



# New hybrid nanofluid containing encapsulated paraffin wax and sand nanoparticles in propylene glycol-water mixture: Potential heat transfer fluid for energy management



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## ABSTRACT

The reduction in specific heat commonly encountered due to the addition of nanoparticles to a heat transfer fluid such as propylene glycol-water mixture, can be overcome by co-dispersing surfactant-encapsulated paraffin wax, leading to formation of a hybrid nanofluid. Experimental investigations have been carried out on the preparation and evaluation of thermophysical properties of a hybrid nanofluid containing pluronic P-123 encapsulated paraffin wax (70–120 nm diameter, 1–5 wt.%) and sand nanoparticles (1 vol%) in propylene glycol-water mixture. The comparison of results of differential scanning calorimetry of pure paraffin wax and encapsulated paraffin wax revealed encapsulation efficiency of 84.4%. The specific heat of hybrid nanofluids monotonously increased with paraffin wax concentration, with 9.1% enhancement in specific heat for hybrid nanofluid containing 5 wt.% paraffin wax, in comparison to propylene glycol-water mixture. There exists an optimum paraffin wax concentration (1 wt.%) for the hybrid nanofluid at which the combination of various thermophysical properties such as specific heat, thermal conductivity and viscosity are favorable for use as heat transfer fluid. Such a hybrid nanofluid can be used as a substitute for propylene glycol-water mixture in solar thermal systems.

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## 1. Introduction

Heat transfer fluids play an important part in energy generation systems. Solar thermal systems rely on the capability of heat transfer fluids to absorb thermal energy in solar concentrators and transfer the same to water for steam generation. The steam generated can be utilized for power generation, process heating, cooking etc. One of the important properties of heat transfer fluid, thermal conductivity, can be improved by dispersion of nanoparticles in heat transfer fluid, leading to nanofluids [1–3]. The thermal conductivity of nanofluid is higher than that of the base fluid in which the nanoparticles are dispersed, which can be attributed to one or more of the mechanisms such as Brownian motion, nanoparticle clustering and liquid layering [4–9]. In some instances, a hybrid of two different nanoparticles is used for the preparation of nanofluids [10]. In the context of energy conversion, nanofluids find application in direct absorption solar collectors [11–15], volu-

metric solar absorption collectors [16], evacuated tube collectors [17] and parabolic trough collectors [18].

Phase change materials (PCM) are widely used in the latent heat thermal energy storage system owing to their higher storage density (energy storage per unit mass of storage material). Phase change materials can be encapsulated to prevent their leakage during repeated melting and freezing cycles leading to microencapsulated and macroencapsulated phase change materials [19–21]. The microencapsulated phase change materials can be mixed with heat transfer fluids resulting in the formation of slurries that can be used as heat transfer fluids. The heat capacities of such slurries containing microencapsulated phase change materials are higher than that of pure liquid and hence have been used for enhancement of convective heat transfer and as thermal storage media [22,23].

The use of nanocapsules rather than microcapsules will improve the dispersion of PCM capsules in the heat transfer fluid. Fang et al. [24,25] initiated research on preparation of nanocapsules containing PCM, following which Li et al. [26], Chen et al. [27] and Zhang et al. [28] prepared nanocapsules with “n-hexadecane core (PCM) & urea formaldehyde resin shell”, “n-dodecanol core (PCM) & Poly(methyl methacrylate) (PMMA) shell” and “n-octadecane core (PCM) & Poly(methyl methacrylate)/

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## Nomenclature

Symbol	Meaning
a, b, c & d	exponents in Eq. (8)
$C_p$	specific heat (J/kg K)
dT	temperature window
Gr	Grashof number
k	thermal conductivity (W/m K)
Mo	Mouromstev number
x	mass fraction of paraffin wax
x'	volume fraction of paraffin wax

### Greek symbols

$\mu$	viscosity (mPa s)
$\eta_e$	encapsulation efficiency

$\eta_r$	encapsulation ratio
$\lambda$	latent heat (J/g)

### Subscripts

ep	encapsulated paraffin wax
p	paraffin wax
PG-W	propylene glycol-water mixture
m	melting
mt	matrix
f	freezing
hnf	hybrid nanofluid
SPGW	sand-propylene glycol-water

poly(ethyl methacrylate) (PEMA/PMMA) shells" respectively. The size of resultant core-shell structures ranged between 100 and 300 nm with good encapsulation efficiency [27–29]. Cingarapu et al. [30] dispersed core-shell nanoparticles containing tin core and silica shell (Sn@SiO<sub>2</sub>) in Therminol 66 and evaluated the thermal conductivity and specific heat of the Sn@SiO<sub>2</sub>-Therminol 66 nanofluid. Thermal conductivity enhancement was inline with the predictions of effective medium theory with 13% enhancement for nanofluids containing 5 vol% of core-shell nanoparticles. The volumetric heat capacity was enhanced by 11% within the temperature window of 100–270 °C [30]. Thus, the dispersion of core-shell nanoparticles with PCM core and inorganic shell in a heat transfer fluid resulted in enhancement of both thermal conductivity and volumetric specific heat.

