

NANOUP TAKE COST ACTION (CA15119)

Overcoming Barriers to Nanofluids Market Uptake

4th Working Groups Meetings

Workshop on Nanofluids in Energy Systems

Strategic Workshop

BOOK of ABSTRACTS

28-29 May 2018
Napoli
Italy



Edited by

Leonor Hernández López & Oronzio Manca



V: Università
degli Studi
della Campania
Luigi Vanvitelli

Scuola Politecnica e
delle Scienze di Base
Dipartimento di Ingegneria

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Event #3

4th Working Group Meetings

Workshop on Nanofluids in Energy Systems Strategic Workshop

28-29 May 2018, Napoli, Italy

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NANOUP TAKE COST ACTION (CA15119)

Overcoming Barriers to Nanofluids Market Uptake

4rd Working Group Meetings

Workshop on Nanofluids in Energy Systems Strategic Workshop

28-29 May 2018, Napoli, Italy

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May 28th 2018			
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11:10 - 11:20	1, 3, 4	Agresti, Filippo	HNO ₃ oxidation of Single Wall Carbon Nanohorns for the production of surfactant free black nanofluids
11:20 - 11:30	1	Carlos A. Nieto de Castro	Thermal Conductivity of Ionic Melts and Nanofluids - Where we are
11:30 - 11:40	1	Manca, Oronzio	Heat transfer enhancement by impinging slot jets with nanofluids in channels with and without metal foams
11:40 - 11:50	3	Navarrete, Nuria	Characterization Of Nano-Encapsulated Metal Alloy Phase Change Materials For A Molten Salt-Based Nanofluid
11:50 - 12:00	3	Udayashankar, Nithiyantham	Corrosion properties of nanofluids based on molten nitrate salts for thermal energy storage applications
12:00 - 12:10	3	Barison, Simona	Design and Characterization of Phase Change Material Nanoemulsions as Thermal Energy Storage and Transport Media
12:10 - 12:20	3	Marcos, Marco A.	Gold-silica core-shell nanoparticle dispersions in PEG400 as stable phase change materials for thermal energy storage
12:20 - 12:30	3	Awad, Afrah	Heat transfer study of nanosalt for solar energy storage
12:30 - 12:40	3	Farber, Peter	Progress Report about Two-phase CFD Simulations of a Heat Storage Device with Nanofluid
12:40 - 12:50	3	Iglesias, Jose	Thermal performance of organic phase change material in the presence of graphene nanoplatelets.
12:50 - 13:00	3	Valdesueiro, David	Tailoring the properties of Nanoparticles by ALD Nanocoatings
13:00 - 13:10	2	Timko, Milan	Thermomagnetic properties of magnetic nanofluids and hybrid nanofluids
13:10 - 13:30		Open discussion	WG1 and WG3

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15:10 - 15:20	2	Vallejo, Javier P.	Heat transfer efficiency in a double pipe heat exchanger of functionalized graphene nanoplatelets/glycolated water nanofluids
15:20 - 15:30	2	Antonis, Sergis	Isothermal analysis of Nanofluid Flow inside HyperVaportrons using Particle Image Velocimetry
15:30 - 15:40	2, 3, 4	García, Fran	Analysis of the Thermal Signature of Wind-turbine Generators: implications for their main Operative Parameters and future application of nanofluids
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16:40 - 16:50	4	Çetin, Levent	A Proposal for Thermal Conductivity Measurements of Magnetic Nanofluids Under the Influence of External Magnetic Field
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17:00 - 17:10	4	Mancin, Simone	THE EFFECT OF OXIDIZED CARBON NANOHORN NANOFLUID POOL BOILING ON AN ALUMINUM SURFACE
17:10 - 17:20	4	Tibaut, Jan	Numerical simulation of a nanofluid in a pipe flow
17:20 - 17:30	4	Martínez, Raúl	CFD modelling of volumetric vapour generation and its applications to the receiver design
17:30 - 17:40	4	S. Kassavetis	Plasmonic Nanofluids for Solar Cells Applications
17:40 - 17:50	4	Nardini, Sergio	Performance evaluation of a solar cooling system with nanofluids
17:50 - 18:00	4	Navas, Javier	Towards highly stable nanofluids for Concentrating Solar Power
18:00 - 18:10	4	Buschmann, Matthias	Round robin test for surface tension and contact angle of nanofluids
18:10 - 18:30	Open discussion		WG3 and WG4

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May 29th 2018

09:30 – 10:30

Key note lecture. Modelling and experimental study of nanofluids: Challenges and perspectives with a focus on energy applications. Annalisa Cardellini, Ph.D. Politecnico di Torino

10:30 – 11:00

Coffee break

11:00 – 13:00

Strategic Workshop open for all participants

- **Reports from each WG**
- **Dissemination, STSM, TS for the 3rd Grant Period**
- **Possible new joined articles or proposals**
- **12:00- 12: 30 H2020 future calls for nanofluids
Dr. Martina De Sole (APRE)**
- **Keeping the network alive after Nanouptake**

13:00 – 14:30

Lunch break

14:30 – 16:00

Management Committee Meeting

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KEYNOTE LECTURE

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Overcoming Barriers to Nanofluids Market Uptake

Modelling and experimental study of nanofluids: Challenges and perspectives with a focus on energy applications

Annalisa Cardellini¹, Matteo Alberghini¹, Matteo Fasano¹, Matteo Morciano¹, Ali Khodayari¹, Eliodoro Chiavazzo^{1*}, Pietro Asinari^{1*}
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Keywords: nanofluids, multi-scale modelling, thermal properties, solar energy, water

In this lecture, we first present a comprehensive, multi-scale modelling approach to predict the macroscopic thermal transport properties of nanofluids. To our knowledge, this represents the first bottom-up attempt in inferring the nanofluid properties systematically starting from fundamental principles (molecular dynamics). It follows a novel coarse-grained model, which was developed to understand how nanoscale interfacial phenomena affect the mechanism of nanoparticle interactions, clustering, and stabilization. Moreover, by coupling the computed nanoparticle (NP) cluster distribution with a theoretical continuum model, we could evaluate some thermal transport properties of NP suspensions in aqueous solution. Importantly, a subsequent validation of the results with both experimental and previous theoretical models highlights the potential of the current model in the design of nano-colloidal suspensions. Despite the actual computational efforts involved, the present multi-scale thermal approach may contribute to a systematic translation of nanofluid technology from lab experiments to large-scale industrial production and commercialization.

The study of nanofluids is then carried out experimentally. An original and biocompatible nanofluid is optically characterized and tested to be employed for the direct thermal solar energy collection, showing advantages in terms of efficiency as compared to traditional solutions. Specifically, a lab scale prototype is designed to assess the properties of the nanofluid as volumetric solar receiver. The efficiency of the prototype is evaluated both under solar simulator and in-field, and a suitable comparison with a conventional set-up shows an enhancement of the energy performances of the nanofluid-based volumetric receiver.

Finally, we will show the application of titania (TiO₂) based micro-suspensions for municipal water treatment. Here the suspension exploits the UV part of sunlight spectrum to drastically reduce the bacteria content in the treated water. Performances of both conventional (homogeneously distributed particles) and unconventional (heterogeneously distributed particles) suspensions will be discussed and compared on the basis of treated water productivity and quality.

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ABSTRACTS WORKING GROUP 1

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Overcoming Barriers to Nanofluids Market Uptake

Effect of SiO₂ nanoparticles on the internal structure of molten Solar Salt.

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Keywords: Solar Salt, Contact Angle, SiO₂, DLS, Structure

INTRODUCTION:

In this work the internal structure of Solar Salt (SS) – SiO₂ nanofluids is investigated. A series of contact angle (CA) measurements were conducted to investigate the effect of nanoparticles on the wettability of the SS and hence the surface energy of the material. In order to explain the results of the CA measurements, Dynamic Laser Scattering (DLS) equipment was used to study the agglomeration rate with respect to temperature and time.

METHODS:

The Solar Salt (60% NaNO₃ – 40% KNO₃) was mixed and sonicated with 1% amorphous SiO₂ particles. After drying, the material was scrapped and milled.

All samples were ensured to be of the same weight and were compressed at same rates. In this way drop dimension and heterogeneity related effects were minimized. The samples were tested on an Al₂O₃ {0 0 0 1} substrate (30mmx30mmx10mm), with a roughness of S=0.364µm.

RESULTS AND CONCLUSIONS:

Experiments were performed on the CA of SS with concentration of 0%, 0.5%, 1.0%, 1.5% and 2.5% SiO₂.

In the case of the base salt the CA is linearly reduced with an increase in temperature, which is what commonly occurs. However, with the presence of silica the CA appears to remain stable up until the temperature of 310°C. At that point there is a large drop in the CA, followed by a second drop at 330-340°C. After that the CA of the nanofluid retain similar values to the base case. 310°C is the melting point of sodium nitrate (NaNO₃). Therefore, the fact that there is a rapid CA drop, indicates some internal skeleton collapse. Probably, the nanoparticles formulate a certain internal matrix that is affected by the melting of the NaNO₃. Similarly 334°C is the melting point of potassium nitrate (KNO₃), which has a similar effect on the CA.

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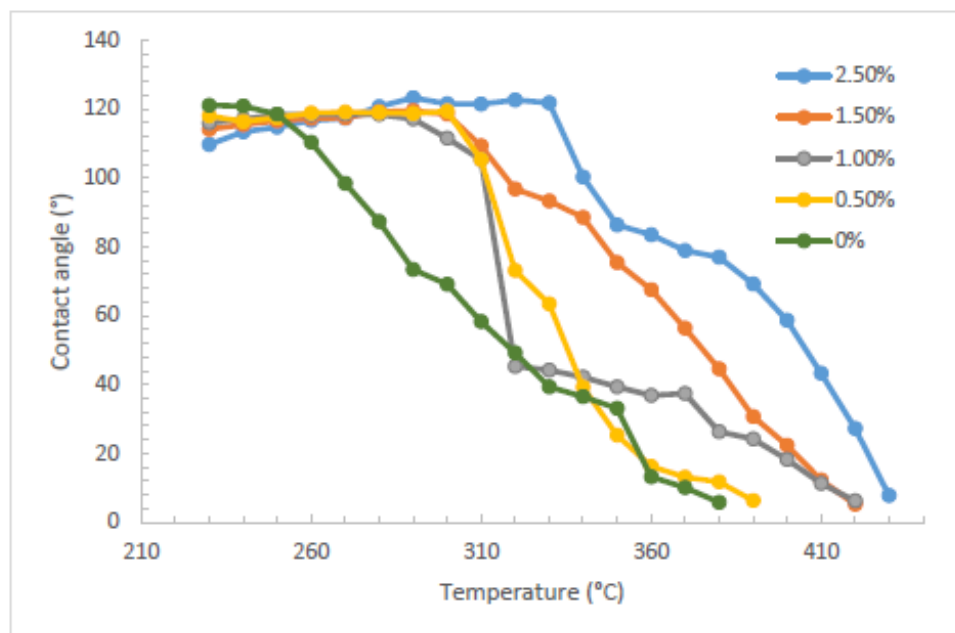


Figure 1: CA measurements of SS-SiO₂ on Al₂O₃

To further validate this effect DLS measurements were conducted with respect to time and temperature. To better evaluate the effect of time and temperature the sample was first heated up at 250°C where measurements were taken every 30min until the mean nanoparticle diameter was stable for 2 consequent values. These measurements were conducted 3 times and led to an average nanoparticle diameter of 205 nm at the start of the experiment, 485nm after 30min, 863nm after 1h, 1065nm at 1:30h and 1082nm at 2h. After 2 hours the sample was heated up to 350°C in order to evaluate the effect of temperature on the agglomeration. The resulting measurements showed that the average mean diameter was above 3000nm. Certain measurements provided no results as the diameter was <10000nm. To identify if this effect was gradual, measurements were taken after waiting at 290°C, 310°C 330°C and 340°C. The resulting diameters were 1103nm, 1169nm, 853nm and 3329nm respectively. It was deduced that agglomeration is largely increased between 330°C to 340°C confirming CA observations. To further strengthen this observation experiments were started at 270°C, 290C and 310°C. Results provided patterns almost identical to the experiments started at 250°C.

In conclusion, there is an internal structure change in the SS-SiO₂, nanofluid between 310C and 340C, which leads to high agglomeration of SiO₂ nanoparticles past this point. This effect is independent of time and is related to the temperature. It is hypothesized, since 310C is the melting point of NaNO₃ and 334C the melting point of KNO₃, that nanoparticle agglomeration affects the formulation of eutectic mixtures.

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Wetting of NaNO_3 on MgO , NaNO_3 - SiO_2 nanofluid. Thermal Energy storage through Molecular Dynamic Simulations.

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Keywords: NaNO_3 , MgO , SiO_2 , molecular, simulations

INTRODUCTION:

Molecular dynamic (MD) simulations is a trending tool used to effectively calculate and validate properties in the nanoscale and subsequently interpret macroscopical phenomena. Wetting behavior plays an important role in the formulation of composite materials. The contact angle (CA), is the most frequently quoted property, used to describe the wetting between materials. Molten salt based nanofluids are of special interest, due to the increments reported in both thermal conductivity and heat capacity as well as for its practical application in Thermal Energy Storage systems. The physical phenomena involved in the thermal properties increment is still a source of controversy. In this work interactions of thermal energy storage materials is investigated through MD simulations.

METHODS:

The Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) software was used to perform a series of MD simulations on the CA and surface tension of NaNO_3 on MgO , as well as on the thermal conductivity of the NaNO_3 - SiO_2 nanofluid. The Lennard-Jones interatomic potential was used to calculate the interactions between atoms. A set of parameters was specifically formulated for the purpose of this work.

To validate the formulated interatomic potential, thermal conductivity, viscosity, specific heat capacity, density and surface tension were all calculated and compared with experiments.

A quenching procedure was applied to obtain the structure of molten NaNO_3 . The crystalline cell structure of NaNO_3 was replicated, leading to a periodic dimension boundary box containing 5040atoms. The salt was heated up to 1200K in the NVT ensemble, followed by a rapid cooling process in the NPT ensemble from 1200K to 593.15K and ending with an equilibration process in the NVT ensemble at 593.15K.

For the formulation of the silica nanoparticle a similar process was followed. Upon obtaining the structure of amorphous silica, a 1nm particle was extracted from the bulk and placed in the center of the box containing molten salt atoms.

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RESULTS AND CONCLUSIONS:

The CA of NaNO_3 on MgO has been calculated at temperature intervals of 10K. The agreement with experimental data is excellent. The model predicts accurately the wetting process of molten NaNO_3 on MgO . Since, both surface tension and CA data were calculated throughout these simulations the work of adhesion was also computed from the Young-Durpe equation. It was found that the work of adhesion is over appreciated, due to a base deviation of the surface tension values for molten NaNO_3 from experimental results. However, since the trend of the values is guided by the change in the CA the results had a similar trend with the experimental ones, proving that the force in the contact line can be computed from the Young-Durpe equation, also in the nanoscale for the case of ionic liquids. Validity of this equation has been observed also for the case of water.

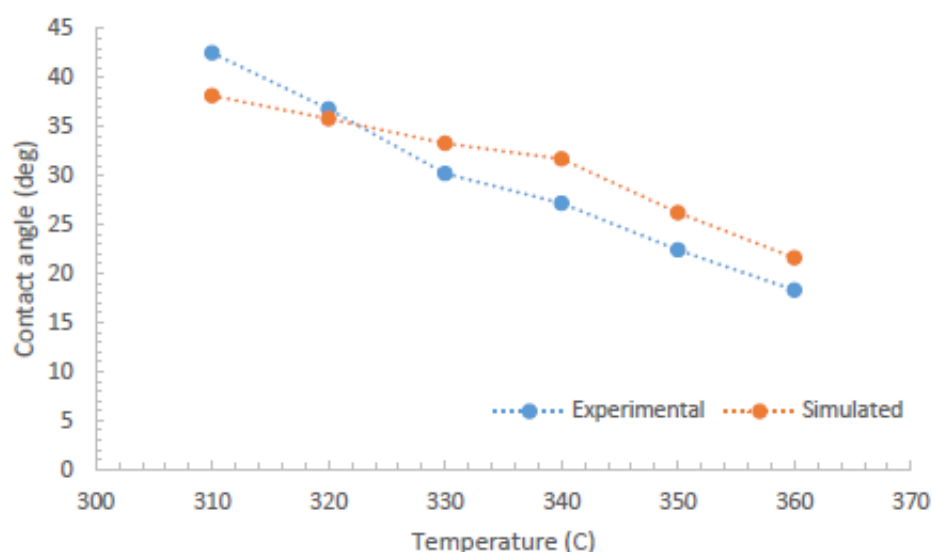


Figure 1: Contact angle of NaNO_3 on MgO , comparison with experimental data

In terms of the molten salt nanofluid simulation, the thermal conductivity was calculated for the case of the 0.5% and 1.0% SiO_2 and was found to be 0.97 (W/mK) and 1.13 (W/mK) compared to 0.78 (W/mK) and 0.832 (W/mK) obtained from experimental values. This amount of deviation is considered satisfactory for MD simulations. Furthermore, the trajectory of the atoms at the nanoparticle-salt interface was visualized. It was observed that in the initial steps of the simulations the salt atoms attach themselves to the surface of the nanoparticle and create a solid-like structure. As the nanoparticle moves throughout the simulation these particles remain attached to the surface creating a layer of a thickness of 0.5nm for a 1nm simulated nanoparticle. The formulation of this layer was linked to the van der Waals forces between salt and silica atoms being stronger than those between the salt atoms.

Further studies are necessary, to evaluate the effect of the nanoparticle diameter on the thermal properties, and the identification of the reasons behind the plateau in enhancement.

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HNO₃ oxidation of Single Wall Carbon Nanohorns for the production of surfactant free black nanofluids

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Keywords: Single Wall Carbon Nanohorns, oxidation, stability, black nanofluids

INTRODUCTION: Single wall Carbon Nanohorns (SWCNHs), tiny graphene sheets wrapped to form horn-shaped cones with a half-fullerene cap, having 30–50 nm length and 2–5 nm diameter, are not easily dispersible in water due to the hydrophobic nature of their surface, as other graphene-based materials [1]. Thus, surfactants are generally used to achieve a sufficient nanofluid stability [2]. Despite the abundant use of surfactants for nanofluid stabilization, they have some drawbacks like formation of foam, chemical interaction in covalent functionalization, degradation in extreme conditions, easy desorption from the surface to cite some [3-4], with consequent destabilization of the suspension.

In this work, we exploited the partial surface oxidation of SWCNHs as a clean and strategical tool to achieve stable suspensions in water without the need of surfactants.

METHODS: In order to get stable suspensions in water of SWCNHs without surfactants, a surface oxidation by using concentrated HNO₃ was performed. 0.05 g SWCNH were poured into 25 mL HNO₃. Four samples were prepared by stirring the suspension at different temperatures (50 – 80 °C) and for different times (1 – 4 h) in order to investigate different degrees of surface oxidation. The processed powders were then separated from HNO₃ by paper filtering and thoroughly washed with deionized water until the filtrate reached a neutral pH. Finally, the powders were washed with 100 mL ethanol and dried in air at 120 °C for 2 h.

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Suspensions of oxidized SWCNHs were prepared at the concentration of 0.05 g/L by pouring 0.0125 g of each powder in 250 mL deionized water in two steps: (a) sonication for 10 min using a Sonics VCX130 (Sonics & Materials, Inc.) operating at 20 kHz and 65 W, equipped with a 12 mm tip, in order to get a pre-disaggregation of nanopowders; (b) processing the sonicated suspensions for 15 min with a high-pressure homogenizer (Panda, GEA Niro Soavi), operated at 1000 bar. For comparison, a reference nanofluid was prepared by using the non-oxidized pristine powder of SWCNHs. Since no stable colloid can be obtained using the pristine powder "as it is", a surfactant solution of Sodium Dodecyl Sulfate (SDS) at the concentration of 0.005 g/L was used as a dispersing media. The surface damage and oxidation degree of SWCNHs were evaluated by SEM microscopy, Thermogravimetric Analysis, Residual Gas Analysis, XPS and UV-visible spectroscopy. Moreover, the carboxylation influence on suspension stability was evaluated by Dynamic Light Scattering and ζ -potential measurements.

