2nd Spanish Fluid Mechanics Conference

SFMC 2023

Barcelona, Spain | 2 - 5 July 2023

2nd SPANISH FLUID MECHANICS CONFERENCE

2nd Spanish Fluid Mechanics Conference

SFMC 2023

Barcelona, Spain
2 - 5 July 2023

A publication of:
International Center for Numerical Methods in Engineering (CIMNE)
Barcelona, Spain

ISBN: 978-84-123222-4-8

Printed by: Artes Gráficas Torres S.L., Huelva 9, 08940 Cornellà de Llobregat, Spain

Microscale and Nanoscale Flows

Multiphase Flows

Use of nanofluids in energy applications

Rosa Mondragón Cazorla[1] and Leonor Hernández López*[1]

[1]Department of Mechanical Engineering and Construction, University Jaume I, SPAIN

Since 1990s, nanofluids (mixtures of liquids and solid nanoparticles with at least one dimension below 100 nm) have received growing attention due to their enhanced thermal and optical properties. In this abstract we briefly discuss some of studies we have developed in the field of nanofluids applied to different energy systems.

INTRODUCTION

The need for energy and more efficient energy systems has grown with the increasing global population and with modern society.

One possible way to improve the performance of energy systems is to harness the enhanced thermal and optical properties of nanofluids. These nanofluids are normal working fluids including small (<100 nm) solid particles. Initially nanofluids were investigated for their potential to improve thermal conductivity. After that, nanofluids were also investigated for their potential to boost other thermal properties such as sensible (specific heat capacity) and latent thermal energy storage or convective heat transfer. The optical properties of base fluids were also found to enhance due to the addition of small quantities of nanoparticles.

The Multiphase Fluids Group (MFG) in Jaume I University have been working since 2009 in the synthesis, characterization and evaluation of the nanofluids performances within different energy applications. Some of the most relevant results are presented hereafter.

THERMAL NANOFLUIDS: HEAT TRANSFER

Improving the thermal properties of the heat transfer fluids (HTF) is a key issue for many applications based in heat transfer. Several nanofluids have been synthesised (via the two-step method) or readjusted from commercially available nanofluids, covering different base fluids (water or thermal oils as Therminol 66, VP1) and nanoparticles (SiO_2, Al_2O_3, CNT, halloysite, Sn). Important variables such as nanoparticle size or concentrations were varied and different relevant properties were evaluated: stability, thermal conductivity, specific heat, viscosity, etc.) [1-6]. Heat transfer coefficients were calculated from the measured experimental values and/or also directly measured in experimental thermal hydraulic loops [2,5-6]. As an example, enhancements up to 20 % in thermal conductivity were measured for an alumina nanofluid (5 v.% concentration) with respect to water [1]. Also, the experimental heat transfer coefficient increased with respect to that of the base fluid (water) on a constant Reynolds number basis, being the enhancements up to 84 % for SiO_2 nanoparticles (5 v.%) at Re = 30000 [2]. For higher temperatures, enhancements up to 9 % at 140 °C in the convective heat transfer coefficient was achieved using a Sn nanofluid (1 wt.%) versus the performance of the pure base fluid (Therminol 66) [6]. These increases can play an important role to improve efficiencies and to cut the costs of many industrial applications that involve heat transfer. However, the increase in viscosity due to the addition of solid nanoparticles was found to play an important role as it significantly increases the pressure drop. Additionally, the colloidal stability of the nanofluids (with time, for high temperatures, for thermal cycling, etc.) is a key issue, so that the nanofluid maintains its properties during its life cycle. In this regard, usually surfactants are required to ensure the good stability of the nanofluids.

THERMAL NANOFLUIDS: THERMAL ENERGY STORAGE (TES)

Molten salts are used in CSP plants as a TES material because of their high operational temperature and stability of up to 500 °C. However, they present relative poor thermal properties and energy storage densities, which can be improved doping the molten salts with nanoparticles (nanosalts). Different nanosalts have been tested varying the base salt (solar salt, Hitec, binay carbonate) and nanoparticles (mainly SiO_2 and Al_2O_3) trying to maximise the sensible heat [7,8]. Increasements in specific heat of 25 % was measured for solar salt with SiO_2 (1 wt.%) [7]. Also the influence of the synthesis method has been analysed [8], suggesting that the method has a great influence to find a good commitment between viscosity and stability.

In order to increase the total thermal storage energy density of molten salts, nanoencapsulated phase change particles (nanoPCM with a core-shell structure) with a latent heat contribution of the nanoparticle core, has also been tested. Self-encapsulated nanoPCM ($Sn@SnO_x$, $Al\text{-}Cu@Al_2O_3$) or with coatings generated by Atomic Layer Deposition ($Sn@Al_2O_3$, $Sn@SiO_2$) have been evaluated [9-12]. Enhancements up to 18% in the total thermal energy storage (sensible + latent) for solar salt with $Al\text{-}Cu@Al_2O_3$ (10 wt.%) [11] were achieved.

The colloidal stability of nanosalts is also a key issue. To be able to evaluate it, a new experimental set-up to measure the particle size distribution of molten salt-based nanofluids at high temperatures by means of Dynamic Light Scattering was developed [9].