Puupponen et al. [31] prepared stearic acid-water and paraffin-water emulsion nanofluids using sodium dodecyl sulfate (SDS)/Span 85 mixture and SDS respectively as the surfactants. A shift of 3–4 °C in the temperature at the onset of melting was observed in stearic acid-water and paraffin-water emulsion, in comparison to that of pure stearic acid and paraffin wax. Among the various emulsion nanofluids prepared, the one that contained 3 wt.% paraffin provided the maximum specific heat enhancement of 1%, in comparison to that of pure water.

Mossaz et al. [32] evaluated the performance of un-encapsulated dispersion of 10 wt.% of NaOH/KOH phase change material in Therminol 66 under high temperature convective heat transfer conditions. Though the nanofluids achieved higher heat transfer rate at fixed pumping power, coalescence of salt particles in cold and hot spots and incomplete melting were observed due to the use of un-encapsulated phase change material. This work highlighted the need for the use of encapsulated phase change material.

Barlak et al. [33] have reported the viscosity and thermal conductivity of water and ethylene glycol-based nanofluids containing nanoencapsulated phase change material. For this purpose, the phase change material (n-nonadecane) was used as the core, while polyurethane was used as the shell material [33,34]. The thermal conductivity enhancement was not appreciable at lower particle concentrations. The lower thermal conductivity enhancement could be attributed to the use of low thermal conductivity polymer shell.

Aqueous propylene glycol solution is one of the heat transfer fluids used in solar flat plate collectors. Hence any improvement in thermophysical properties of propylene glycol-water mixture is likely to contribute directly to improvement in solar energy collection. The term 'hybrid nanofluid' can be used to define a stable colloidal dispersion of nanoencapsulated phase change material and nanoparticles in a heat transfer fluid. Such a hybrid nanofluid is expected to possess higher thermal conductivity and higher

specific heat than that of the heat transfer fluid. This manuscript discusses the preparation and thermophysical properties of a hybrid nanofluid containing dispersion of pluronic P-123 encapsulated paraffin wax and sand nanoparticles in propylene glycol-water nanofluid. Sand nanoparticles can be prepared by top-down approach on large scale. It is pertinent to note that very limited studies have been carried out with respect to hybrid nanofluids and there is no prior art on hybrid nanofluids with propylene glycol-water as base fluid. This manuscript is outcome of the authors' attempts to prepare a new hybrid nanofluid based on propylene glycol-water mixture for potential application in solar energy collection.

## 2. Materials and methods

### 2.1. Materials

Paraffin wax, with a melting point range of 58–60 °C, was purchased from Ranbaxy Laboratories Limited, India. Pluronic P-123 was procured from Sigma-Aldrich, USA. Double distilled water was prepared in the laboratory and was used for preparation of aqueous solutions.

### 2.2. Preparation of paraffin wax-water nanoemulsion

Paraffin wax contains a mixture of hydrocarbons and hence is strongly hydrophobic. Therefore, covalent or non-covalent functionalization is required for dispersing the same in water [35]. It is desirable to have dispersed phase in spherical shape to ensure high colloidal stability and hence an appropriate surfactant had to be chosen. Pluronic P-123 is a non-ionic surfactant comprising triblock copolymer of poly(ethylene glycol)-poly(propylene glycol)-poly(ethylene glycol) [36]. Pluronic P-123 is known to form spherical micelles in water and hence is suitable for preparation of paraffin wax nanoemulsion containing dispersed phase in the form of spheres. It is undesirable to utilize higher mass of surfactant, due to its plausible detrimental influence on thermophysical properties. Hence the surfactant loading was maintained within the range of 0.05–1 g/g of paraffin wax. The maximum concentration of paraffin wax in the paraffin wax-water nanoemulsion was fixed at 10 wt.%.

Heated paraffin wax was added to a continuously heated, stirred and ultrasonicated surfactant solution such that the temperature of the mixture was maintained in the range of 70–75 °C. The dispersion was rapidly cooled after ultrasonication for the predetermined duration. The type of ultrasonication (probe/bath) and the duration of ultrasonication were varied to determine the

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