RESULTS AND CONCLUSIONS: TGA and RGA measurements showed that increasing time and temperature of treatment leads to the formation of functional groups, like carbonyl or carboxyl, which decompose by the release of water and CO₂. SEM micrographs confirmed that the oxidation process partially damages the peculiar structure and morphology of SWCNH aggregates, which is also confirmed by UV-Vis measurements showing the reduction of the interband π plasmon peak (π - π^* transition) at about 260 nm, related to the graphene-like structure. Anyway, we demonstrated that the oxidation route can be optimized in order to maximize the carboxylic presence, as detected by XPS, and the nanofluid stability, at the same time reducing the material damage, so minimizing the influence of a mild oxidation on functional features, like optical and spectral properties. This method led to stable nanofluids of these important carbon nanostructures by avoiding the use of surfactants, thus opening to new potential applications of water-based colloids.

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Overcoming Barriers to Nanofluids Market Uptake

Thermal conductivity of aqueous iron oxides nanofluids

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Keywords: nanofluids, thermal conductivity, magnetite, maghemite, goethite, ferrihydrite

INTRODUCTION:

There are more than 20 iron oxides, oxo-hydroxide and hydroxide, which differ in structure, chemical and physical properties. For example, magnetite, maghemite, hematite and ferrihydrite are ferromagnetic; lepidocrocite and akaganeite are paramagnetic while goethite is antiferromagnetic at room temperature. The magnetic properties of iron oxides also depend on particle size. The most common example is magnetite which became superparamagnetic at sizes below 15 nm [1]. Under optimum conditions (medium, pH, pressure, temperature), most of them can be converted to another iron oxide [1]. Hematite and goethite are the most stable iron oxides, representing often the end products of the polymorphs transformation. Iron oxide nanoparticles find applications in targeted drug delivery, biosensors, magnetic hyperthermia, contrast agents in magnetic resonance imaging (MRI), magnetic storage media, magnetic ink and many other [2]. Using of iron oxides in nanofluids for heat exchange system are usually limited to magnetite and maghemite. In this study, the thermal conductivity of four aqueous iron oxides (magnetite, maghemite, goethite and ferrihydrite) nanofluids were determined.

METHODS:

Iron(III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), iron(II) chloride tetrahydrate ($\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$), Iron(III) nitrate nonahydrate ($\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$) and sodium hydroxide (NaOH) were purchased from Sigma-Aldrich and used as received.

Thermal conductivity study was performed at room temperature and 50 °C on KD2Pro (Decagon Devices) using the transient hot wire technique. The hydrodynamic size of nanoparticles was determined using the dynamic light scattering (DLS) technique using a Zetasizer Nano ZS (Malvern Instruments Ltd.).

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RESULTS AND CONCLUSIONS:

Iron oxide nanoparticles can be prepared using various methods such as thermal decomposition, sol-gel, microwave irradiation, calcination, hydrothermal method and others [3]. In the present work, precipitation in strong alkaline medium was chosen as preparation method for magnetite, maghemite, goethite and ferrihydrite nanoparticles due to its reproducibility, scalability and the quality of prepared nanoparticles. The structure of iron oxides was confirmed using Raman spectroscopy and wide-angle X-ray diffraction, while the morphology was studied using transmission electron microscopy. Thus, magnetite and maghemite nanoparticles are spherical with some irregularities and the size of about 7 and respectively 8 nm, ferrihydrite have irregular shape and the goethite was found to be rod-like particles of about 85 nm in width. In the next step, the iron oxide nanoparticles were used to prepare aqueous nanofluids. In order to obtain stable nanofluids, the aqueous dispersions of iron oxides were ultrasonicated. The hydrodynamic size of nanoparticles was studied using dynamic light scattering. It was found that initially the aqueous maghemite nanofluids consist of aggregates of 141 and 1181 nm. After three minutes of ultrasonication, the aggregate size decreased to 107 and 1063 nm, while after five minutes these became even smaller, dropping at 37 nm and 157 nm. By ultrasonication for longer time, the hydrodynamic size of nanoparticles didn't change significantly. Therefore, before analysing, all the samples were ultrasonicated for five minutes. The aqueous nanofluids were prepared using 10 g/L of magnetite, maghemite or ferrihydrite nanoparticles. Because at this concentration the goethite fluid was unstable, lower concentration, 1 g/L, was used for this iron oxide species.

The thermal conductivity of the prepared aqueous iron oxide nanofluids was measured at room temperature and 50 °C. At room temperature the thermal conductivity was 0.610 W/mk for pure water increasing to 0.642, 0.649, 0.649 and 0.658 W/mk in the case of ferrihydrite nanofluids (10 g/l), magnetite (10 g/l), maghemite (10 g/l) and goethite (1 g/l), respectively. At 50 °C, the difference between thermal conductivity of pure water (0.644 W/mk) and those of nanofluids was lower: 0.651, 0.659, 0.659 and 0.662 W/mk for ferrihydrite, magnetite, maghemite and goethite nanofluids, respectively. Also, the thermal conductivity dependence on the magnesium concentration of aqueous nanofluids was studied. As expected, increasing the concentration of nanoparticles in nanofluids leads to an increase in thermal conductivity from 0.643 at 1 g/l to 0.649 at 10 g/l. Thus, aqueous goethite nanofluids, even at the lowest concentration, have the highest thermal conductivity of the four studied oxides nanofluids.

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Overcoming Barriers to Nanofluids Market Uptake

Thermal Conductivity of Ionic Melts and Nanofluids - Where we are.

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Keywords: ionic melts, nanofluids, thermal conductivity

INTRODUCTION: Thermal conductivity has been proved to be one of the most difficult properties of materials to be measured with high accuracy. This fact is due to the different molecular mechanisms of heat transfer in solids, liquids and gases, with neutral or ionic media, and to the difficulties in isolation of pure conduction from other mechanisms of heat transfer, like convection and radiation, a fact that arises from the contradictory requirement of imposing a temperature gradient on the fluid while preventing its motion. Its accurate measurement in fluids has been a very successful task since the late 70's, due to the efforts of several schools in Europe, Japan and United States. However, the application of the most accurate techniques to several systems with technological importance, like ionic liquids, nanofluids and molten salts, has not been made in the last ten years in a correct fashion, generating highly inaccurate data, which do not reflect the real physical situation. It is the purpose of this paper to review critically the best available techniques for the measurement of thermal conductivity of fluids, with special emphasis in transient methods and their application to ionic liquids, nanofluids and molten salts.

GENERAL EQUATIONS: For isotropic fluids, the thermal conductivity is defined by the Fourier's law, and depends on the thermodynamic state of the fluid prior to the perturbation, and must be related with a reference state, not necessarily equal to the initial one [1]:

$$\mathbf{q} = -\lambda \nabla T \quad (1)$$

where \mathbf{q} is the instantaneous flux of heat, the response of the medium to the instantaneous temperature gradient ∇T , and λ the thermal conductivity of the medium. As it is impossible to measure local fluxes and local gradients Fourier equation cannot be used directly, and the energy equation has to be adapted to a given geometry. The equation of energy conservation in the system is the basis for the formulation of the working equation of any method of measurement. The equation of change for non-isothermal systems can be found on the excellent book by Bird, Stuart and Lightfoot [2], which written for unit mass is:

$$\rho \frac{DU}{Dt} = -(\nabla \cdot \mathbf{q}) - P(\nabla \cdot \mathbf{v}) - (\boldsymbol{\tau} : \nabla \mathbf{v}) \quad (2)$$

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where ρ is the fluid density, U is the internal energy, t the time, P the hydrostatic pressure, v the hydrodynamic velocity of the fluid and τ the stress tensor. This equation does not include nuclear, radiative, electromagnetical or chemical terms for energy. In addition it is applicable to Newtonian fluids. The notation D/Dt represents the substantial derivative, meaning that the time rate of change is reported as one move with the fluid. If the sample is not moving (solid or stationary fluid, no convection), the properties of the sample do not vary with temperature (small temperature gradients) and using Fourier law (Equation (1)), this last equation can be transformed to:

$$\rho C_p \frac{\partial T}{\partial t} = \lambda \nabla^2 T \quad (3)$$

where ∇^2 is the symbol for the Laplacian. It is important to recognize that transport of energy by radiation is always present, and must be corrected for each measuring technique, especially if measurements are performed at high temperatures. Equation (3) is the basis of all experimental methods for the measurement of thermal conductivity.

A variety of experimental methods have been developed, for gaseous, liquid, supercritical or solid phases, over wide range of thermodynamic states. These methods are based on the simplified energy equation (1) and can be classified in two main categories [1, 3-4]:

- Unsteady state or transient methods, in which the full equation (4) is used and the principal measurement is the temporal history of the fluid temperature (transient hot-wire, transient hot-strip, the interferometric technique adapted to states near the critical point etc.);
- Steady state methods, for which $\partial T/\partial t=0$ and the equation reduces to $\nabla^2 T=0$, which can be integrated for a given geometry (parallel plates, concentric cylinders, etc.).

CONCLUSIONS: The use of methods of measurement today, uses and abuses of the previous equations. Examples will be given on the problems that arise to measure accurately the thermal conductivity of ionic melts, its nanosalts, and nanofluids in general, and how NANOUP TAKE can contribute to the production of accurate data, necessary for the design of industrial applications.

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Overcoming Barriers to Nanofluids Market Uptake

Heat transfer enhancement by impinging slot jets with nanofluids in channels with and without metal foams

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Keywords: Heat Transfer Enhancement, Impinging Slot Jet, Channels, Metal foam, Numerical simulation.

INTRODUCTION: The analysis of impinging jets is fundamental due to its strong impact in heat enhancement and its combination with other heat enhancement methods can determine very efficient systems in heat transfer removal and control [1]. Moreover, the simultaneous application of nanofluids and porous media allows to realize the heat transfer enhancement in thermal systems [2]. Configurations with slot jets have recently attracted more attention because of their cooling effectiveness, uniformity and controllability, as demanded by modern electronic equipment, featured by increasing heat flux and decreasing dimensions [3]. Different fluids could be selected in order to work with impinging jets. Additives in the working fluids can be considered in order to improve the thermal properties, like nanoparticles added to pure liquids. Such fluids are called nanofluids and they are made by a base fluid with dispersed nanosize structures. In this work a configuration, representing a confined and submerged slot jet impinging in a channel with or without metal foam on a moving or stationary target surface, heated at constant uniform temperature. The aim consists into the evaluation of the differences among four configurations of impinging slot jet with water/ Al_2O_3 nanofluids in a channel with: stationary target surface (1) without or (2) with foam and moving target surface (3) without and (4) with foam. Moreover, the jet can also be inclined with an angle equal to 30° .

METHODS: A two-dimensional confined slot-jet impinging normally in an aluminum foam on a stationary or moving target surface at uniform assigned temperature, and working with water/ Al_2O_3 nanofluids is studied numerically. The impinging jet is featured by a width, W , and a distance between the nozzle, H , while L denoted the target surface length. H/W is equal to 4 ($H=24.8$ mm and $W=6.2$ mm) as reported in Fig. 1. The target velocity is 0.2 times the uniform velocity of the fluid at the inlet section (the slot jet). The single phase model is used to describe the nanofluid behavior and the metal foam is assumed in local thermal equilibrium. The governing equations of continuity, momentum and energy are solved in rectangular coordinates for a steady state, turbulent and incompressible flow with thermophysical

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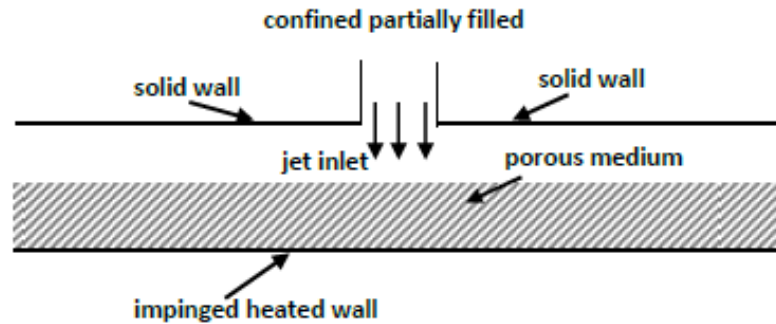


Figure 1: Sketch of the confined impinging slot jet.

properties considered temperature independent. The $k-\epsilon$ model is employed to close the turbulent flow problem. A uniform velocity profile, with Reynolds number equal to 5000, and a uniform temperature profile are applied at the inlet section as boundary condition while on the outlet sections, the static pressure was defined. The governing equations with the assumed boundary conditions are solved by means of Ansys Fluent code.

RESULTS AND CONCLUSIONS: Simulations are performed for the four different configurations for vertical jet and inclined jet with an angle of 30° . The velocity of the target is 0 and 0.2 the inlet jet velocity and the assigned temperature is 303 K. The jet inlet temperature is 293 K and the velocity is correspondent to a Reynolds number equal to 5000. The thermophysical properties are evaluated with the correlations given in [4]. The aluminium foam has a porosity of 0.92 and 10 pore per inches. The nanoparticles volumetric concentration is 0% and 4%, in water. The results are given in terms of local Nusselt number profiles along the target surface and are given in Figure 2 and 3 for the configurations without metal foam and with metal foam, respectively.

The increase due to the nanofluid is lower than the one due to the metal foam at this assigned Reynolds number. It could be very interesting to evaluate the behaviors for laminar flow ($Re < 2000$) and extend the investigation in a larger range of Reynolds number.

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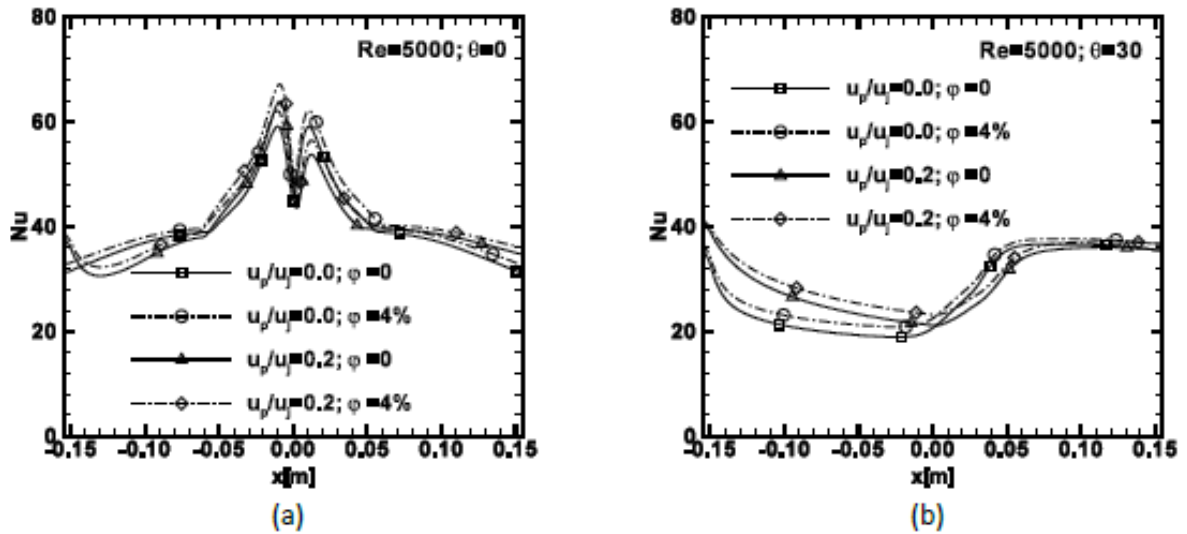


Figure 2: Local Nusselt number profile at Re=5000 for impinging jet with nanofluid without metal foam: (a) vertical jet and (b) inclined jet, 30°

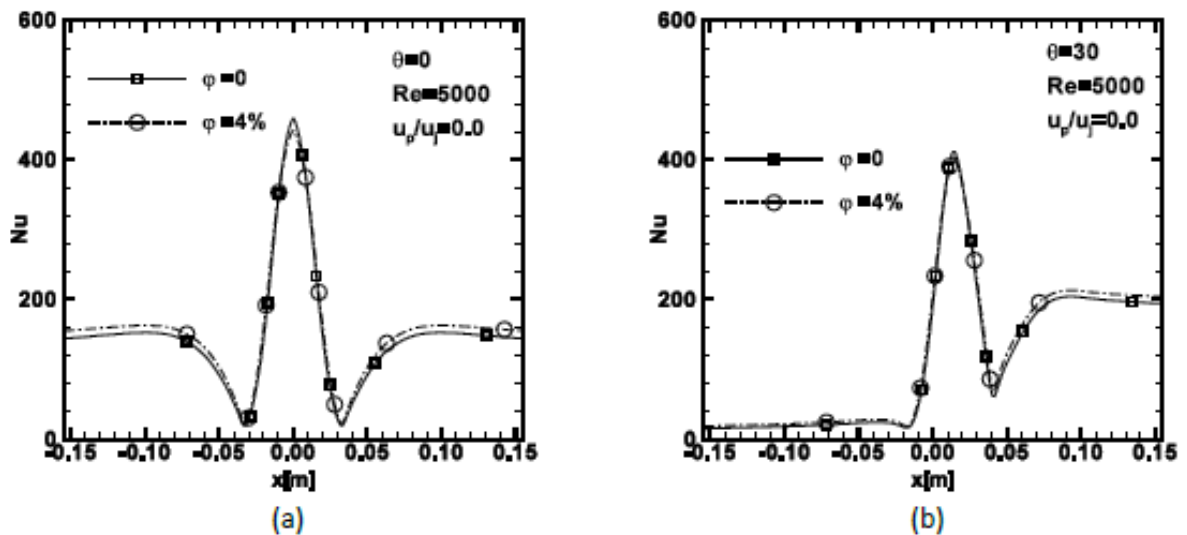


Figure 3: Local Nusselt number profile at Re=5000 for impinging jet with nanofluid with metal foam: (a) vertical jet and (b) inclined jet

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ABSTRACTS WORKING GROUP 2

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Heat transfer enhancement in automotive cooling circuits by nanofluids

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Keywords: Automotive cooling circuit, Nanofluids, Heat Transfer Enhancement, Power Consumption, Transient simulation.

INTRODUCTION: Continuous technological development in automotive industries has increased the demand for high efficiency engines. Optimizing design and size of a radiator in order to reduce a vehicle weight is a requirement for making the world green. Using of fins is one of the technique to increase the cooling rate of the radiator. However, traditional approach of enhancing the cooling rate by using fins and microchannels has already showed to their limit [1]. Furthermore, heat transfer fluids such as water and ethylene glycol have very low thermal conductivity. As result there is an urgency for new and innovative heat transfer fluids for increasing heat transfer rate in an automotive cooling circuit. Nanofluids represent potential substitute of conventional coolants in engine cooling system. Recently different studies have demonstrated superior heat transfer performances of nanofluids [1-3]. Bozorgan et al. [4] carried out a numerical analysis on an application of CuO-water nanofluid in automotive diesel engine radiator. The results showed that for the nanofluid at 2% volume concentration circulating through the flat tubes while the automotive speed is 70 km/hr, the overall heat transfer coefficient and pumping power are approximately 10% and 23.8% more than that of base fluid for given conditions, respectively. An experimental study was accomplished by Hwa Ming Nieh [5]. An alumina (Al_2O_3) and titania (TiO_2) nano-coolant (NC) were used to enhance the heat dissipation performance of an air-cooled radiator. The experimental results showed that the heat dissipation capacity and the efficiency factor of the nanofluid are higher than ethylene glycol, and that the nanofluid with TiO_2 is more efficient than one with Al_2O_3 according to most of the experimental data. Gulhane and Chincholkar [6] carried out an experimental study on the application of water-based Al_2O_3 nanofluid at lower concentrations in a car radiator. The results showed that the heat transfer coefficient enhances with an increase in particle concentration, flow rate, and inlet temperature of coolant and the maximum increase in heat transfer coefficient is 45.87 % compared to pure water.

METHODS: A heating system, a hydraulic pump and a heat exchanger are considered for the simulation of the cooling circuit. The heat exchanger represents the car radiator in the circuit.

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The nanofluid consisted of water containing 0 - 2 - 4 - 6 vol% Al_2O_3 nanoparticles. flows into the circuit. The studies are conducted for three different engine operating conditions (Low, Medium and High). Physical properties of the Al_2O_3 nanoparticles and water such as thermal conductivity, specific heat capacity, density and dynamic viscosity are evaluated by means [7-9]. The described automotive cooling system is fully modelled in TRNSYS (version 17).

RESULTS AND CONCLUSIONS: Simulations are performed for four different volume concentration values of nanoparticles, from 0% to 6%, in water. The investigation is carried out in order to evaluate the energy consumption by the pump and the temperatures at the radiator outlet (Figure 1).