SOLAR NANOFLUIDS: DIRECT ABSOPTION SOLAR COLLECTORS (DASC)

In conventional solar collectors, the absorption material is a dark surface that heats up and transfers heat to the HTF. In 1970 the idea of directly exposing the HTF to incident radiation was proposed as an alternative to avoid the thermal losses in conventional collectors. This concept, in which heat is absorbed volumetrically by the working fluid instead of the surface, is known as direct absorption solar collectors (DASC). As commonly used HTFs (water, oils, molten salts, etc.) are transparent in most of the solar spectrum and possess low solar radiation absorption capacity, the use of solar nanofluids (with enhanced optical properties) offers high solar-to-thermal conversion efficiencies. Different solar nanofluids have been evaluated in our labs, using water as base fluid and different nanoparticles (gold and carbon black) in very low concentrations [13-14]. Increments up to 200 % in photothermal efficiencies have been obtained for a water-based carbon nanofluid (33 mg/l) [13].

The combination of nanoparticles that absorb solar radiation and PCM materials that can store energy due to the latent heat, result in materials with a triple function in DASC systems: solar absorption material, HTF and TES. In this regard, hybrid carbon-paraffin/water nanoemulsions have been synthesized to evaluate the enhancement in thermal energy storage density and optical properties with good results [15].

CONCLUSIONS

Different results from nanofluids used as materials for energy systems have been presented, including heat transfer, thermal energy storage and solar energy harvesting. Although promising results have been obtained, several barriers to scale-up remain: stability, pumping power, cost, environmental issues, etc.

* lhernand@uji.es

[1] Mondragón R, Segarra, C., Martínez-Cuenca R, Juliá J.E., Jarque JC (2013) "Experimental characterization and modeling of thermophysical properties of nanofluids at high temperature conditions for heat transfer applications" *Powder Technology*, 249, 516-529

[2] Martínez-Cuenca R, Mondragón R., Hernández L., Segarra C., Jarque J.C., Hibiki T., J.E. Juliá J.E. (2016) "Forced-convective heat-transfer coefficient and pressure drop of water-based nanofluids in a horizontal pipe", *Applied Thermal Engineering*, 98, 841-849

[3] Alberola J.A., Mondragón R., Juliá J.E., Hernández L., Cabedo L. (2014) "Characterization of halloysite-water nanofluid for heat transfer applications" *Applied Clay Science*, 99, 54-61

[4] Gimeno-Furio A., Navarrete N., Mondragon R., Hernandez L., Martinez-Cuenca R., Cabedo L., Enrique Julia J.E. (2017) "Stabilization and characterization of a nanofluid based on a eutectic mixture of diphenyl and diphenyl oxide and carbon nanoparticles under high temperature conditions" *Int. Journal of Heat and Mass Transfer*, 113, 908-913

[5] Gil-Font J., Hatte M.A., Bailey M., Navarrete N., Ventura-Espinosa J., Goulas A., La Zara D., van Ommen J.R., Mondragón R, Hernández L. (2020) "Improving heat transfer of stabilised thermal oil-based tin nanofluids using biosurfactant and molecular layer deposition" *Applied Thermal Engineering*, 178, 115559

[6] Gil-Font J., Navarrete N., Cervantes E., Mondragón R., Torró S.F., Martínez-Cuenca R., Hernández L.(2022) "Convective heat transfer performance of thermal oil-based nanofluids in a high-temperature thermohydraulic loop". *Int. Journal of Thermal Sciences*, 171,107243

[7] Andreu-Cabedo, P., Mondragon, R., Hernandez, L. et al. (2014) "Increment of specific heat capacity of solar salt with SiO2 nanoparticles" *Nanoscale Res Lett* 9, 582

[8] Navarrete N., Hernández L, Vela A., Mondragón R. (2020) "Influence of the production method on the thermophysical properties of high temperature molten salt-based nanofluids" *Journal of Molecular Liquids*, 302, 112570

[9] Navarrete N., Gimeno-Furió A., Joep Forner-Escrig J., Juliá J.E., Mondragón R. (2019) "Colloidal stability of molten salt –based nanofluids: Dynamic Light Scattering tests at high temperature conditions" *Powder Technology*, 352, 1-10

[10] Navarrete N., La Zara D., Goulas A., Valdesueiro D., Hernández L., van Ommen J.R., Mondragón R. (2020) "Improved thermal energy storage of nanoencapsulated phase change materials by atomic layer deposition" *Solar Energy Materials and Solar Cells*, 206,10322

[11] Navarrete N., Mondragón R., Wen D., Navarro M.E., Ding Y, Juliá J.E. (2019) "Thermal energy storage of molten salt –based nanofluid containing nano-encapsulated metal alloy phase change materials", *Energy*, 167, 912-920

[12] Navarrete, N., Gimeno-Furio, A., Mondragon, R. et al. (2017) "Nanofluid based on self-nanoencapsulated metal/metal alloys phase change materials with tuneable crystallisation temperature". Sci Rep 7, 17580

[13] Gimeno-Furió A., Martínez-Cuenca R., Mondragón R., Vela Gasulla A.F., Doñate-Buendía C., Mínguez-Vega G., Hernández L. (2020) "Optical characterisation and photothermal conversion efficiency of a water-based carbon nanofluid for direct solar absorption applications" *Energy*, 212,118763

[14] Burgos J., Mondragón R., Begum Elcioglu E., Fabregat-Santiago F., Hernández L. (2022) "Experimental Characterization and Statistical Analysis of Water-Based Gold Nanofluids for Solar Applications: Optical Properties and Photothermal Conversion Efficiency" *RRL Solar*, 6,7, 2200104

[15] Burgos J., Ayora-Fernández M., Mondragón R., Nithiyanantham U., Fabregat-Santiago F., Hernández L., (2022) "Characterization of hybrid carbon - paraffin/water nanoemulsions for DASC: stability, thermal energy storage and optical properties" IMPRES. Barcelona, pp. 115–116