040 kg/m^3 respectively, was used.

2.2. Strategy for preparation of hybrid nanofluid

The hybrid nanofluid to be prepared was conceptualized to contain two different nano-dimensional materials in a base fluid with equal volumes of two different polar liquids. One of the nano-dimensional materials is the magnesium-lined paraffin wax nanoparticle, while the other is nanostructured magnesium oxide. For this purpose, a dispersion of magnesium-lined paraffin wax in water, denoted as PWM-water emulsion was prepared. Simultaneously, nanostructured MgO was dispersed in propylene glycol yielding MgO-propylene glycol nanofluid (MOPGNF). Equal volumes of MgO-propylene glycol nanofluid containing ‘2*ϕ’ volume fraction of nanostructured MgO and PWM-water emulsion containing ‘2*x’ mass fraction of paraffin wax were mixed and probe ultrasonicated for appropriate duration to yield hybrid nanofluid (HNF) containing ‘ϕ’ volume fraction of MgO nanoparticles and ‘x’ mass fraction of paraffin wax. The flow diagram for the preparation of hybrid nanofluid is shown in Fig. 1.

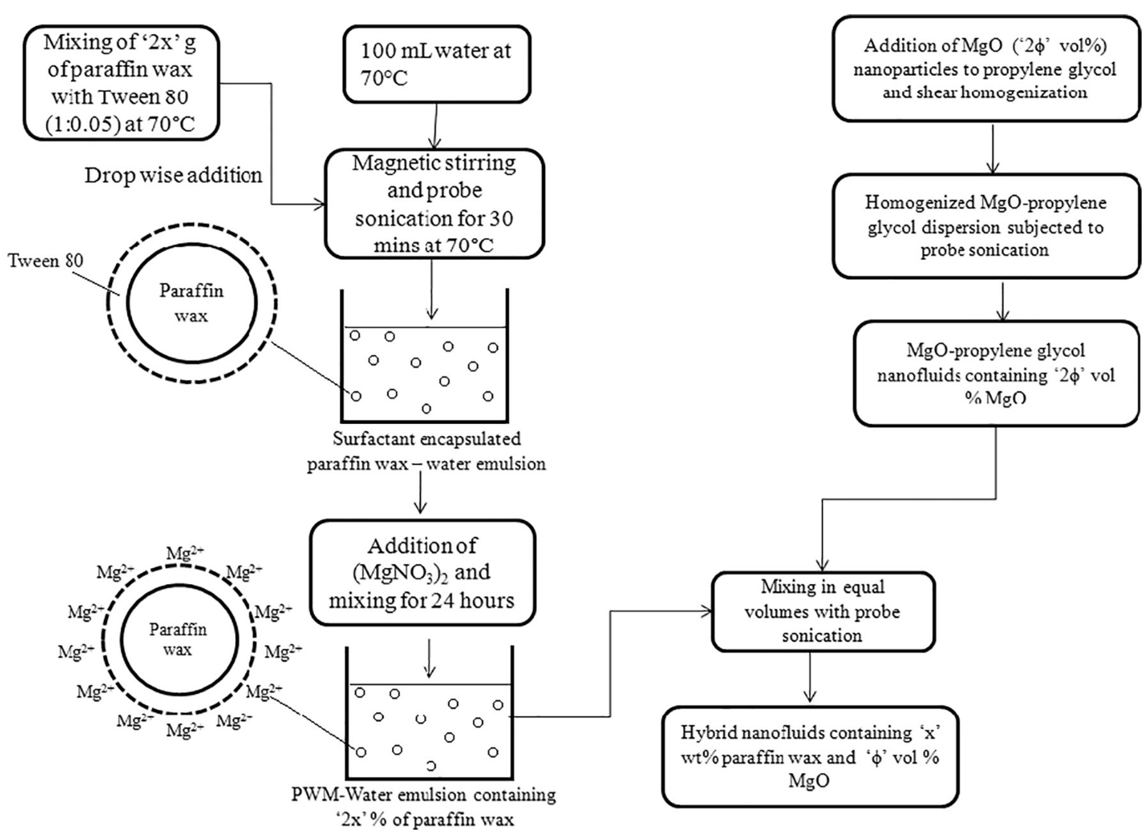

Fig. 1. Flow diagram showing the steps involved in hybrid nanofluid preparation.