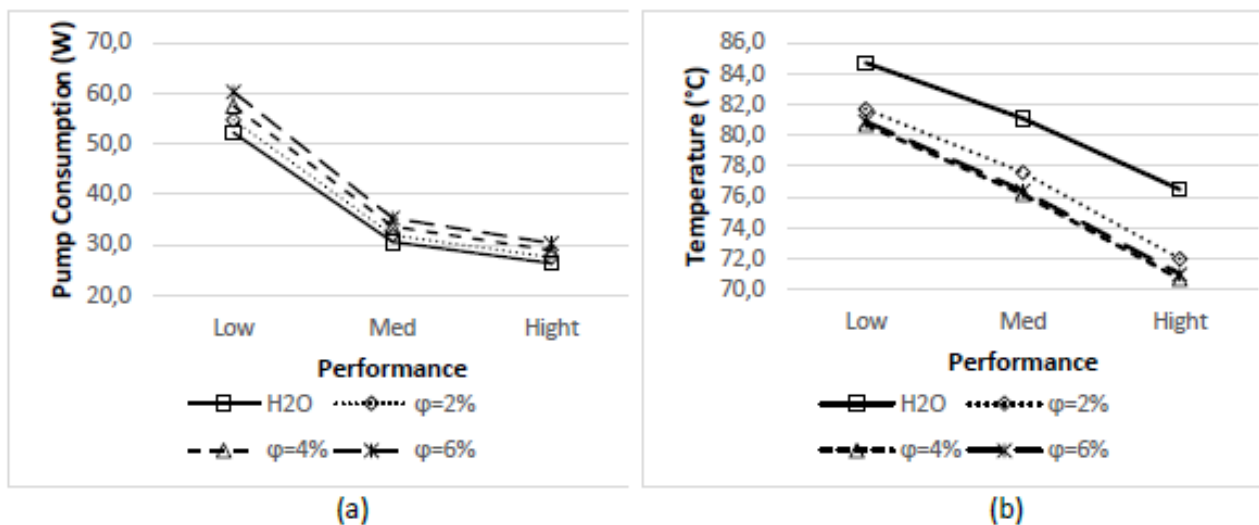


Figure 1. Pumping consumption (a) and outlet radiator temperature (b) for different nanoparticles concentrations

The increase of the volumetric concentration of nanoparticles ϕ in the working fluid leads to an increase in its density with respect to the pure water, which implies an increase in energy consumption. Furthermore, a reduction of pumping consumption occurs as the operating conditions increase, due to the reduction of the mass flow of the refrigerant, necessary for the cooling of the engine. The temperatures at the outlet of the radiator show a decreasing trend with the increase in the volumetric concentration of the nanoparticles in the base fluid. Furthermore, it shows that the outlet temperature is a function of the refrigerant velocity. The heat transfer rate is also evaluated for the three different engine operating conditions and it can be seen, in the Figure 2, as the nanofluids with a higher volumetric concentration of nanoparticles have a higher heat transfer rate. This increase is not significant for volumetric concentrations above 2%.

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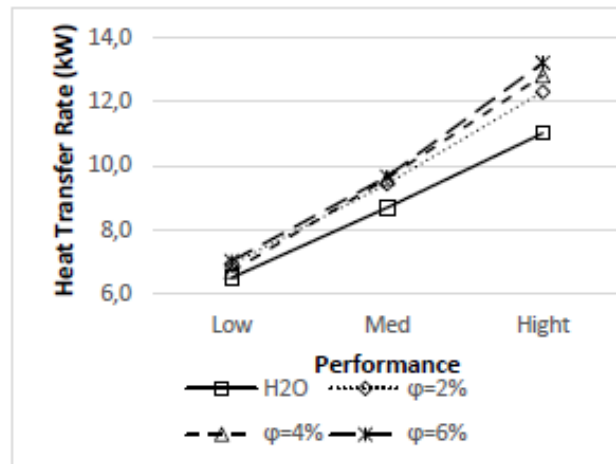


Figure 2. Heat transfer rate for different nanoparticles concentrations

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Overcoming Barriers to Nanofluids Market Uptake

Heat transfer efficiency in a double pipe heat exchanger of functionalized graphene nanoplatelets/glycolated water nanofluids

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Keywords: graphene nanoplatelets, propylene glycol, heat transfer, pressure drop, nanofluid

INTRODUCTION: Thermal energy is one of the most employed energy forms in industrial and domestic applications. The poor thermal conductivity of the classical thermal fluids is currently the most limiting feature for their performance enhancement. Over the last two decades, nanofluids have progressively received more attention as improved heat transfer fluids. Nevertheless, despite the evidence on their improved thermophysical profiles, there exists discrepancy about their potential improvement in real heat exchange processes. Glycolated waters like propylene glycol + water mixtures are heat transfer fluids commonly employed due to their protection against low freezing temperatures. The forced-convection heat transfer performances in a double pipe heat exchanger of four different loaded graphene nanoplatelet dispersions in propylene glycol:water 30:70 wt.% solution have been analysed in this work. Convection heat transfer coefficients and pressure drops were firstly determined. Then, a dimensionless analysis was carried out through Nusselt, Nu , and Reynolds, Re , numbers.

METHODS: Graphene nanoplatelets were supplied by Ionic Liquids Technologies GmbH (Heilbronn, Germany), propylene glycol was purchased from Sigma-Aldrich (Missouri, USA) while water was obtained by a Milli-Q 185 Plus system from Millipore Ltd (Watford, UK). The preparation of the analysed nanofluids was carried out by a two-step method. The amount of each component of the base fluid and the amount of nanoadditive corresponding to each designed mass concentration (0.25, 0.50, 0.75 and 1.0 wt.%) were firstly weighed and then, after mixing, maintained under an ultrasonication process for 240 min. The thermophysical properties necessary to the analyses were experimentally determined in a previous work [1]. An experimental facility consisting of a double pipe heat exchanger as main component was used to obtain heat transfer coefficients and pressure drops. In this device, the cold tested fluid (base fluid or nanofluid) is pumped through the inner tube and the hot water through the outer

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tube. Both tested fluid and water return to the desired initial conditions through the different facility circuits [2]. The data acquisition system allows directly measuring the temperatures in the inlet and outlet of the double pipe heat exchanger for both fluids, their flow rates, as well as the tested fluid pressure drop. For each tested fluid, the flow rates were varied from 0.2 to 0.7 m³·h⁻¹ for the temperatures of 298.15, 308.15 and 318.15 K. The values of the water convection coefficients were obtained by the corresponding Gnielinski correlations [3].

RESULTS AND CONCLUSIONS: Obtained convection heat transfer coefficients for analysed nanofluids show an improvement with respect to base fluid for most conditions. The highest enhancements were achieved for the 0.50 wt.% or 0.75 wt.% concentration, reaching a maximum increase of 15.3 % for the 0.50 wt.% nanofluid at 298.15 K. Figure 1 shows as Nu increases with the increasing loading of nanoadditive for the same level of turbulence.

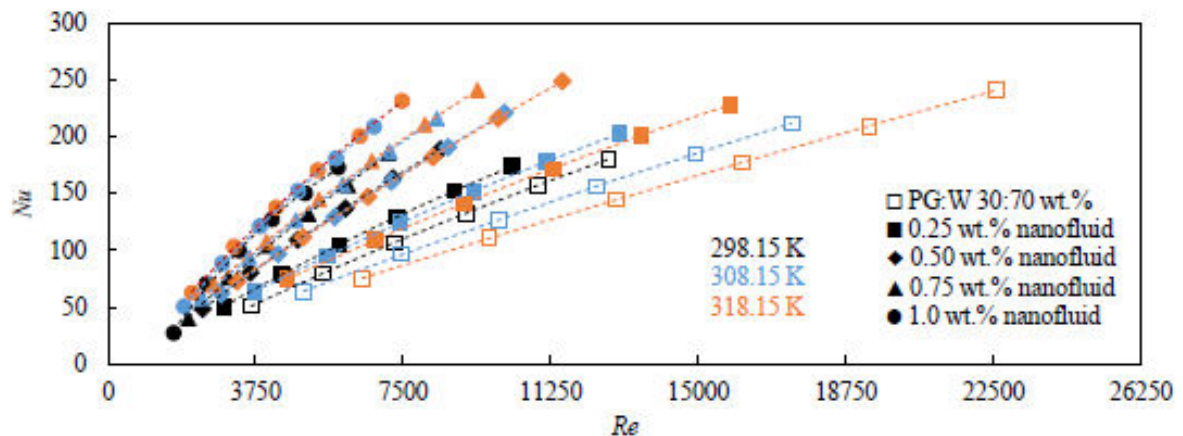


Figure 1. Nusselt number, Nu , as a function of Reynolds number, Re , for the base fluid and several concentrations at different tested fluid temperatures.

As an example, Nu increase achieves 167 % at 318.15 K with $Re = 7500$ for the 1.0 wt.% nanofluid. Figure 1 also shows as Nu enhancements are different between the lowest concentration and the three highest, between which the values are closer. Regarding pressure drop results, slightly increases with the rising nanoparticle loading were found, with a maximum increase of 12.4 % for the 1.0 wt.% concentration.

ACKNOWLEDGEMENTS:

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NANOUP TAKE COST ACTION (CA15119)

Overcoming Barriers to Nanofluids Market Uptake

Isothermal analysis of Nanofluid Flow inside HyperVapotrons using Particle Image Velocimetry

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Keywords: Nanofluids, HV, HHF, Viscosity, PIV, Cooling

INTRODUCTION: The focus of this work is to understand if and how the geometry of heat exchangers might be potentially affecting the nanofluid coolant flow boundary conditions established and how this might be hence further affecting their thermal characteristics.

This work contains a cold isothermal high spatial resolution particle image velocimetry (PIV) study of the instantaneous and mean flow structures of a nanofluid flowing inside two HyperVapotron (HV) models and compares them to those present when using water [1]. HVs are two phase High Heat Flux exchangers popular with the nuclear fusion industry. The properties of nanofluids alone might have the potential of improving the overall HV device performance. However, the operation of the device is strongly linked to the flow field of the coolant. The study attempts to quantify possible changes in the flow and hence examines whether the replacement of the traditional coolant with a nanofluid in a HV might disrupt the designed flow field of the device during operation in single phase heat transfer mode.

METHODS: Two variations of the HV models from the Joint European Torus (JET) and Mega Amp Spherical Tokamak (MAST) experiments were used. The basic difference between the two models is the free stream channel height which is expected to affect the size of the momentum boundary layers formed inside the devices when operated with the same free stream velocities (this is a boundary condition). The models are shortened to include five grooves and are manufactured from high optical quality transparent Perspex. The choice of the number of grooves used was based at this stage on a qualitative computational fluid dynamics (CFD) investigation performed on the models at the design process that reproduced the irregular signature vortices expected in HV for the mean flow. A closed circuit isothermal coolant flow was established through these models.

A laser-based Particle Image Velocimetry (PIV) technique [2] was used to measure with high spatial resolution (30 μ m) the flow velocity field inside the models. An Nd-Yag pulsed laser (a Litron Nano T PIV) was used at a beam wavelength of 532nm [1]. The pulse width of the laser was 7-9ns, while the delay between the two pulses was adjusted from 5-40ms, according to the expected velocities. A non-intensified LaVision Imager Intense CCD camera with a resolution of 1376x1040 pixels was used to capture the images. The camera was coupled to a Nikkor 50mm F/2.8 lens with manual focus. A band pass optical filter with 10nm bandwidth around the 532nm wavelength was used to reduce optical noise on the recordings. The beam was steered and manipulated into an almost 2D laser sheet before entering and illuminating tracing particles dispersed in the flow. Cross correlation algorithms and an image recognition vortex detection algorithms were used to process the tracked flow fields. A total of 1000 image

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pairs were collected which led to maximum statistical uncertainties of the order of $\pm 3.8\%$ and $\pm 3.5\%$ for the mean of JET and MAST respectively within a 95% confidence level. The maximum uncertainty of the measurements considering the PIV and flow meter uncertainty is hence estimated to be around 6% of the given quantities. The uncertainty of the image recognition analysis for the characterisation of the vortex location was below $\pm 500\mu\text{m}$.

Water based 50nm diameter Al_2O_3 nanoparticles were prepared using the two step preparation method from a dry powder. The final nanofluid used had a volumetric particle loading of 0.0001%.

RESULTS AND CONCLUSIONS: It is apparent from this work that small nanoparticle volumetric concentration nanofluids can significantly modify the hydrodynamic flow fields inside HVs. The changes were geometry dependent and cannot be explained using classical relationships (e.g. Einstein viscosity equation). The changes can be traced down to the momentum boundary layers of the flow. It is speculated that shear thinning occurs inside the momentum boundary layers due to dynamic nanoparticle migration effects when Nanofluids are used [2]. The flow changes are expected in their turn to be affecting significantly the temperature boundary layers in the presence of a heat flux either favourably or adversely.

It is clear from this work that more studies of the hydrodynamic effects of nanofluids inside given geometries is required – this is a novel finding with severe implications when nanofluids are used as a retrofitted solution to already existing heat exchangers. Caution also must be followed upon using shear inducing viscometers as these are expected to suffer from particle migration effects as well. An overall rethinking of the viscosity definition for nanofluids should be carried out to better describe and model them analytically.

The effects of heat flux on the performance of devices operated with nanofluids is under way that will be able to provide more answers regarding the complex physical phenomena observed.

This abstract is part of a larger study on HV devices published by the authors [3]–[7] with ongoing investigations under the EUROfusion fellowship of the lead author.

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Overcoming Barriers to Nanofluids Market Uptake

Analysis of the Thermal Signature of Wind-turbine Generators: implications for their main Operative Parameters and future application of nanofluids

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Keywords: Thermal Signature, Failure Modes, Energy Availability, Cooler improvements, Derating

INTRODUCTION: The replacement of heat transfer fluids employed in the wind turbine cooling systems by nanofluids is one of the main objectives of a coordinated project of the universities of Santiago de Compostela and Vigo for which Enel Green Power is collaborating [1]. Wind Energy is a relevant vector in the Energy mix at a global level. Due to its entrance in the electric system operators, and due to the high percentage of wind share in the energy mix, the Levelized Profit of Energy has suffered a big discount during the last 5 years in all the major countries. Due to this fact, it is very important to control the operative expenses, by reducing the average time to return after a failure, increase the average time between failures, and the energy availability. The majority of Wind Turbines have a lot of sensors, to control the operative parameters, especially the temperature. With these sensors it is possible to develop the thermal signature per wind turbine model, age, site conditions etc. The information provided by these sensors allows protecting the component's integrity and in the majority of the cases are the responsible of the deratings due to high temperature conditions. Moreover, this information has a high value that may be later treated to perform correlations, regressions, and to analyse the thermal signature as a function of variables that can predict future behaviours due to aging effect, increase power, or prevent failures.

METHODS: Enel Green Power has a Control and Diagnostic Centre located in Rome. This Centre receives all the signals from all the installed turbines and storage these signals in a Database, including the events (error messages) from each turbine. Statistical analysis of any kind is possible to using any conventional statistical software. The cost of interventions

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to solve the errors, outages, maintenance, operations etc. is tracked with a specific software. The Case study, the Root Cause Analysis and all the documents that show the history and the know-how is tracking with a Case-Method software. For this study, we have chosen a type of MW-Rate turbine for which we have data of 1000 units.

RESULTS AND CONCLUSIONS: The events are classified in external and internal, which are always related to stoppage of the wind turbine. The external events are due to atmospheric conditions or force majeure and in our study correspond to the 22.7% of the total events. The internal events (87.8 %) can be due to possible or real failures in the electronic (35.3 %), hydraulic (8%), electrical (10.8 %) and mechanical (23.2 %) components. In this MW-Rate turbine type, we have an incidence of 10% of the outages related temperature alarms. These events may cause either a downgrade of cooling capability, or a stoppage to recover as soon as the temperature goes down, and they decrease the global electrical energy availability. Similar effects appear in other turbine models. The main heat sources contributing to these events were the Converter, Generator, Transformer and Gearbox. We have calculated the correlation coefficients, r , among the temperatures of these components as well with the active and reactive power. The configuration of the turbine (Double Fed Induction Generator) entails a high temperature correlation between Converter temperature and Generator temperature ($r=0.72$). We did not extract the cooling effect, meaning that each of these last components has their own cooling system that affects the correlation. But a large part of the correlation of both temperatures is based in the super synchronous stage, in which the generator and the converter are working at a full capacity. In general terms, the electrical components have an important correlation coefficients with the reactive power or super synchronous situation, and the gearbox temperature correlates with the active power ($r=0.62$), and not necessary in the same range as the electrical components. Therefore, we may act in two aspects reducing either the gearbox temperature or that of the electrical component. We conclude that a significant fraction of the total time the turbine is not working with the active nominal power. This is due to the temperature trigger, telling us that we have at least 10% of entitlement if we are able to reduce the temperature of the cooling vector, in this case glycol mixed with water, as well as in the transformer and in the converter. These studies are necessary for example to know how nanofluids or nanolubricants might increase the competitiveness of the wind energy. For this purpose, in situ test with nanofluids will be performed soon.

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Overcoming Barriers to Nanofluids Market Uptake

Gr-Al₂O₃ Hybrid Nanoparticles based Multi-Functional Drilling Fluid

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Keywords: Drilling fluids; nanoparticles; rheology, thermal conductivity, multi-functional

INTRODUCTION:

The global demand of energy is expected to increase as much as 50% in the next 20 years and the demand for oil and gas will also increase [1]. The area of finding "easy oil" is coming to an end, and future supply will become more reliant on hydrocarbons produced from unconventional hydrocarbon sources and enhanced oil recovery (EOR) processes. The performance of a drilling fluid is important for smooth and stable production of hydrocarbons. Drilling fluid is an essential element in the well-construction process that remains in direct contact with the wellbore throughout the entire drilling operation. A well-constructed and reliable wellbore can significantly reduce the nonproductive time. The design of a drilling-fluid system is central to achieve this objective [2]. Drilling fluids should be formulated to work appropriately under expected wellbore conditions, possessing good rheological and thermophysical properties. Quite recently, considerable attention has been paid to using nanoparticles to improve drilling fluid performance [3]. A considerable effort has been recently devoted to employing nanoparticles in drilling fluids to control the mud filtrate volume [4-6], minimizing differential pipe sticking [7], improving drilling and production at high pressure and high temperature (HPHT) conditions [8-10], enhancing shale stability [11-13] and improving rheological properties [14-16]. Nanoparticles were used by some researchers to develop thermal, electrical and HPHT rheology of water-based mud [10, 17]. It is detected that the increase of nanoparticle concentration promotes thermal and electrical features of drilling fluids. The results of recent studies showed that nanoparticles enhanced thermal and electrical characteristics by approximately 35% compared to water based mud (WBM)

These studies have shown that the addition of nanoparticles could improve some properties of the drilling fluid, which shows some promise for future applications. However current state-of-art studies have a number of limitations, as commented here. Firstly, the understanding of the properties of nanoparticle- based drilling fluids is insufficient. Most of the studies have

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been focused on one property, such as rheological property or filtration property [ref]. As a drilling fluid provide multi-functions during the drilling operation, such as cooling, lubrication and cutting transport. Addition of nanoparticles would clearly affect these functions, and it is essential to understand the variations of related properties for have a complete assessment of the nanoparticle effects. Secondly, the effect of nanoparticles is multi-facets and their influence on different properties are different. The addition of one nanoparticle may improve one property but may not improve the other. It is unlikely that the addition of one type of particle could improve all related properties. The search for right nanoparticle or hybrid particles is still ongoing. Thirdly, prior studies have been largely focused on the steady state operation, which may not reflect the real conditions. A drilling fluid cycle is often unsteady, varied between a movement and a steady state, and it is essential to investigate the performance of Nano-mud based on both static and dynamic conditions. t. Finally the drilling fluids behave as viscoelastic materials, exhibiting both viscous and elastic behavior, but the study of the viscoelasticity behavior of Nano-drilling fluid is very limited in the literature [ref xx]. Identifying the differences in viscoelastic response could lead to better design of a drilling fluid recipe.

Aiming to address these limitations, this work develops a novel hybrid nanoparticle system, Gr-Al₂O₃, dispersed in a WBM, and examines their properties under both dynamic and static conditions. The rheological, electrical and thermal properties of the newly formed drilling fluids are examined to reveal their potential functions.

2.1 Preparation of Nano Drilling Fluids

The drilling fluids were prepared in the laboratory according to the table (2-1). The formulation of the fluid was conducted by scaling the water to 335ml. Bentonite is the first component added to water; this was mixed until the fluid was observed to be smooth. The nanoparticles were always the last additive to the mud. The weight percentage of the nanoparticles was based on a calculation of the entire weight of the fluid. The fluid was set to mix by a Hamilton beach mixer for 20 minutes. The laboratory analysis was initially performed on base mud to apply them as a reference to evaluate the development of nanoparticles additives.

Table 1 Components of prepared Water-based mud

Component	Quantity
Water	335 ml
Bentonite	20 gm

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At this stage of experimental work, different types of the nanoparticle are used. In Table 2.2, nanoparticles additives and their properties are mentioned: The Morphology of the particles was characterised by a transmission Electron microscope (TEM) and is shown in figure 1.

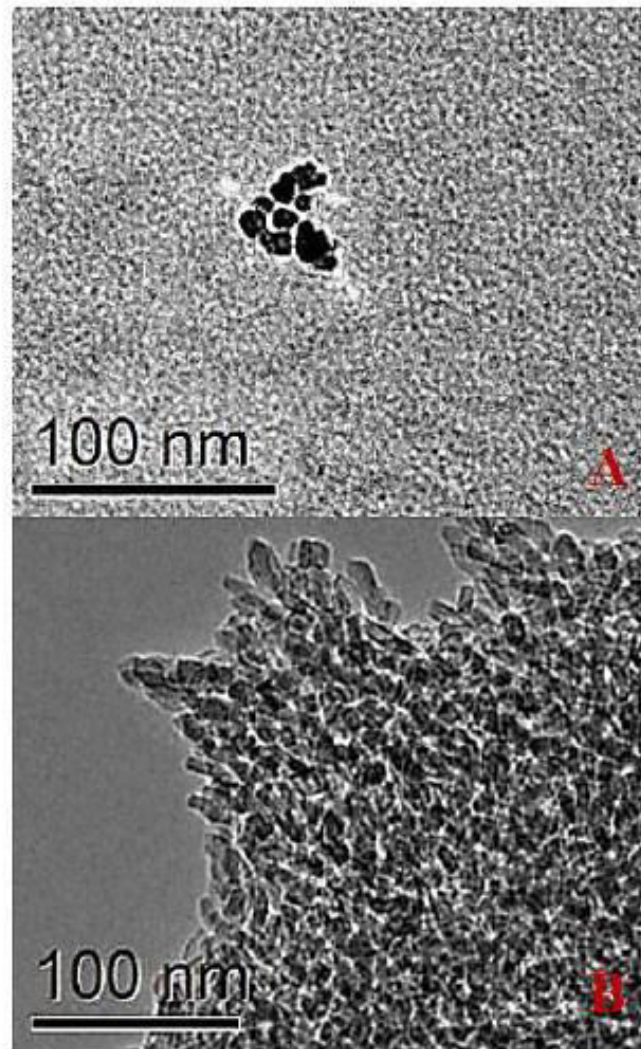


Figure 1 Transmission Electron Microscope (TEM) images of Graphite nanoparticles (A) and Aluminum oxide nanoparticles (B)

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Table 2 Properties of nanoparticles

Nanoparticles	Average size	Supplier
Graphite nanopowder	1-2 nm	Nanoshel
Aluminium oxide	45 nm	Nanophase

2.2 Experimental apparatus

In general, Fann 35 Viscometer is used to measure the rheology of the drilling fluid in most oil fields across the world. However, in this research, viscosity measurements are done by the Anton Paar MCR301

Rheometer (Fig. 2). This Rheometer is more precise and more advanced: it can measure viscosity and related attributes. The MCR301 was used to do more analysis of fluids while Fann 35 failed [17-19]. The flow behaviour of drilling fluids was investigated by using a rotational system. The oscillation amplitude sweep test was employed to find the linear portion of the viscoelasticity and to observe the structural characteristics of fluids, While the combination oscillation-rotation-oscillation was utilised to study the thixotropy.

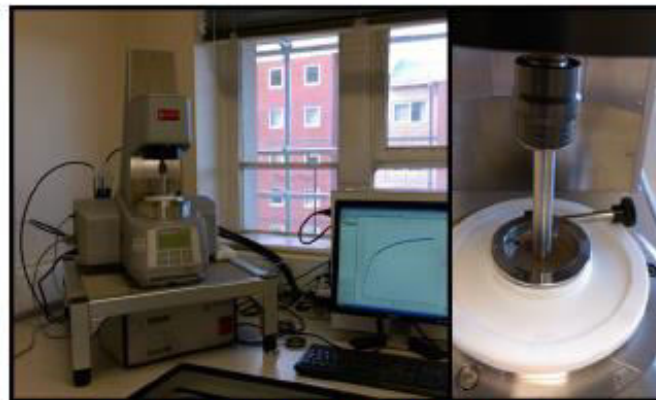


Figure 2 Anton Paar MCR301 Rheometer

The KD2 Pro Thermal Properties Analyzer made by Decagon Devices, Inc. has been employed to conduct the thermal conductivity of the prepared Nano-drilling fluids with the accuracy of 5%. The KD2 Pro is a handheld device, battery-operated, menu-driven device which works based on the transient heated needle to conduct thermal properties of solid and fluid media. The KD2 pro KS-1 a sensor with 60 mm in length and 1.3 mm in diameter, is designed explicitly for use in fluids.

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The Zetaprobe manufactured by Colloidal Dynamics, LLC has been used to measure the zeta potential of various Nano-drilling fluids without dilution. The Colloidal Dynamics Zetaprobe worked based on the electroacoustic method which offers straight measurement (without dilution) for colloidal dispersions with moderate and high particle concentrations while the other techniques necessitate sample dilution and sample preparation which are both time-consuming and error-prone. The Zetaprobe builds from a compact design with built-in titration, a versatile dip probe sensor, and software wizards as in figure (3).



Figure 3 The Zeta probe used to measure Zeta potential of drilling fluids

3. Results and Discussion

3.1 Rheology

Rheology is a crucial parameter of drilling-fluid performance. Modification, the rheology of drilling fluid, can be a convenient solution to most drilling difficulties like pipe sticking, loss circulation and formation damage. The drilling fluid behaves as viscoelastic materials. This confirms that drilling fluids display both viscous and elastic behaviour. Therefore, it's essential to investigate the viscoelasticity behaviour of drilling fluids to understand how additives can develop the structure of drilling fluids. Identifying the differences in viscoelastic response could lead to better design of a drilling fluid recipe. The speed of the structural recovery (thixotropy) is also essential. To evaluate flow and viscoelastic properties of drilling muds and it is regularly suitable to deal with them separately, some rheometric assessments that can be conducted on a rheometer. Flow curves usually use the graphical description of flow behaviour. It exhibits the flow behaviour at low shear rates as well as high shear rates. The viscosity of drilling fluid decreases with increasing shear rate. This flow behaviour is called shear-thinning as in figure 4

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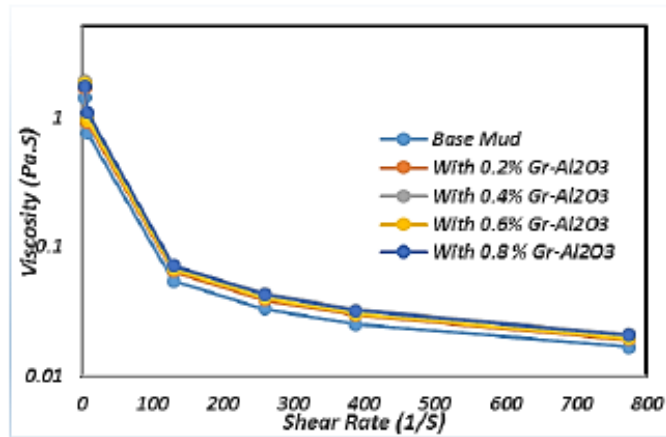


Figure 4 Measure viscosity of the prepared drilling fluids as a function of shear rate

. Therefore, it is not sufficient to indicate only the viscosity. It is consistently necessary to designate also the shear rate that was utilised for the mensuration. The viscosity of drilling fluid is slightly increased with hybrid nanoparticle addition. The reason behind that could be because there is more than one type of nanoparticles settled into the pore structure on the surface of clay particle. These nanoparticles don't have the same structure, size, conformation and properties that contribute to gain a stronger connection between bentonite particles, which might promote gelation of the bentonite. The concentration of nanoparticles in drilling fluid also plays a role in general flow behaviour. As nanoparticles concentration increase, the viscosity of the drilling fluid increase as clear for Gr-Al₂O₃ addition.

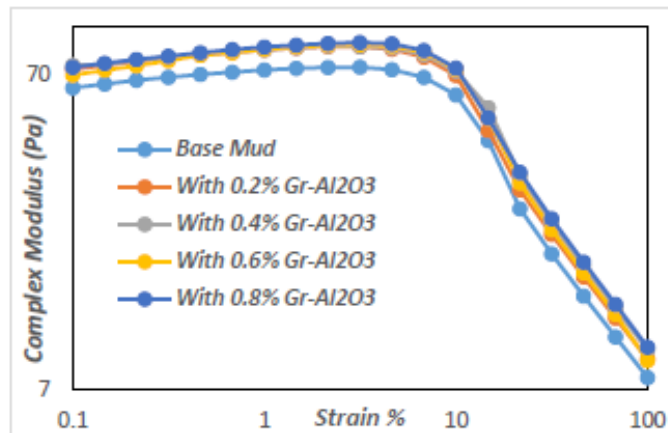


Figure 5 Measured Complex modulus of the prepared drilling fluids as a function of deformation percentage

Characteristics such as loss and storage modulus, complex modulus, dynamic yield point, structural

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stability, and phase angle describe the viscoelastic behaviour of drilling fluids. The inter-particle interaction plus the particle networks in the drilling fluids can be measured by noting the passage from a solid-like condition to a liquid-like status. Presentation of variation complex modulus (overall resistance to deformation) as a function of strain obtained through oscillatory amplitude test is used as a suitable tool for investigation of the strength of the particle connection in the fluid (the stiffness of material; the higher the modulus, the more stringent the material).

As clear from figure 5, the complex modulus increase with increasing nanoparticles concentration. This means that nanoparticles give more elastic properties to the fluid before flow point and this what we need since this state helps retain cuttings and weighting materials suspended in the drilling fluid instead of allowing for settling into the wellbore.

The results also indicate that nanoparticles can develop the structure of drilling fluid. Moreover, even nanoparticles give the more elastic property to drilling fluid; the yield stress is still same. This means that Nano drilling fluids display sufficient abilities both at rest and in the movement since they have better gel structure and this gel can break with same shear stress. When drilling fluid pumps are shut off or running at very low speed, the drilling fluid will take on a gel-like state. This state of the drilling fluid helps retain cuttings and weighting materials suspended in the drilling fluid instead of allowing for settling into the wellbore. It is appropriate that the drilling fluid quickly develops high gel strength to resist the settling of massive particles out of suspension.

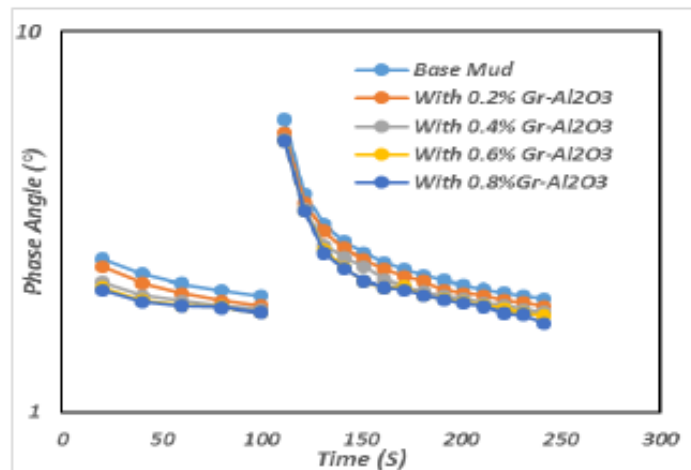


Figure 6 Measured Thixotropy of the prepared drilling fluids as a function of time and shear rate

The laboratory results proved that the addition of hybrid nanoparticles could develop the thixotropic properties of drilling fluids. As clear from the figure (5), the increase of nanoparticles concentration secures more elastic behaviour to the drilling fluid and increase the degree and the speed of the

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structural recovery through reducing the time required for rebuilding. It is preferable to minimise the reconstruction time to prevent the sedimentation of the weighting materials and drilled cuttings.

3.2 Thermal conductivity

The thermal conductivities of the prepared drilling fluids have been measured by using KD2 pro apparatus. This device has been standardized by using distilled water before the measurements. The thermal conductivity measurements were done at constant temperature. The thermal Conductivities of the prepared drilling fluids as a function of nanoparticle concentration are investigated. Table 3 and Figure 7 show the thermal conductivity improvement as a function of nanoparticles concentration for base water-based fluid at room temperature. Results indicate that an increase in the nanoparticle Concentration enhances the thermal conductivity.

The laboratory results illustrate that the water-based drilling fluid thermal conductivity is improved by around 10% in the presence of 0.8 wt% Gr-Al₂O₃ at room temperature. An improved drilling fluid thermal conductivity is an indication of the ability of the fluid to cool faster as it moves up to the surface. On the other hand, with enhancement the heat transfer between the drill bit and drilling fluid, the bit remains cooler and this possibly helpful for innovative design of drilling muds for high temperature and high pressure (HTHP).

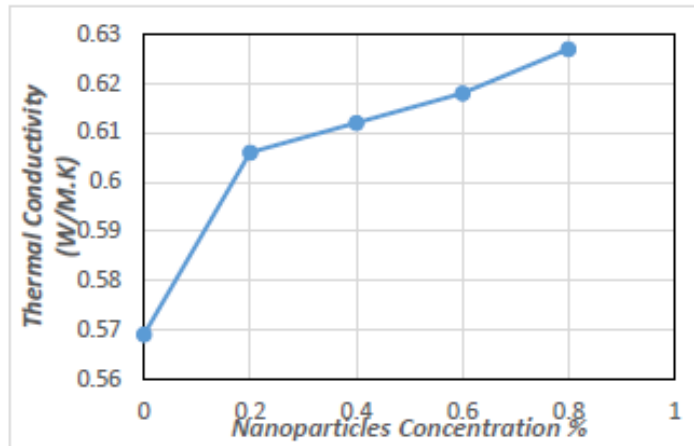


Figure 7 Thermal conductivity of prepared drilling fluids as a function of nanoparticles concentration

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Table 3 Thermal conductivity measurements of drilling fluids at 20 °C (w/m.k)

Fluid Samples	Thermal Conductivity	Improvement %
WBM	0.569	0
0.2 wt% Gr-Al ₂ O ₃	0.606	6.5
0.4 wt% Gr-Al ₂ O ₃	0.612	7.55
0.6 wt% Gr-Al ₂ O ₃	0.618	8.61
0.8 wt% Gr-Al ₂ O ₃	0.627	10

3.3 Electrical conductivity

Table 5 records, the electrical conductivity values of water-based muds measured at each nanoparticles concentration. It is noticed that the addition of Nano-particles to base mud enhances the electrical conductivity. These tabulated results are used to generate a graph of thermal conductivity improvement against nanoparticle concentration as illustrated in the figure. The laboratory outcomes indicate that the water-based drilling fluid electrical conductivity is improved by around 4% in the presence of 0.2 wt% Gr-Al₂O₃. The enhancement of the electrical conductivity is observed to be from about 4 to 8.4% when the concentration of Gr-Al₂O₃ increased from 0.2 to 0.8 wt%. The electrical conductivity has a significant influence of the nature of the drilling fluid upon electric logs (resistivity imaging) as the drilling fluid must be the medium through which the electric logging device is made to traverse the formations. Electrical logs have been used to distinguish the differences between shales, sandstones, limestones, and other rock forms readily. Besides electric logs have been found, in some instances, to be useful in estimating the nature of fluid contained within the pores of a rock. The electrical conductivity of a drilling mud, its filtrate, and filter cake are three of its more important qualities, as far as electric logging is concerned.

Table 4 Electrical conductivity measurements of drilling fluids at 20 °C (mS/cm)

Fluid Samples	Electrical Conductivity	Improvement
WBM	2.84	0
0.2 wt% Gr-Al ₂ O ₃	2.93	3.2
0.4 wt% Gr-Al ₂ O ₃	2.97	4.6
0.6 wt% Gr-Al ₂ O ₃	3.01	6
0.8 wt% Gr-Al ₂ O ₃	3.08	8.4

3.4 Zeta potential

The nanoparticles charge and zeta potential play a significant role in the performance of the rheological behaviour. The nanoparticles with a positive charge displace the dissociated cations from

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the surface of bentonite which result in a different clay platelet structure, yielding higher yield stress values [5, 20]. While the nanoparticles with a negative surface charge increase the repulsion forces between the clay platelets, which leads to deflocculating of the platelets and, thus, higher viscosities and weaker yield structure. Sodium montmorillonite, the main component of the standard bentonite, has a lot of permanent negative charge on the basal surface [21]. They are between 90–95% of the total charge [22]. As a result, the zeta potential of Bentonite drilling fluids is negative over the entire pH range [23, 24].

Figure (8) displays the enhancement of zeta potential as a function of nanoparticles concentration for base water-based mud at room temperature. Results indicate that an increase in the nanoparticle Concentration enhances the zeta potential. The laboratory results display that the zeta potential of the water-based drilling fluid is improved by around 13% in the presence of 0.8 wt% Gr-Al₂O₃ at room temperature. The drilling fluid suspensions with high charge are appropriate during drilling operations to retain the suspension components discretely. The resultant drilling mud particles can penetrate to the porous wall of the wellbore and clog the pores. Also, a thin and impermeable cake is formed which minimise drilling fluid losses

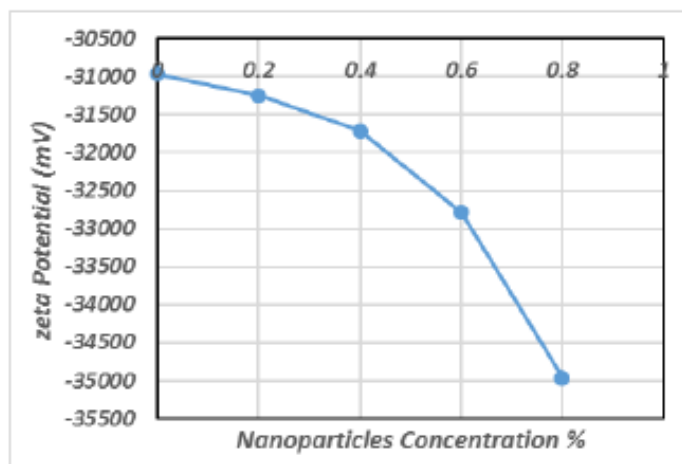


Figure 8 Zeta potential of prepared drilling fluids as a function of nanoparticles concentration

Conclusions

During recent decades, researchers and scientists discovered nanoparticles, and currently, there are efforts to use this technology in the drilling operation. In this research, we explore the possibility of using hybrid nanoparticles to develop water-based drilling fluids properties. Based on experiential research that has been undertaken, it is possible to conclude that hybrid nanoparticles could be employed as multi-functional additive for drilling muds. In the present work, Gr-Al₂O₃ nanoparticles were applied as additives to water-based drilling fluids and below outcomes could be identified:

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- Based on rheological investigations, the Nanoparticles addition has the power to form a drilling mud that displays sufficient features both at relaxation and in movement.
- The experimental outcomes demonstrate that the water-based drilling mud thermal conductivity is improved by around 10% in the presence of 0.8 wt% Gr-Al₂O₃ at room temperature.
- The laboratory results indicate that the water-based drilling mud electrical conductivity is improved by around 8.4% when the concentration of Gr-Al₂O₃ was 0.8 wt%.
- The laboratory outcomes identify that the water-based drilling fluid zeta potential is enhanced by around 13% in the presence of 0.8 wt% Gr-Al₂O₃.

In our future research, we intend to concentrate on the possibility to use different hybrid nanoparticles to enhance lubrication, filtration and other drilling fluid properties.

Acknowledgments

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Overcoming Barriers to Nanofluids Market Uptake

A Benchmark Study on Heat Capacity of Nanofluids and Nanosalts

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Keywords: Nanofluids, Nanosalts, Nanoparticles, Stability, Heat capacity

INTRODUCTION: It is well-known that literature data on various thermophysical properties of nanofluids are very scattered and anomalous which hinder not only to reach unanimous conclusions on these properties but also to fully identify and understand the underlying mechanisms [1-4]. Although intensive research works on nanofluids have been continued and scattered data keep piling up in the literature, no co-ordinated joint research efforts have been devoted on the heat capacity of nanofluids as well as of nanosalts. It is therefore of great importance to conduct a benchmark study on this key property of these new nanosystems. For the first time a Europe-based benchmark study on this property (C_p) of these emerging nanoparticles dispersed systems (nanofluids and nanosalts) has recently been launched under the auspices of Nanouptake COST action. The main objective of this co-ordinated work is to reach unanimous conclusions on heat capacity of nano fluids and nanosalts by conducting research in different laboratories under a set of defined protocols for different types of sample nanofluids and nanosalts.

METHODS: A set of standard protocols will be made and will be followed by the participating researchers/groups to conduct this benchmark study. Different types of sample nanofluids as well as nanosalts will be prepared following under same preparation and stability protocols in different laboratories and heat capacity of those samples will be measured in all participating laboratories using various types of available measurement methods and devices (calorimetry).

RESULTS AND CONCLUSIONS: The results of this benchmark study will be presented, compared and analysed thoroughly. It is anticipated that the findings of this study not only help to reach conclusions on the status (e.g., enhancement/no change/deterioration) of heat capacity of these two new nano-media, but also to explore the actual factors behind the results. Most importantly, this extensive multi-lab study will certainly be a step-forward to explore and assess the application potential of these emerging nanofluids and nanosalts in heat storage and energy harvesting areas.

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Overcoming Barriers to Nanofluids Market Uptake

Thermomagnetic properties of magnetic nanofluids and hybrid nanofluids

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Keywords: thermal conductivity, transformer oil, magnetic nanoparticles, carbon nanotubes

Within two Nanouptake STSMs, the measurements of thermal conductivity of a magnetic nanofluid and a hybrid nanofluid containing magnetic nanoparticles and carbon nanotubes (CNT) in dependence on particle volume fraction and magnetic field were performed at the Department of Energy Sciences, Faculty of Engineering at the Lund University, Sweden. For this purpose, the nanofluids based on a novel type of transformer oil MOL TO 40 were prepared at Institute of Experimental Physics. From the concentrated magnetic nanofluids, another samples with various particle volume fractions were prepared by dilution procedure.

In order to measure the thermal conductivity of the studied nanofluids, a thermal constants analyzer (TPS 2500S from Hot Disk AB, Sweden) was employed. A special attention was paid to the fixation of the commercial thermal conductivity double spiral Hot Disk sensor with Kapton insulation (Fig. 1a). The sensor was fixed in a Teflon frame in order to ensure its stable position in stronger magnetic fields. In order to reduce the amount of the measured sample volume; a homemade Teflon container was prepared too (Fig. 1b). The sensor was inserted vertically into the container with liquid samples to avoid the risk for bubbles. To apply an external magnetic field on the investigated samples, an ensemble of permanent magnets were attached to the Teflon container as depicted in Fig. 1c. In this way, the nanofluid was exposed to a quasi-homogenous magnetic field. The intensity of the field was measured in the empty container by means of a Hall probe. The thermal conductivity as well as the thermal diffusivity was measured on all the prepared samples at various magnetic field values (0, 45 mT, 90 mT and 210 mT). The experiments were performed at ambient temperature set to 21 °C. The heating applied to the sample was 30 mW, the measurement time was set to 3 s. Finally, the statistical values were determined as an average of 5 measured values.

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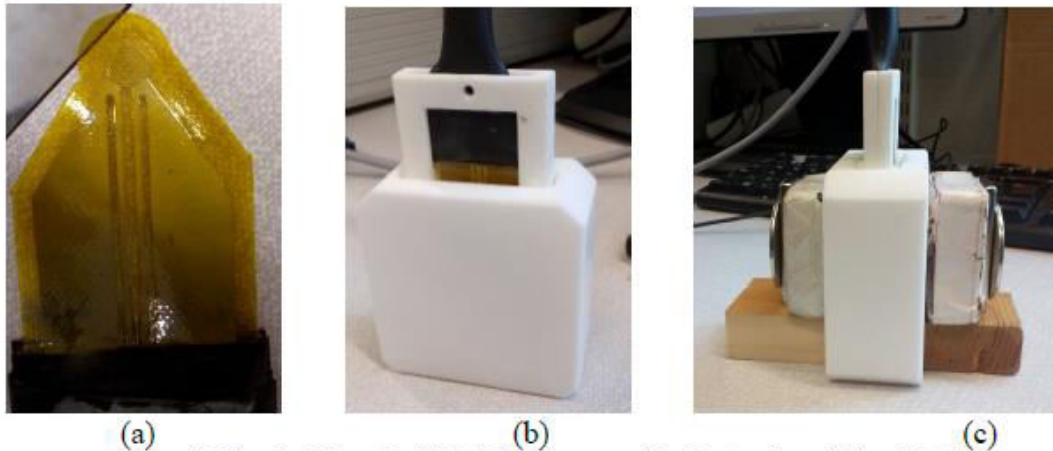


Fig. 1 The double spiral Hot Disk sensor with Kapton insulation (a). The sensor fixed in a teflon frame inserted in the experimental container (b). The ensemble of permanent magnets attached to the Teflon vessel walls (c).

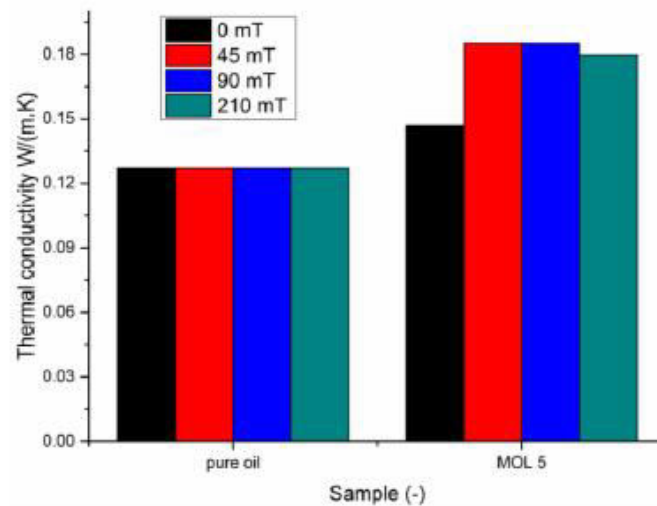


Fig. 2 Thermal conductivity of the pure oil and the most concentrated magnetic nanofluid (3.5 %) measured a various magnetic fields.

The thermal conductivity measured on the transformer oil and the most concentrated magnetic nanofluid at various magnetic fields is presented in Fig. 2

It is clear that the oil thermal conductivity is independent on the applied magnetic field. Then, the presence of the magnetic nanoparticles increases the thermal conductivity by about of 15.7 %. Moreover, with increasing magnetic field, this thermal conductivity increases too, as 45,8 % enhancement has been achieved at the value of 90 mT. At higher magnetic field (210 mT) the thermal conductivity starts to decrease. This decrease can be caused by the inhomogeneous particle distribution in the strong magnetic field, where the majority of the particles is accumulating near the magnets, leaving so the sensor area surrounded by a lower particle concentration.

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ABSTRACTS WORKING GROUP 3

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Overcoming Barriers to Nanofluids Market Uptake

Characterization Of Nano-Encapsulated Metal Alloy Phase Change Materials For A Molten Salt-Based Nanofluid

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Keywords: Thermal storage, Solar energy, Nanofluids, Molten salts, Phase-change materials

INTRODUCTION: A nanofluid is a Heat Transfer Fluid (HTF) or Thermal Energy Storage (TES) material with enhanced heat transfer properties by the addition of nanoparticles [1]. Their use usually implies an increment in the thermal conductivity of the fluid, but additional enhancements in the heat capacity of molten salts and ionic liquids have been registered [2].

Heat capacity of fluids can also be increased by using nanoencapsulated Phase Change Materials (nePCM). These nanoparticles are composed of a PCM core and a covering shell with high melting temperature. Thus, an increase in the heat capacity of the nanofluid compared to the base fluid can be obtained due to the latent heat of the cores [3]. The main drawbacks of nePCM are the complexity in the synthesis process of the shell and the high supercooling they sometimes present (the difference between the core melting and crystallization temperatures, due to homogeneous crystallization)[4].

The present work proposes a nanofluid composed of a mixture of molten nitrates widely used in Concentrated Solar Power plants, and nePCM consisting of an Al/Cu nucleus encapsulated by the metallic oxide formed when exposed to oxygen. NePCM and nanofluids with different concentrations have been characterized regarding their physical and thermal properties, and the suitability of the encapsulation has been proven for high temperature working conditions.

METHODS: Nanoparticles of an Aluminium-Copper alloy in an 80%Al-20%Cu percentage were obtained from Advanced Powder Technologies LLC. The base fluid used was the mixture of sodium and potassium nitrates known as solar salt (60% and 40% wt. respectively. Labkem, analytical grade ACS). Nanofluids consisting of solar salt and Al/Cu nanoparticles with mass concentrations of 0.5%, 1%, 1.5%, 5% and 10% were synthesized adding the nanoparticles to the previously mixed nitrates and mechanically blending.

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The nePCMs were observed by TEM (JEOL-JEM 2100) and SEM (JEOL-JSM 6510) to analyse their morphology, size, shell thickness and distribution in the base fluid.

Differential Scanning Calorimetry (DSC2, Mettler Toledo) was used to study the melting and crystallization processes regarding temperatures, phase-change enthalpies and their evolution through thermal cycling. Besides, specific heat was measured at 300, 350 and 400°C.

RESULTS AND CONCLUSIONS: The suitability of Al/Cu nePCM in nanofluids for their use in thermal engineering applications has been tested. Figure 1 shows some example of the results. Figure 1a) depicts the DSC analysis of Al/Cu nePCM where the melting and crystallization peaks are shown. It can be observed that there is very little supercooling in this nePCM. Figures 1b) and 1c) show the resistance of the nePCM to thermal cycling, both alone and in the nanofluid proving the oxide encapsulation is resistant to working conditions.

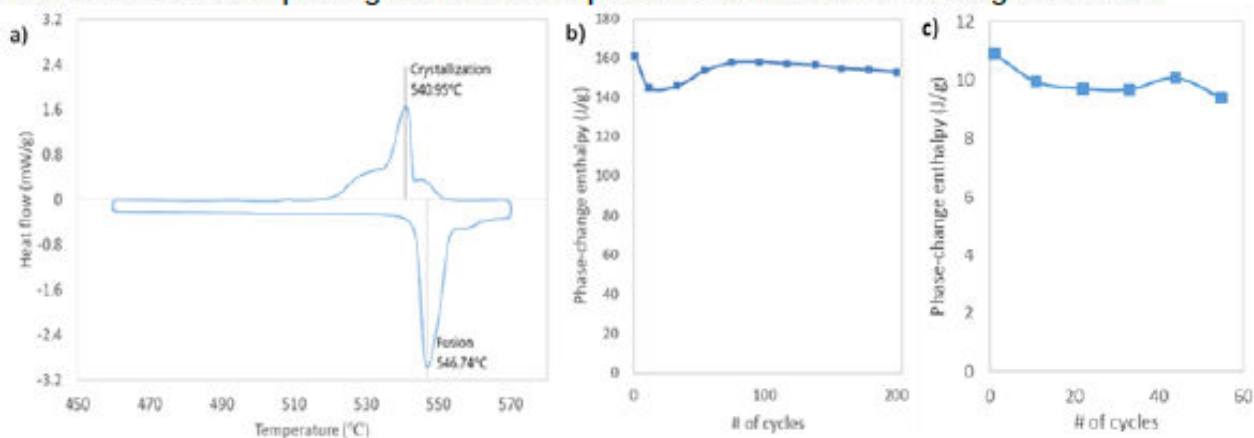


Fig 1. a) DSC of Al/Cu nePCM with fusion and crystallisation peaks marked. b) Evolution of phase-change enthalpies through thermal cycling (nePCM). c) Evolution of the enthalpies when immersed in the nanofluid.

Taking into account changes in specific heat and the contribution of the latent heat from the nePCM, increases in heat capacity from 0.2% up to 7.8% have been registered for the higher concentration nanofluids (5% and 10% mass loadings) with respect to the base fluid alone.

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Overcoming Barriers to Nanofluids Market Uptake

Corrosion properties of nanofluids based on molten nitrate salts for thermal energy storage applications

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Keywords: Corrosion, Nanofluid, Molten salt, Thermal energy storage, Carbon steel (CS)

Introduction

Nowadays, rapid increase of renewables with simultaneous decrease of fossil fuels share in the overall energy consumption is considered mandatory worldwide. Concentrated solar power (CSP) is considered as one of the most efficient technologies taking advantage of its relatively simple method for energy storage in the form of heat - thermal energy storage (TES). The use of TES for electricity production has provided several important benefits, like lower environmental impact and higher dispatchability compared to other methods [1]. Different combinations of alkaline salt mixture were used to store the thermal energy for CSP. The salt combinations were NaNO₃-KNO₃ (60:40 wt%), NaNO₃-KNO₃-NaNO₂ (7:53:40 wt%) and NaNO₃-KNO₃-Ca(NaNO₃)₂ (15:43:42 wt%) etc. [2]. Currently binary NaNO₃-KNO₃ molten salt is used in most of the commercial plants due to the acceptable operating temperature and compatibility [1]. Many investigations were focused on the enhancement of thermophysical properties of molten salts (heat capacity, thermal conductivity) by the addition of minor percentage of the nanoparticle - molten salt based nanofluids. The results already had shown the enhancement of the specific heat capacity, thermal conductivity and enthalpy when SiO₂, Al₂O₃, TiO₂ nanoparticles were used [3-5]. Although, the enhancement of thermophysical properties was achieved, the corrosion aspects of molten salt nanofluids need to be investigated. There is a very few works on corrosion properties of such nanofluids. Recently, it was demonstrated the corrosion rates increase for HitecXL ((NaNO₃-KNO₃-Ca(NaNO₃)₂ (15:43:42 wt%)) based nanofluids at 310 °C as compared to the pure HitecXL [6].

The present work mainly focused on the corrosion properties of binary nitrate eutectic salt nanofluid formed by NaNO₃-KNO₃ nitrates and Al₂O₃ and SiO₂ nanoparticles. Such properties were demonstrated for common construction material - carbon steel A516.Gr70 at 390 °C for the exposure time periods of 250, 500, 1000 and 1500 hours. The corrosion rates were found and were demonstrated to be considerably affected by the presence of nanoparticles in the molten nanofluid. Particularly, the presence of nanoparticles decreases the corrosion layer thickness more than twice. From SEM-EDX and XRD analysis the mechanisms as well as the reasons for observed results were revealed. It was demonstrated that incorporation of nanoparticles into corrosion-oxide layer may be responsible for its stabilization and lowering corrosion rates. Obtained results were compared to the previous study on the corrosivity of HitecXL based nanofluid in order to formulate some general anticorrosion guidelines for molten salt based nanofluids [6].

Experimental

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The immersion corrosion tests were conducted under atmospheric conditions for carbon steel A516.Gr70 in contact with eutectic $\text{NaNO}_3\text{-KNO}_3$ salt, eutectic salt + 1 wt% of Al_2O_3 NPs and eutectic salt + 1 wt% of SiO_2 NPs. The eutectic salt was prepared by melting of 51wt% NaNO_3 and 49 wt% KNO_3 . The nanofluids were prepared by an innovative dry method by using 1 wt% Al_2O_3 and SiO_2 nanoparticles. Experiments at 390 °C of 250, 500, 1000, 1500 hours were conducted. The samples before and after the corrosion tests were analysed by means of SEM-EDX (surface and cross section), XRD and mass variation. In addition, differential scanning calorimetry (DSC) and thermal gravimetric analysis (TGA) were applied in order to verify the absence of fluid degradation after 1500 hours corrosion test. As an example, figure 1 shows the SEM images of the cross section of carbon steel after 1500 corrosion tests with pure molten salt, Al_2O_3 based nanofluid and SiO_2 based nanofluid.

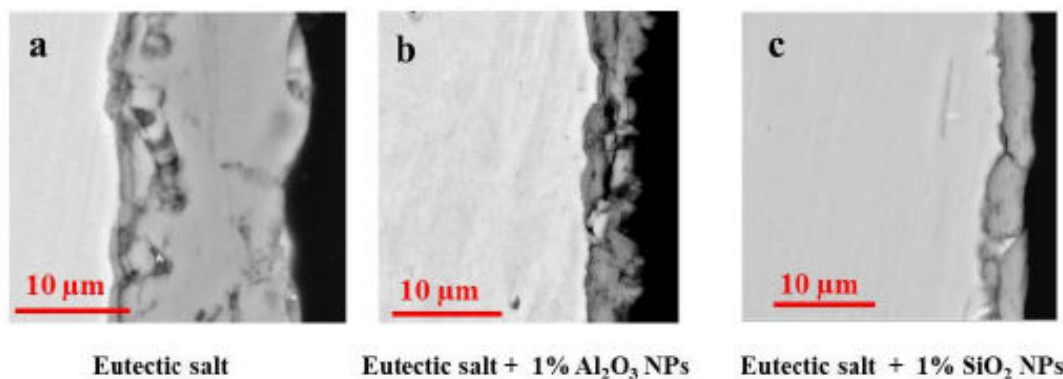


Figure 1. SEM images of the cross section of carbon steel after 1500 hours corrosion tests at 390 °C with a) pure molten salt, b) molten salt + Al_2O_3 NPs, c) molten salt + SiO_2 NPs.

Conclusion

From the performed analyses, oxidation was determined as the main mechanism of carbon steel degradation upon high-temperature corrosion tests with molten nitrate salt. It was found that adding 1%wt of Al_2O_3 and SiO_2 nanoparticles in this salt decreases more than twice the corrosion layer thickness compared to the pure salt. That was explained by observed incorporation of Al_2O_3 and SiO_2 nanoparticle into the corrosion layer. By comparing the obtained results with previous study, it was concluded that adding nanoparticles can have both positive and negative effect on the corrosivity of nanofluid depending on the conditions of the test (temperature for example). It was shown that it is particularly important to control the conditions of microbubbles formation in nanofluid, which enhances the oxidation process.

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Overcoming Barriers to Nanofluids Market Uptake

Design and Characterization of Phase Change Material Nanoemulsions as Thermal Energy Storage and Transport Media

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Keywords: Paraffin, Water, Nanoemulsion, Latent heat storage, Transport properties

INTRODUCTION: Phase change materials, PCMs, have been presented as promising solutions to bridge the gap between energy request and its availability. Phase change material emulsions (PCMEs) or phase change slurries (PCS) have been largely investigated in the last years as potential working fluids which could be used to reduce energy consumption in HVAC systems.[1] They basically contain water and PCMs and as such do possess much larger energy storage capacity than currently used chilled water based systems and higher thermal conductivity of PCMs. Phase change material emulsions (PCMEs), consisting of PCM-droplets stabilized with appropriate surfactants in carrier fluids, are receiving increasing attention to face these limitations [1-2]. Nanometric-sized drops are desirable to ensure long-term stability and ease pumping during phase transition. Nevertheless, sub-cooling issues are typically observed in nanometric sized PCMEs [3]. Thus, a nucleating agent must be incorporated to the dispersed phase in order to reduce the temperature difference between melting and crystallization, a phenomenon that undesirably broadens the operating temperature range. This study presents the preparation and characterization of three different types of paraffin-in-water emulsions as potential thermal energy storage and transport media, covering the temperature range from 20 to 70 °C.

METHODS: PCM-in-water nanoemulsions were prepared by solvent-assisted emulsification and high-energy ultrasonication. Commercial RT55 and RT70HC paraffin waxes (Rubitherm GmbH) and pure n-heptadecane (Alfaesar, 99%) were used as disperse phases, sodium dodecyl sulphate (Alfa Aesar) was utilized as surfactant, while commercial RT55 and n-octacosane (Alfaesar, 99%) were considered as nucleating agents.

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Drop size distributions in both solid and liquid states of PCMs were determined by Dynamic Light Scattering (DLS) using a Malvern Zetasizer Nano ZS apparatus. In order to evaluate stability in the long-term and after cycling, DLS measurements at room temperature were conducted for at least 30 days and repeated for 25 freeze-thaw cycles.

Latent heats and phase change temperatures were determined using two Differential Scanning Calorimeters (Setaram Instrumentation and Q2000 from TA Instruments). Thermal diffusivity was studied by a photoacoustic device and by a ThermTest TPS2500S Hot Disk Thermal Analyzer® (Hot Disk AB), while dynamic viscosity measurements were performed by an AR-G2 rheometer (TA Instruments), with a plate-cone geometry.

RESULTS AND CONCLUSIONS:

A peculiar solvent-assisted procedure has been developed to prepare PCM-in-water emulsions. With this procedure, stable PCMEs with PCM concentrations of 2, 4 and 10 wt% in water were prepared. All emulsions showed very high negative ζ -potentials, meaning a high colloidal stability that decreased in absolute value by increasing paraffin concentration. The reduction of ζ -potential reflected on the particle size that increased with paraffin concentration starting to a minimum of around 60 nm to a maximum of around 220 nm depending on paraffin. The stability was also verified during 25 repeated freeze-thaw cycles, as demonstrated in Figure 1.

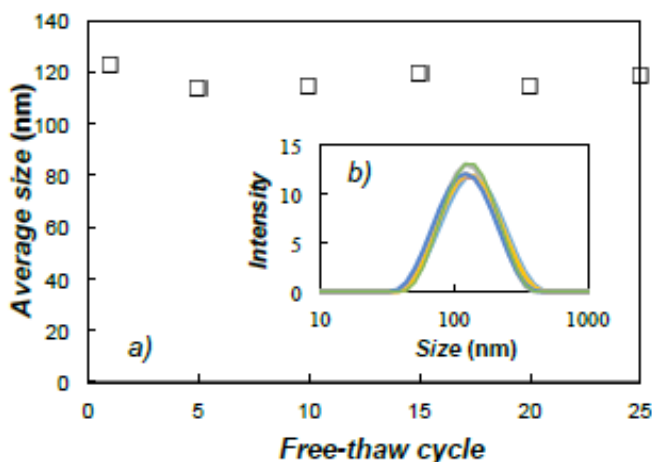


Figure 1. (a) Average size and (b) size distribution of 4wt.% heptadecane-in-water emulsion after repeated freeze-thaw cycles.

Thermal diffusivity measurements showed a moderate reduction of these values with respect to pure water, which increased with paraffin concentration due to the lower thermal diffusivity of paraffin. All samples showed a small increase in paraffin melting temperature, but particularly a sub-cooling effect, that can reach also 15-20°C below the solidification temperature. Therefore, various nucleating agents were tested and will be presented.

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Considering the paraffin concentration and the reported heat of melting of bulk materials, the estimated heat of melting of paraffin into the emulsions was sensibly lower with respect to the expected values and this fact is under investigation. Moreover, the PCM particles size influence on PCMEs was investigated.

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Gold-silica core-shell nanoparticle dispersions in PEG400 as stable phase change materials for thermal energy storage

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Keywords: Au@SiO₂, PEG400, NePCMs, heat storage, thermal conductivity

INTRODUCTION: Energy has been and still is one of the fundamental bases for the progress of humanity and contributes directly to the well-being of societies. It is evident though that energy consumption has a negative impact on the environment and thus enhancing the performance of most thermal facilities has become mandatory. Energy storage allows improving the flexibility of thermal installations by correcting unforeseen imbalances between supply and demand, but also enhances their efficiency and maximize their use [1]. Among different energy storage technologies, phase change materials (PCMs) are particularly attractive due to their large densities of energy storage with reduced temperature differences. In order to face the two main problems preventing practical implementation of PCMs, namely subcooling and low heat transfer rates, the dispersion of additives with high thermal conductivities, also known as Nano-enhanced Phase Change Materials (NePCMs), has been proposed as a promising solution. In this study, new NePCMs were designed as dispersions of synthesized gold-silica core-shell nanoparticles, Au@SiO₂, in a poly(ethylene glycol) PEG400. The influence of Au@SiO₂ concentration on (solid-liquid) phase change characteristics and isobaric heat capacity were analysed in order to provide an insight about the potential of these materials to be used as thermal energy storage media.

METHODS: ~12 nm oleylamine-coated gold nanoparticles were synthesized by quickly injecting a solution of HAuCl₄ and oleylamine in toluene onto a boiling mixture containing toluene and oleylamine. After refluxing for two hours, the resultant gold nanoparticles were precipitated with ethanol, washed several times and redispersed in cyclohexane. In order to enhance their stability in poly(ethylene glycol), the as-prepared nanoparticles were coated with a silica shell by means of a water-cyclohexane reverse microemulsion, using Igepal CO-520 as surfactant, tetraethyl orthosilicate as silica precursor and ammonia as basic catalyst.

A pharmaceutical-grade poly(ethylene glycol) PEG400 supplied by Panreac AppliChem was used as base PCM. Molecular weight and purity of pure polymer were determined by electrospray ionisation mass spectrometry, while thermal stability was evaluated through

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thermogravimetric analysis. NePCMs were prepared following a two-step method by dispersing Au@SiO₂ nanoparticles in the PEG400 with an ultrasonic bath (Ultrasounds, JP Selecta S.A.) working at 20 kHz and with a maximum power of 200 W. The long-term stability of dispersions was evaluated using a Zetasizer Nano ZS (Malvern Instruments) based on dynamic light scattering technique.

The (solid-liquid) phase transitions of the NePCMs were characterized in the temperature range from (193 to 315) K with a Q2000 (TA Instruments) differential scanning calorimeter, DSC, equipped with a RSC90 cooling system. This same device operating with the quasi-isothermal method (TMDSC) was also utilized to obtain isobaric heat capacities in both solid and liquid phases.

RESULTS AND CONCLUSIONS: Dispersed nanoparticles exhibit in NePCMs an average hydrodynamic diameter relatively close to those sizes observed by using Transmission Electron Microscopy, which indicates that no significant agglomeration occur. The addition of Au@SiO₂ does not show any remarkable penalty in isobaric heat capacity, within the studied nanoparticle concentration range. Figure 1 shows the thermograms obtained for base poly(ethylene glycol) and for the NePCM at 0.5% mass concentration, using a heating rate of 2 K·min⁻¹ and cooling rates of 1, 5 and 10 K·min⁻¹.

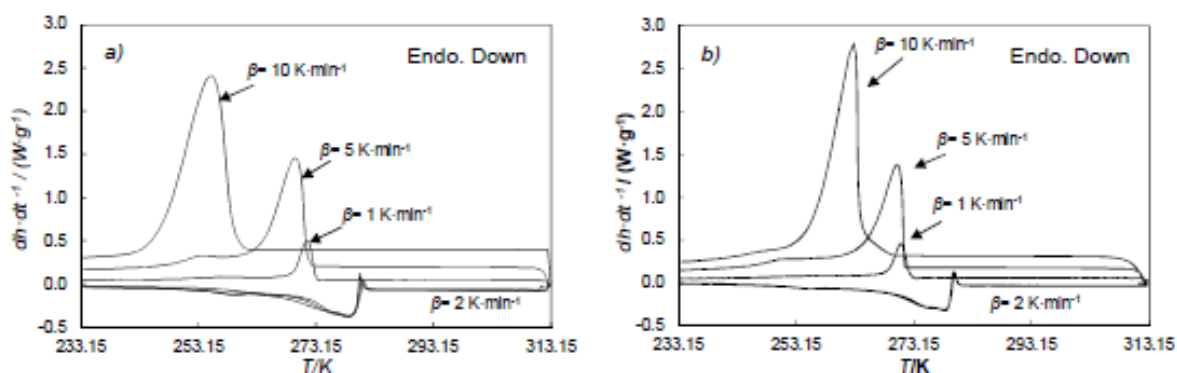


Figure 1. Thermograms obtained at 2 K·min⁻¹ heating rate and different cooling rates for: a) PEG 400, b) 0.5 wt.% Au@SiO₂/PEG400 NePCM.

The addition of Au@SiO₂ nanoparticles eases the heat transfer and reduces subcooling by facilitating heterogeneous nucleation.

ACKNOWLEDGEMENTS: This work was supported by the "Ministerio de Economía y Competitividad" (Spain) and FEDER program through ENE2014-55489-C2-2-R and ENE2017-86425-C2-1-R projects. Authors also acknowledge the financial support by Xunta de Galicia, GRC ED431C 2016-034. D.C. thanks Xunta de Galicia for a postdoctoral fellowship.

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Overcoming Barriers to Nanofluids Market Uptake

Heat transfer study of nanosalt for solar energy storage

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Keywords: nano-nitrate salt (nanosalt), solar energy storage, thermal conductivity, experimental work, CFX of PCM/nano-PCM.

Abstract

My PhD project is about the solar energy storage system using the nitrate salt without and with nanoparticles as a storage medium. Nanoparticles could improve thermophysical properties of the nanosalt material. The specific heat capacity, latent heat and thermal conductivity of nanosalt were increased in comparison to the base nitrate salt without any additives [1]. We tested different types of nitrate salt such as the single salt (potassium nitrate, KNO_3) or the binary solar salt (sodium nitrate (NaNO_3): potassium nitrate (KNO_3) with 60:40 molar ratio). Furthermore, different types and concentrations of nanoparticles were studied such as iron oxide nanoparticle, copper oxide nanoparticles and titanium dioxide nanoparticles [1]. In addition, we studied the effect of the preparation method of nanosalt, as shown in Figures (1 and 2). The in-situ method was compared with the well-known two step method using same concentration and type of nanoparticles and the same base material [2]. In the one step method, the copper oxide nanoparticle was directly prepared inside the binary solar salt under different condition for the preparation procedure [2]. An improvement in the storage energy observed [2]. The other aspect of the PhD project is the large scale experimental setup [3]. In this experimental rig, the heat transfer is studied for nitrate salt and compared with nanosalt. In the experimental rig, temperatures were measured in different radial, axial and theta directions. The effect of nanoparticles types and concentrations were considered and an improvement in the charging process and the cooling process were obtained. The nanosalt showed faster charging and cooling processes than the nitrate salt without any additives. Additionally, a CFX code is built to study the heat transfer using the same dimensions of the experimental set up. The average value of the measured thermophysical properties (such as thermal conductivity and latent heat) were inserted in the CFX code. In addition, the cp of solid

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phase and cp of liquid phase were function of temperature and measured using differential scanning calorimeter device. The density in the CFX code was function of temperature. The CFX code is validated with the experimental data and good matching is resulted as shown in Figure (3).

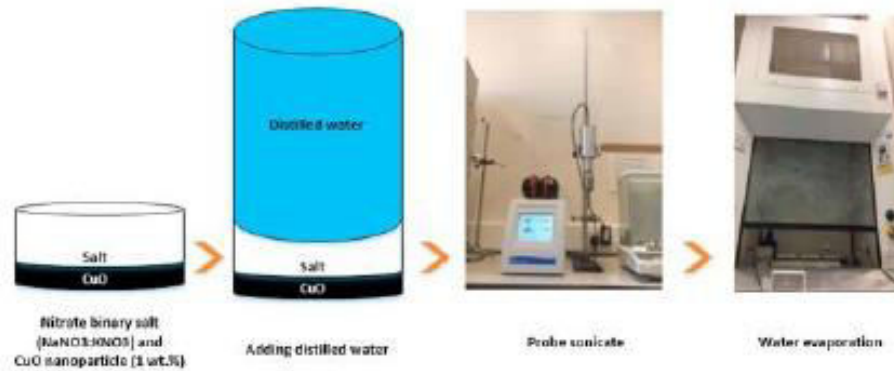


Figure (1) Shows the two-step method of nanosalt preparation.



Figure (2) Shows the one-step method of nanosalt preparation.

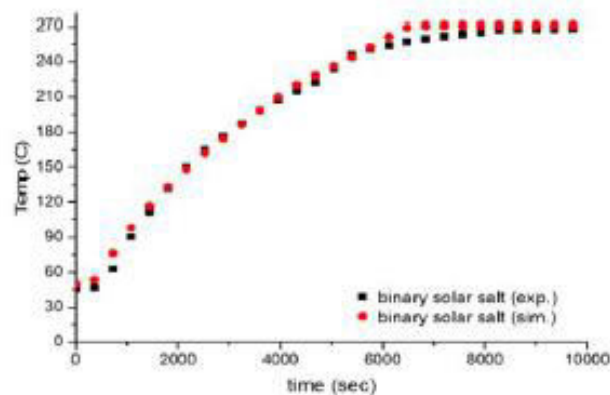


Figure (3) Show the transient temperatures distributions of solar salt (experimental vs simulation data)

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Progress Report about Two-phase CFD Simulations of a Heat Storage Device with Nanofluid

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Keywords: Computational Fluid Dynamics, CFD, Nanofluid, Heat Storage

INTRODUCTION: Thermal energy storage systems can be used if there is a difference between demand and supply of energy. There are several application areas, one of which is the storage of solar power [1].

Nanofluids can be beneficial for heat storage processes with phase change materials due to the increased thermal conductivity because this could lead to higher heat flux through the boundaries. On the other hand the higher dynamic viscosity of nanofluids compared to the base fluid may deteriorate the flow at the boundaries and therefore lower the heat flux. A literature research was conducted about nanofluids, heat storage devices and Computational Fluid Dynamics (CFD) simulations [2]. CFD is the numerical simulation of fluid flow together with heat and mass transfer [3]. CFD enhances the insight in the physical processes under investigation and reduces time-to-market and development cost of engineering systems. To our knowledge no publications about experiments of nanofluid heat storage devices in the sense of an engineering heat storage device with nanofluids investigated experimentally was found as well as no publication about CFD simulations of an engineering heat storage device with nanofluids is available. The CFD simulations with nanofluids focussed on forced convection heat transfer in tubes [e.g. 4] or on natural convection in enclosed cavities [e.g. 5].

To close this lack of knowledge a publication with experiment and CFD simulations of an engineering heat storage device with a phase change material without nanofluids presented in [6] was taken to set up a math. model of it and to validate it. The model was then enhanced with an Eulerian-Lagrangian model for the two-phase modelling of the nanoparticles and first simulations of the heat flux through the boundaries were conducted.

METHODS: For mesh generation Ansys ICEM CFD 17.1 and as the solver Ansys Fluent 17.1 was utilized. The equations solved were for the fluid the continuity equation, the momentum balance equation (to model the change between liquid and solid of the phase change material a porous domain is incorporated) and the energy balance equation with an enthalpy-porosity technique to model the transition domain between solid and liquid [7, 8]. For the nanoparticles Newtons second law was used to model the movement and the energy balance equation for every solid particle was utilised to calculate the temperature [7, 8]. A two-way coupling between particles and fluid was set to calculate the interaction between the

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phases with respect to momentum and thermal energy. The working fluid was an eutectic mixture of potassium nitrate (KNO_3) and sodium nitrate (NaNO_3) with 54:46 wt. %. For the nanoparticles copper was used with a diameter of 100 nm and a concentration of 1.0 vol%.

RESULTS AND CONCLUSIONS: As the design or assessment parameter, i.e. the parameter of interest, the heat flux through the boundary was taken. Comparison of the experimental results without nanoparticles with the simulation outcomes (also without nanoparticles) show acceptable to good agreement.

The simulations with nanoparticles were applied to the charging and discharging process of the heat storage device. For modelling the particles not every single particle was calculated but instead so called parcels were used, where a specific number of particles is put together in a heap. Using the nanoparticles in the simulations for the discharging process converged solutions in time could be obtained, while for the charging process no converged solution in time could be achieved, due so far to unknown reasons. For the discharging process a strong influence of parcel size (i.e. number of particles in a parcel) on the heat flux was noticed. A solution converged with respect to the parcel size could be accomplished for the discharging. Another influence is the numerical mesh size. Meshes up to 16 million cells were investigated for the discharging. So far no mesh converged solution has been achieved. These preliminary results indicate that the heat flux through the boundary is higher for the simulations with nanoparticles. This research will be continued in the second half of 2018 using a 128 core compute cluster in order to achieve mesh converged solutions.

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Overcoming Barriers to Nanofluids Market Uptake

Thermal performance of organic phase change material in the presence of graphene nanoplatelets

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Keywords: NePCM, Graphene Nanoplatelets, Thermal Conductivity, TES

INTRODUCTION: Thermal Energy Storage, TES, with Phase Change Materials, PCMs, has been consolidating as a growing area of research. This can be illustrated by means of the increasing number of publications in the literature in the last two decades [1]. TES has a great number of applications such as space heating and cooling, domestic hot water production or solar energy storage [1].

Commonly used PCMs must have a phase change temperature in a desirable range, a high latent heat and a congruent and reproducible transition [2]. Most of these PCMs have low thermal conductivities, hindering heat transfer processes and so, restricting their field of use [1, 2]. Different possibilities to increase the thermal conductivity appeared in the last years, such as utilization of composites, addition of fins or use of nanoparticles [3]. Dispersions of nanoparticles into PCMs, named as Nano-enhanced Phase Change Materials, NePCMs, improves heat transfer but also the phase change transition, acting as nucleating agent [4].

In this work, graphene nanoplatelets dispersions in PureTemp[®] 8 for cold storage at mass concentrations of 0.5% and 1% were designed. Thermal performance of these dispersions has been characterized by measuring heat capacities, thermal conductivities, and densities.

METHODS: Graphene nanoplatelets, GnP, with a mass purity of 99.5% and a declared size of 11-15 nm were provided by IoLiTec (Heilbrom, Germany), while PureTemp[®] 8, PT8, was purchased from Entropy Solutions (Plymouth, USA). PT8 is characterized, according with manufacturer specifications, by a melting point of 281 K and a latent heat of 178 J·g⁻¹. Acetic acid was purchased from Sigma-Aldrich (St. Louis, USA) with a mass purity of 99.7% and a declared density of 1.049 kg·m⁻³. Each component of the designed NePCMs was weighted in an analytical balance Sartorius CPA225 (Göttingen, Germany) with an uncertainty of 10⁻⁵ g.

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The dry nanoplatelets were characterized by means of Transmission Electron Microscopy, TEM, analyses. The used microscope is a JEOL JEM-1010 TEM (JEOL, Tokyo, Japan) operating at an acceleration voltage of 100 kV. Nanoparticles exhibit a plate-like shape of up to some micrometers, as can be seen in Fig. 1.

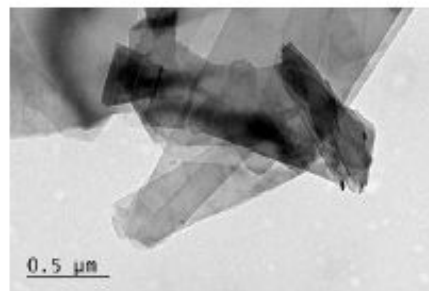


Figure 1. TEM image of dry GnP at x10,000 magnification.

Dispersions of nanoplatelets in PureTemp® 8, GnP/PT8, were performed following a two-step method. GnP were dispersed at 0.5 wt% and 1 wt% by means of an ultrasonic homogenizer Bandelin Sonopuls HD 2200 (Berlin, Germany) during 30 min.

Densities were experimentally obtained with a DMA 500 (Anton Paar, Graz, Austria) vibrating U-tube densimeter, with an estimated relative uncertainty of 0.1%. Thermal conductivities were determined by using a KD2 Pro Thermal Properties Analyser (Decagon Devices, Inc., Pullman, USA) coupled with a KS-1 probe of 1.3 mm diameter and 60 mm long. The estimated standard uncertainty is better than $0.01 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ for the $0.02\text{-}0.2 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ range. Heat capacities were measured by a Differential Scanning Calorimeter, DSC, Q2000 (TA Instruments, New Castle) with an estimated standard uncertainty better than 3% overall the entire temperature.

RESULTS AND CONCLUSIONS: Thermal conductivity and heat capacity of the base PCM and the designed NePCMs were measured in the temperature range from (283.15 to 333.15) K. Instead, density was measured in the temperature range from (288.15 to 313.15) K.

PT8 and GnP/PT8 dispersions exhibit low thermal conductivity values and a decreasing behaviour with the temperature as an organic material. Thermal conductivity enhancements of 12.6% and 23.5% were found for GnP/PT8 dispersions at 0.5 wt% and 1.0 wt% mass concentration, respectively. These enhancements have not temperature dependence.

Acknowledgements: This work was supported by the "Ministerio de Economía y Competitividad" (Spain) and FEDER program through the ENE2014-55489-C2-2-R and ENE2017-86425-C2-1-R projects. Authors acknowledge GRC ED431C 2016-034 Program by the Xunta de Galicia.

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Morphologies and thermal characterization on nanoparticle-seeded salt enhanced by metal foam

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Keywords: HITEC salt, copper foam, aluminium oxide nanopowder, structural characteristics, thermal characterization

INTRODUCTION: Energy crisis accelerate the development of utilization of renewable energy. Molten salts as a phase change material (PCM) can be a potential media for the storage of solar energy as one of renewable energy. HITEC salt (40 wt. % NaNO_2 , 7 wt. % NaNO_3 , 53 wt. % KNO_3) as a typical molten salt has been extensively studied. However, it normally exhibits low thermal conductivity, and effectively improving its thermal conductivity is of great interest. Impregnating PCMs into metal foam appears to be an effective way to compensate the low thermal conductivity, where it might decrease the latent heat and specific heat capacity of the composite to some extent. Dispersing nanoparticles into PCMs can keep and increase the specific heat capacity of the nanocomposite slightly. Thus the integration of metal foam and nanoparticles should be attractive to enhance the thermo-physical properties of pure salt. In this study, aluminium oxide (Al_2O_3) nanopowder seeded HITEC salt/copper foam composite were prepared and characterized.

METHODS: Sodium nitrite, sodium nitrate, and potassium nitrate were mixed with the mass ratios of 40:7:53, and Aluminium oxide nanopowder (Al_2O_3) and nickel with the porosity of 95% were used to enhance the thermo-physical properties of pure salt. Firstly, HITEC salt/ Al_2O_3 nanocomposite was made with dissolution methods, as shown in Fig. 1(a). Pure salt was dissolved into deionized water, and Al_2O_3 with the mass fraction of 1%, 2% and 3% was dissolved in the suspension and the suspension was sonicated for good dispersion, respectively. Then copper foam with the porosity of 95% was physically immersed in the solution. Finally the solution with sonication was reheated in a oven at 250 °C to evaporate the water and make good impregnation. Then the porous copper foam impregnated with salt/ Al_2O_3 nanocomposite was taken out (Fig. 1a). Subsequently scanning electron microscope (SEM) and X-Ray Micro Tomography were used to analyse the material morphologies and inner structure, and both X-ray diffraction (XRD) and Fourier Transform Infrared Spectrometer (FT-IR) were used as the supplement of the component analysis. The effective thermal conductivities of the salt/copper foam composite seeded with Al_2O_3 nanopowder were theoretically predicted with the models, while differential scanning calorimeter (DSC) was used to characterize the phase change behaviour of the composites.

RESULTS AND CONCLUSIONS: SEM image in Fig. 1b indicates that Al_2O_3 nanopowder and copper foam are compatible with salt, as no significant changes of wavelength peaks and intensities were found between pure salt and salt/ Al_2O_3 nanocomposite (Fig. 1c). It was estimated that the effective thermal conductivity of the salt/3

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wt. % Al_2O_3 nanocomposite is 0.818 W/(m K) with modified Maxwell-Garnett model, while that of the salt/copper foam composite seeded with Al_2O_3 is 8.32 W/(m K) using the Calmidi and Mahajan model [1-2], comparing with pure salt of about 0.7 W/(m K), as shown in Fig. 1d and 1e. In addition, slight variation of the extrapolated onset melting temperatures was found between pure salt and the composite. The composite PCMs with good physical and thermal characteristics can be the effective medium in the solar energy storage application.

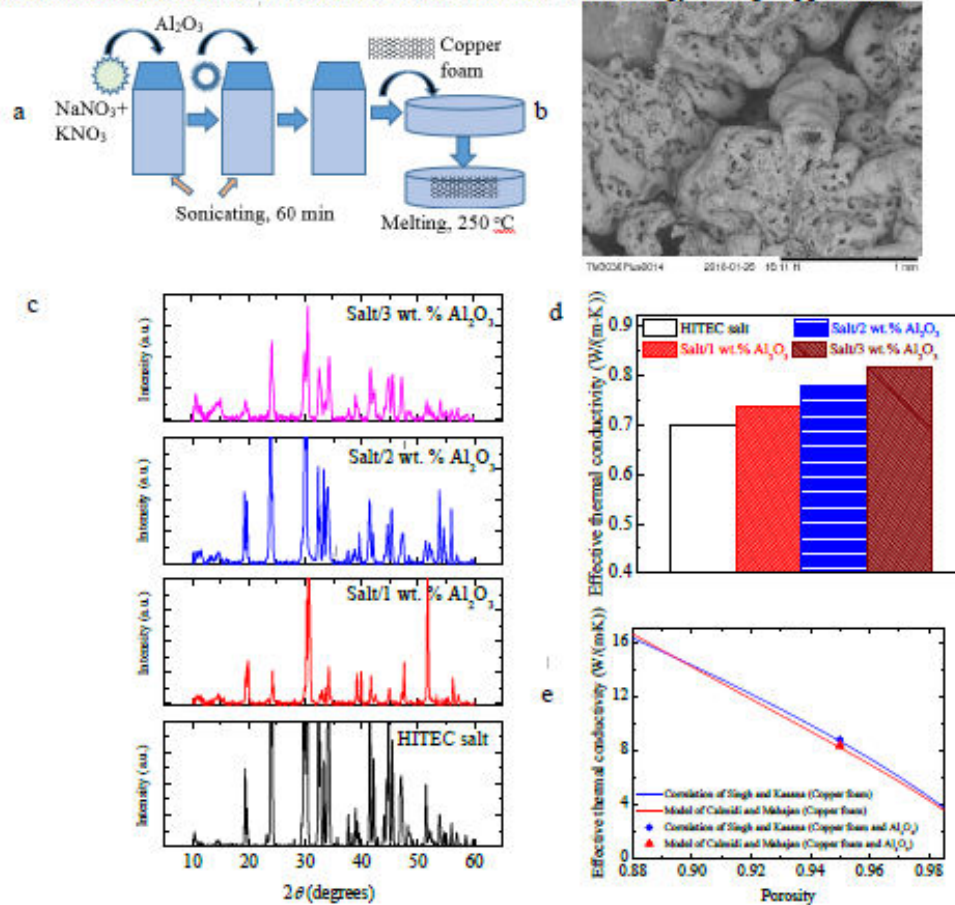


Figure 1: Preparation and thermal characterization of salt/copper foam composite seeded by Al_2O_3 : synthesis process (a), SEM picture (b), XRD (c), effective thermal conductivities of salt/ Al_2O_3 nanocomposites (d) and effective thermal conductivity (e).

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Tailoring the properties of Nanoparticles by ALD Nanocoatings

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In this paper we present a gas-phase coating technology, atomic layer deposition (ALD) that allows the deposition of nanometer-thin conformal coatings on a wide variety of particles (Figure 1). The versatility of ALD covers both the nature and size of the particles, as well as to the chemistry of the coating [1]. For example, particles ranging from nanoparticles to particles of several hundreds of micrometers can be coated with this technique. Additionally, the nature of the substrate can be ceramic (e.g. Al_2O_3 , TiO_2 , SiO_2), metallic (Ti), and polymeric (powder coating paints), amongst many others. The nature of the coating can be also selected from metal oxides (Al_2O_3) or nitrides (e.g. AlN), pure metals (e.g. Pt), organic coatings and even inorganic-organic hybrid coatings [2]. These thin films can be also used for nanofluid applications, achieving an encapsulation of the nanoparticles comprising the nanofluids without interfering with their intrinsic heat properties.



Figure 1. (left) Reaction mechanism of one cycle of atomic layer deposition. (right) Titanium oxide nanoparticles coated with aluminium oxide using ALD [3].

In recent years, atomic layer deposition (ALD) has become a standard tool to apply ultrathin and conformal coatings on substrates of complex geometries, mostly driven by an interest from semiconductor industry applications. The intrinsic advantages of controlling the structure growth at the (sub)nanometer level, while coating complex surfaces – either for providing protection to the substrate or boosting its activity – are also relevant for other industrial applications related to particle technology, such as nanofluids.

In this presentation we will also show one example of the influence of nanometer-thin aluminium oxide films used to encapsulate a polymer-based powder, which confined the softened core material without altering the thermal properties. That can be of use with nanofluids based on phase change materials.

This example aimed at tuning the surface finish of a standard polyester-based powder coating paint, from gloss to matt (Figure 2, left), by depositing ultrathin films of Al_2O_3 on the powder coating particles [4]. The coating experiments were performed in a fluidized bed reactor at 1 bar and 27 °C, using an alternating exposure of the particles to the two precursors (trimethylaluminium and water). By varying the number of coating cycles from 1 to 9, we deposited alumina films ranging from 1 to 30 nm. When the average alumina

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shell was thicker than 6 nm, the shell prevented the flow of the core particles, even though the powder particles did soften above their glass transition temperature. With the particles morphology intact, this resulted in a rough and matte surface finish of the coating after curing. Additionally, the alumina coating acted as a barrier able to encapsulate the softened powder coating above the glass transition temperature, without altering other thermal properties as such as the glass transition temperature (Figure 2, right). This type of application can be extended to the encapsulation of phase change materials with thin alumina films, that would contain a molten core without modifying the thermal properties, which is of crucial importance in the development of efficient nanofluids.

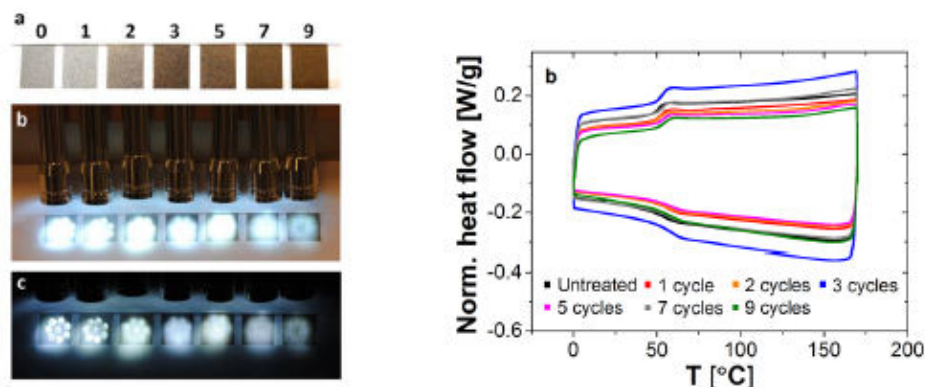


Figure 2. (left) Tuning of the surface finish of the paint from gloss to matte depending on the thickness of the deposited aluminium oxide film. (right) Differential scanning calorimetry profiles of the uncoated and coated powder coating samples.

In this presentation we will show the process of depositing ultrathin films on particles with the coating technique atomic layer deposition, and will present an example on how the performance of a material can be tuned without altering other physical properties such as density, heat capacity, shape or size. Additionally, we will explain how the coating process works, and what can be further done with this versatile technique, aiming at a scaled up process able to produce coated particles at industrially relevant volumes. Finally, we will discuss how this technique could contribute to the development of new nanofluids. This technique can be interesting for this emerging application, since from other fields it has been proven that ultrathin films can enhance the performance of other materials, perhaps applications for nanofluids being the next one.

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ABSTRACTS WORKING GROUP 4

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Overcoming Barriers to Nanofluids Market Uptake

Characterization of graphene oxide nanofluids

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Keywords: graphene oxide, characterization, DLS, size distribution, nanofluid

INTRODUCTION:

Graphene is a two-dimensional sheet of sp²-hybridized carbon. Despite the huge interest in this material, there are few works devoted to the study of nanofluids based on graphene. In particular, there is a lack of studies connecting the accurate characterization of the nanofluids with respect to the temperature range used in the real application with the nanofluid performance in such a system, e.g. in heat exchanger.

During my previous STSM stays at ILK Dresden [1], [2] we found that nanofluids may improve heat transfer capabilities of the thermosyphon, especially for low temperatures of evaporator. Due to the fact that nanoparticles deposit into a porous layer on the inner surface of the evaporator during experiments, their properties are time- and temperature-dependent. This issue is generally neglected in the literature and properties are mostly measured or calculated at ambient conditions. Thus, precise characterization of nanofluids in the dependence of temperature are highly required.

METHODS:

Samples of graphene oxide were synthesized from source graphite through the modified Hummers method [1]. Source graphite material was oxidized chemically through a treatment with a solution of 95% sulfuric acid, sodium nitrate and potassium permanganate in the temperature of 50°C. After oxidation, slurry was diluted in deionized water and then H₂O₂ was added. Afterwards, the solution was washed in a microfiltration device. The resulting solution of concentrated graphene oxide (GO) was diluted to ensure concentration of 1.0 g/L, one of the samples was enhanced with 0.1 g/L of sodium dodecyl sulfate (SDS) and mixed for 4 hours. These samples are stable for over 4 months. Before DLS measurement, the samples was diluted to the required concentration, sonicated for 2 minutes and taken directly for an experiments.

Malvern Zetasizer Nano-ZS and Vasco Flex Particle Size Analyzer have been used to determine the averaged hydrodynamical radius of graphene nanoparticles in the temperature

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range from 25 to 85°C and concentration between 0.1 and 1 g/l. Both devices rely on Dynamic Light Scattering (DLS) method which is commonly used to characterize the size of nanoparticles dispersed in liquids.

RESULTS AND CONCLUSIONS:

The properties of graphene oxide (GO) and water-based nanofluids were determined in respect to concentration, temperature range (25-85°C) and the amount of added sodium dodecyl sulfate (SDS). The main findings are:

- The mean hydrodynamic diameter of graphene-oxide flakes increases with decreasing concentration of graphene nanoparticles. Literature data on this dependency are ambiguous.
- The size of nanoparticles decreases with increasing temperature. Nanofluids are water-based and thus bad quality results for temperatures higher than 75°C may occur due to intensive evaporation and possibility of bubble formation. The research on the GO size dependency on the temperature is not available in the literature and there is no possibility to compare the results.
- Added surfactant did not affect the particle size distribution with a recognizable trend.

The results require further analysis. Although, DLS is said to be reliable for spherical particles, the rough estimation of sizes and trends depending on conditions is also possible for non-spherical objects as well. Care should be taken with respect to the working conditions.

ACKNOWLEDGEMENT:

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The results obtained during STSMs of Agnieszka Wlazlak were presented during ESNf2017 and TFEC2018 conferences [1], [2], submitted as a journal paper (currently under review process) and accepted for IHTC 2018 conference [3].

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Overcoming Barriers to Nanofluids Market Uptake

A Proposal for Thermal Conductivity Measurements of Magnetic Nanofluids Under the Influence of External Magnetic Field

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Keywords: magnetic nanofluid, magnetic field, thermal conductivity, MEMS, Fe₃O₄

INTRODUCTION: Magnetic nanofluids or ferrofluids are colloids which comprise of nano-sized magnetic particles suspended in a non-magnetic carrier liquid. The magnetic particles typically can be magnetite (Fe₃O₄), maghemite (γ-Fe₂O₃), cobalt etc. with their excellent magnetization properties where the non-magnetic carrier liquids can be water, ethylene-glycol, oil, kerosene. They have the potential to be utilized in many different applications such as lubrication, sealing, ink jet printers, dampers, clutches, optical filters, optical sensors, biosensors, biomedical, drug delivery, refrigeration, cooling devices [1]. The ability of being manipulated by an external magnetic makes magnetic nanofluids attractive for especially micro-electromechanical systems (MEMS). Among these micro-sized systems, microfluidics become prominent for heat transfer applications. So that, it is important to investigate the thermal properties such as thermal conductivity of the magnetic nanofluids in the absence and presence of the external magnetic field before employing them in microfluids or other smart cooling devices. In this study, the thermal conductivity of Fe₃O₄-water magnetic nanofluid has been measured under the effect of external magnetic field and the methodology of the magnetic field dependent measurements has been discussed.

METHODS: Fe₃O₄ water magnetic nanofluid with 20% wt. concentration has been supplied commercially from US Research Nanomaterials. The average particle diameter of the sample is 15-20 nm. In order to generate magnetic field, permanent magnets are used. A simple magnet holder design was used for applying magnetic field to the magnetic nanofluid sample. The magnetic field strength was controlled by altering the distance between magnets. The generated magnetic field was measured by a gaussmeter. The magnetic flux density in the air gap between two magnets was simulated. The simulation results were also validated the experimental data obtained by gaussmeter. The thermal conductivity of the magnetic nanofluid was measured by 3-omega method.

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RESULTS AND CONCLUSIONS: Experiments were carried out with two different orientation of the external magnetic field. First, perpendicular and then parallel orientations were applied. That means, the magnetic field lines are parallel or perpendicular to the temperature gradient caused by measurement probe. Figure 1 indicates that the thermal conductivity increases with the application of the external magnetic field. The possible reason behind this phenomenon can be explained by the chain aggregation formation of the magnetic nanoparticles under the influence of the external magnetic field [2].

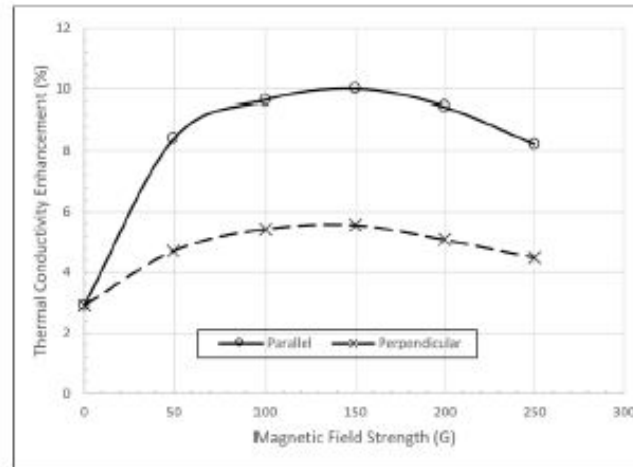


Figure 1 Thermal conductivity enhancement in respect to the external magnetic field strength for both parallel and perpendicular orientation.

Figure 1 also reveals that the thermal conductivity enhancement decreases after 150 G. That can be related with the non-uniformity of the external magnetic field after that point. In the non-uniform magnetic field, there will be a force acting on the magnetic nanoparticles [3]. This causes to the breaking of the chainlike structure and therefore the decrement of the thermal conductivity. Moreover, the thermal conductivity is higher when the applied external magnetic field is parallel to the temperature gradient.

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Wettability Behaviour of Nanofluids

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Keywords: Nanofluids, Surface Tension, Contact Angle, Wettability

INTRODUCTION:

This study presents the discussion of the surface tension (ST) and contact angle (CA) measurements of nanofluids which were done in İzmir Katip Celebi University within the scope of Nanotension Project which is a part of NANOUP TAKE COST Action, and comparison of the results with the available data in the literature.

METHODS: Measurements were performed with graphene oxide+distilled water (GO+DIW) (length of flakes=800-1000 nm, 0.1 g/l), alumina+distilled water (Al₂O₃+DIW) (averaged size 122-125 nm, 0.1 vol.%) and gold+distilled water (Au+DIW) (size < 10 nm, 10 mg/l) nanofluids. ST of nanofluids were measured by using pendant drop method (Biolin Scientific Attension Theta - Optical Tensiometer) and Du Noüy ring method (Biolin Scientific Attension Sigma 701 - Force Tensiometer). CA of samples on V2A 1.4301 stainless-steel substrate was measured by using sessile drop method (Biolin Scientific Attension Theta - Optical Tensiometer). During experiments temperature ranged between 21.5°C and 23.7°C.

RESULTS AND CONCLUSIONS:

Figure 1 shows the comparison of ST results with the available data in the literature (temperature range between 20°C and 30±2°C, size of nanoparticles between 5-nm to 200-nm) [6-16]. A reduction in ST with reference to base fluid has been observed for all nanofluids and for both devices in the present study. Results for water are comparable with the results in literature except simulation result reported by Sinha and Singh [1]. For Al₂O₃+DIW nanofluid,

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both a decrement and an increment were observed. Although, [2] and [3] used same methods with us, they found increasing ST compared with the base fluid. There is a lack of studies about ST of Au+DIW and GO+DIW nanofluids. For Au+DIW nanofluid, ST results by sessile drop method [4] were lower than our results but in the simulations of Au-DIW nanofluid [1], ST was found more than the base fluid and our results. Zheng [5] found the ST of GO+DIW nanofluid greater than the base fluid, which is contrary to our results. Sinha and Singh [1] have reported an increase in the ST with increasing hydrophilicity and a decrease with increasing hydrophobicity as a result of simulations for Au-DIW nanofluids. In the concentration range between 1.72 and 14.78 vol.%, ST increases from 64.02 to 79.84 mN/m for hydrophilic nanoparticles whereas it decreases from 63.03 to 48.77 mN/m for hydrophobic nanoparticles. Considering the hydrophilic or hydrophobic behaviour of the fluid, the main reason of decrease in ST of nanofluids may be the hydrophobic nature of nanoparticles. Hydrophobic nanoparticles are gathered on the free surface of the fluid. The repulsive force between particles and fluid molecules increases the interfacial spacing at the interface and reduces the attractive forces between fluid molecules in bulk fluid, thus causes to reduction in surface tension [12-15]. The maximum reduction has been obtained in gold-DIW nanofluid and it might be the result of using stabilizer, which is already mentioned in the literature [16]. Decrement in CA can be the reasoned by considering the improvement of surface wettability via hydrophilic behavior of the stainless steel. Figure 2 reports the CA values. Comparing the data with literature is difficult due to the custom-made surface samples.

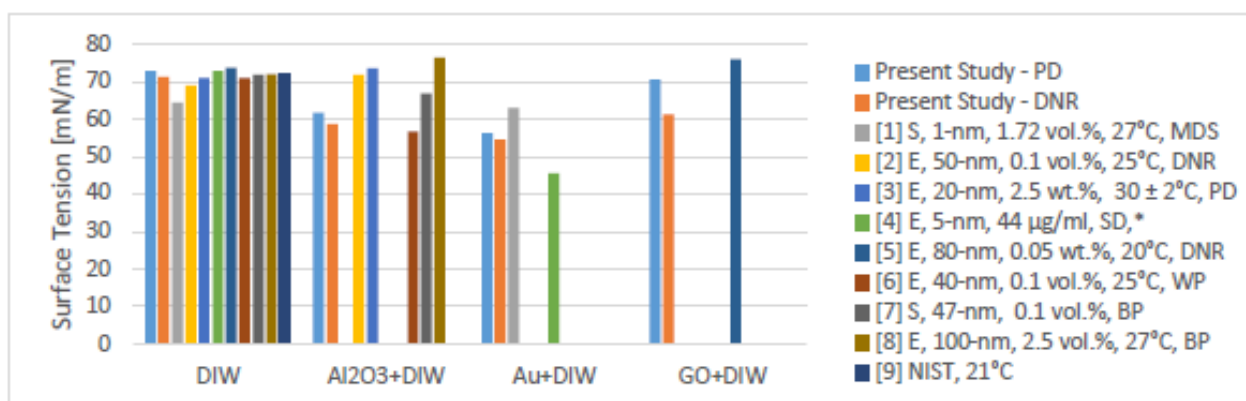


Figure 1. Surface tension of nanofluids. (E: Experimental, S: Simulation; PD: Pendant Drop, SD: Sessile Drop, WP: Wilhelmy Plate, BP: Bubble Pressure, DNR: Du Noüy Ring, MDS: Molecular Dynamic Simulation; *:The nanoparticles were functionalized with a proprietary carboxylic acid and the solution could contain <0.1% of residual hydroxides.)

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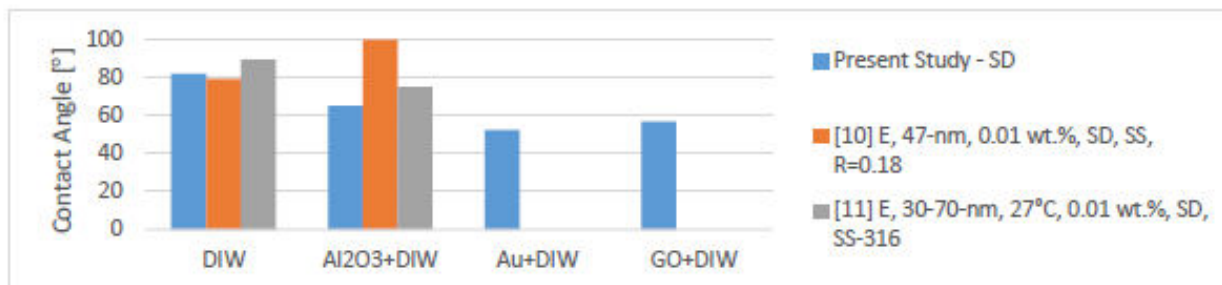


Figure 2. Contact angle of nanofluids (E: experimental, S: Simulation; SD: Sessile Drop; SS: Stainless steel, R: Roughness)

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Overcoming Barriers to Nanofluids Market Uptake

THE EFFECT OF OXIDIZED CARBON NANOHORN NANOFUID POOL BOILING ON AN ALUMINUM SURFACE

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Keywords: pool boiling, nanofluids, critical heat flux, contact angle, coating

INTRODUCTION:

Boiling is known as one of the most effective mechanisms of heat transfer and it is used in many engineering applications that require high heat flux dissipation. It has been demonstrated that the use of nanofluids can enhance the heat transfer efficiency. Several factors as type, size and concentration of nanoparticles, characteristics and geometry of the surface heater, presence of surfactants and pressure have an influence on boiling behaviour [1-4]. The objective of the present study was to investigate the difference in pool boiling between based-water nanofluid and water. The nanofluid used for the pool boiling was based on water using oxidized carbon nanohorns (oxCNH) at 0.1% weight concentration on an aluminium (Al) surface. Before and after the boiling test, scanning electron microscopy (SEM) and contact angle (CA) measurements were performed to characterize and evaluate the resulting coated surface. Also the boiling curves of both fluids were measured.

METHODS:

Pool boiling tests were carried out in an experimental setup that consists of an Al surface, which was exposed to the working fluid and heated by electrical cartridge heaters. All the pool boiling experiments took place inside a confined chamber in order to avoid contamination. On the top, there is a condenser, which is directly fed with the vapour formed.

On the other hand, CA measurements were obtained by image processing. Finally, to study the effect of the pool boiling on the surface and evaluate if deposition of nanoparticles has

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taken place, SEM images were performed with a SIGMA Zeiss instrument (Carl Zeiss SMT Ltd., UK).

RESULTS AND CONCLUSIONS:

SEM images of the Al surface before and after the boiling are presented in Fig. 1. Nanoparticles deposition was observed after the pool boiling.

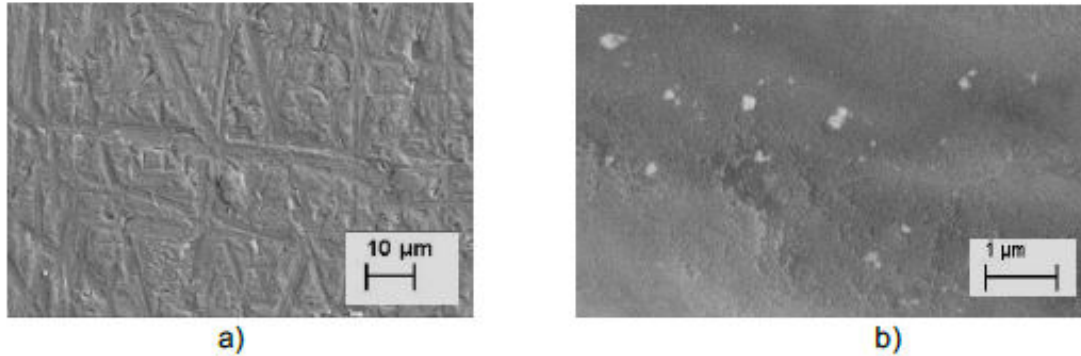


Fig. 1 SEM images of Al surface (a) before and (b) after the pool boiling.

The values obtained for the CA measurements are for water 74° and oxCNH 76.3° on Al surface before the boiling and then, 70.6° and 69° for water and oxCNH, respectively, on the Al surface after the pool boiling. The boiling curves for water as reference and oxCNH nanofluid are given in Fig. 2, showing that nanofluid wall superheat values are higher than those for water. In fact, there is not any noticeable effects of the nanoparticles deposited layer on the contact angle measurements.

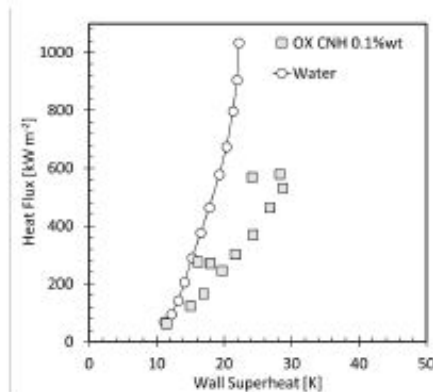


Fig. 2 Boiling curves of water as reference and oxCNH 0.1% wt in water.

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Overcoming Barriers to Nanofluids Market Uptake

Numerical simulation of a nanofluid in a pipe flow

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Keywords: Nanofluids, single-phase model, mixture model, water, pipe flow

INTRODUCTION:

In the framework of the NANOROUND project, started within NANOUP TAKE to compare and validate different nanofluid modelling approaches, we present preliminary results of simulations of laminar nanofluid flow in a heated pipe. We present two models that can solve the flow of a nanofluid. In order to validate our models, we have first, performed water flow simulations in a pipe. Thus, we could compare the numerical simulated flow of water with the numerically simulated flow of nanofluid and look at the differences.

Nanofluids are a mixture of a base fluid and nano particles. The base fluid is usually water. Two approaches can be considered in order to simulate flow of a suspension of particles. The Euler-Euler method or the Euler-Lagrange method. In this study, we used the first method. In this procedure, the fluid and the particles are considered as a continuous fluid. We present the single phase model and the mixture model. An investigation using the single phase model was presented by Ravnik et. al [1]. In this model, the properties of the fluid are obtained from empirical correlations. The mixture model is more complex. The model requires an additional equation in order to solve the dispersion of nano particles in the fluid. Khalili et. al [2] presented the model in order to simulate the flow of nanofluid in a circular enclosure. An experimental investigation into the problem, which we have simulated, was done by Colla et. al [3].

We performed a number of numerical simulations of the nanofluid flow using the same setup. The mass flow rate, heat flux and particle volume fraction were changed.

METHODS: We tested two numerical models in order to simulate the flow of a nanofluid in a heated pipe. The same test case was implemented as it was presented in the experimental test case by Colla et. al [4].

Four conservation laws were implemented in order to solve the fluid flow. Let us consider the vector \vec{v} as velocity vector field. Firstly, the continuity equation for incompressible fluid flow is employed:

$$\vec{\nabla} \cdot \vec{v} = 0. \tag{1}$$

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Secondly, the momentum conservation equation with the Boussinesque approximation of the lift force was implemented:

$$\rho \cdot \vec{v} \nabla \vec{v} = -\vec{\nabla} p + \eta \Delta \vec{v} - \rho \beta \vec{g}(T - T_0), \quad (2)$$

where ρ is the fluid density, η is the dynamic viscosity and β is the thermal expansion. After the velocity field is solved, the temperature field is determined with the energy equation:

$$\vec{v} \cdot (\rho \vec{v} h) = \vec{\nabla} \cdot (\lambda \vec{\nabla} T), \quad (3)$$

where T is the temperature, h is the enthalpy and λ is the thermal diffusivity. The last conservation law is the concentration conservation:

$$(\vec{v} \cdot \vec{\nabla}) \varphi = -\vec{\nabla} \cdot (\vec{j}_B + \vec{j}_T), \quad (4)$$

φ is the particle volume fraction, \vec{j}_B is the Brownian motion and \vec{j}_T is the thermophoresis [5]. The water simulation was performed with equations (1), (2) and (3). In addition, the single phase model was also solved with this three equations. In this model: ρ , η and λ are the properties of the nanofluid. The nanofluid properties were solved from empirical expression, where the properties of the base fluid and nano particles are considered [1]. The second model is the mixture model. In this model equation (4) is employed [2]. This additional equation solves the particle volume in the domain.

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CFD modelling of volumetric vapour generation and its applications to the receiver design

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Keywords: Computer Fluid Dynamics, Multiphase Flow, Radiation, Boiling

INTRODUCTION:

Classic solar-thermal receivers base their performance on the heating of the containers surface. This leads to both high surface temperatures and high radiative losses. Also, accident scenarios may lead to critical heat flux conditions thus degrading the surface material. These drawbacks are tackled when the whole volume of the receiver is used as an absorber. In particular, direct volumetric vapour generation has been proposed to further improve the efficiency of solar receivers [1]. The fluid mechanics of these systems is quite complex given that: (1) the nanofluid absorbs the light field to generate the secondary phase; (2) the two fluid phases exchange mass, momentum and energy; (3) the members of the secondary phase interact between (coalescence and break-up); (4) the secondary phase scatters the light field. Therefore, simple design tools are not able to provide a proper description of their performance. In this contribution we propose the use of Computer Fluid Dynamics to account for these effects. A simple proof-of-concept design example is given.

METHODS:

The simulation relies on the so-called two-fluid model [2]. Here, the nanofluid is modelled as a single phase with constant density and viscosity, and vapour bubbles are modelled as a Eulerian dispersed phase with a given diameter distribution.

The source term for the vapour is modelled as $f N V_b$, being f the nucleation frequency of a site, N the nucleation site volumetric density, and V_b the mean volume of the generated bubbles. To include the bubble scattering, a simple experiment was carried out (see Figure 1). A LED panel was used as light source, and a diffuser served to generate air plumes with different gas-hold up conditions. Image processing permitted to propose a correlation for the scattering coefficient in terms of the volumetric gas concentration.

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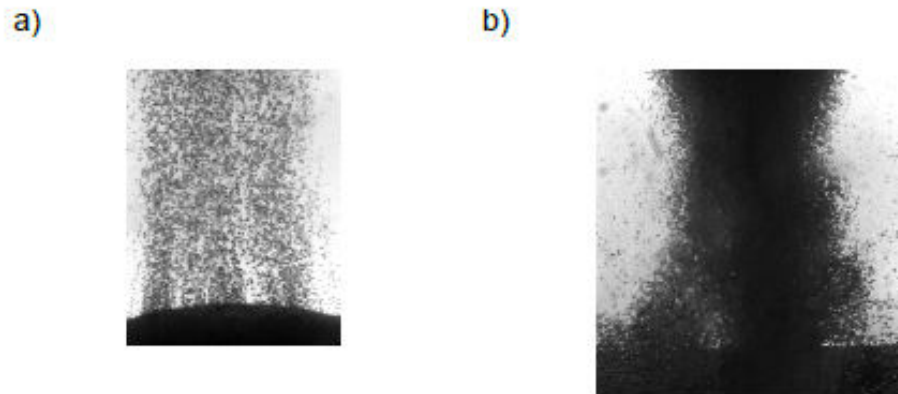


Figure 1: Sample images for low (a) and high (b) gas hold-up conditions.

RESULTS AND CONCLUSIONS:

Figure 2 shows the results for a cylindrical receiver on three scenarios. In case a), a high nanoparticle concentration limits the gas generation to the regions near the surface. This is an undesirable configuration, as most part of the receiver is not acting as expected. In order to avoid it, the nanoparticle concentration can be reduced to produce a most uniform gas distribution, as shown in case b). Alternatively, at high nanoparticle concentrations in a) may be preserved if the receiver diameter is reduced as in c).

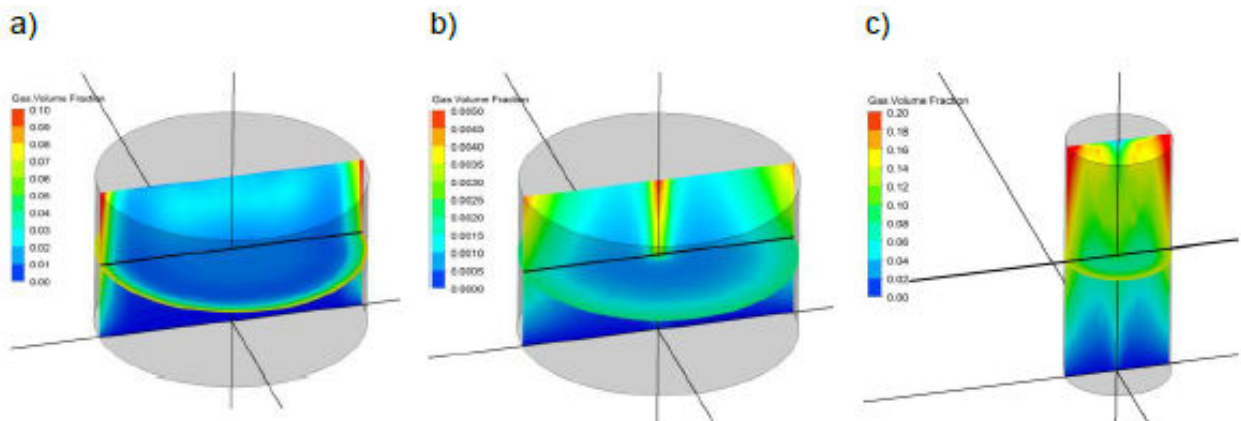


Figure 2: Gas distribution for the three scenarios considered.

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Plasmonic Nanofluids for Solar Cells Applications

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Keywords: plasmonics, laser ablation, electrospray, silver, transition metal nitrides

INTRODUCTION: Nanomaterials and especially the nanoparticles paves novel interdisciplinary ways in a wide-range of applications, from electronics to medicine (biosensors) to energy harvesting (solar cells) and buildings (self-cleaning). This work focus on fabrication and the properties of plasmonic nanomaterials and specially plasmonic nanofluids for solar energy harvesting applications. [1, 2]

METHODS: The plasmonic nanofluids were fabricated using a combination of Laser Ablation processes in aquatic and isopropanol solutions. The 532 nm beam of a picosecond (ps) Nd:YAG laser is used to ablate a silver target and to form silver NPs in the solutions. Secondly, the 532 nm and 355 nm beams of a nanosecond (ns) Nd:YAG laser was employed to refine the silver NPs size distribution and in this way to tune the localized surface plasmon resonance (LSPR) of the plasmonic nanofluid.

The optical properties of the plasmonic nanofluids were evaluated by optical transmittance measurements in the Visible-UV spectral range, while the NPs size distribution and their concentration in the liquid were evaluated after analysis of the transmission spectra and by dynamic light scattering (DLS).

Electrospraying was used to spray to incorporate/add the metal NPs in the structure of an organic solar cell. Thus, the plasmonic solution was sprayed on top of the hole transport layer and in this way a plasmonic layer was introduced at the interface between the hole transport layer (PEDOT:PSS) and the active (P3HT:PCBM) layer.

RESULTS AND CONCLUSIONS: Silver was used as the target material for the fabrication of plasmonic nanofluids. The 532 nm beam from the ps laser resulted to the fabrication of silver nanofluids that showed a broad, not so intense plasmonic peak at the ~ 400 nm, due to the large variation in the size distribution of the Ag NPs. The size of the Ag NPs in the aquatic solution was refined by irradiating the nanofluid with an out-of-focus 532 nm and 355 nm beams from the ns laser. The plasmonic peak in the absorbance spectra appeared more intense (the absorption increases from 0.3 to 0.9) and the analysis showed the absorption peak is less broad, thus the Ag NPs size distribution is narrower, and the under the curve

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area is double as a result of the Ag NPs population increase due to the successful fragmentation of the pristine Ag NPs.

The Ag plasmonic nanofluids were electrospayed into the organic solar cells layers. Specifically they were mixed with PEDOT:PSS and developed on top of the P3HT:PCBM photoactive blend, in order to take advantage of the plasmonic effects.

The devices were tested under AM1.5G at 1000 W/m^2 of illumination, which showed the fabrication of efficient plasmonic solution processed solar cells with improved V_{oc} , FF and J_{sc} values and slightly higher power conversion efficiency compared to this of the non-plasmonic/reference ones.

Finally, the case of the fabrication and the properties of the transition metal nitride nanofluids as well as their possible applications is discussed. [3]

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Performance evaluation of a solar cooling system with nanofluids

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Keywords: Solar Cooling, Nanofluids, Transient simulation, Renewable Energy, Energy Management.

INTRODUCTION: An interesting solution for air conditioning in summer time is a solar cooling system. The use of nanofluids is a possibility to enhance thermal performance of solar components. A review on the applications of nanofluids in solar energy field is developed by Khanafer and Vafai [1]. The objective of our investigation is to model and simulate a complete solar cooling system made up of ETCS (evacuated thermal solar collectors), thermal storage tank and LiBr-H₂O based single effect absorption chiller. As working fluids nanofluids with three particule volume concentration are considered: pure water, Al₂O₃-water based with two different volumetric concentrations 3% and 6%.

METHODS: The solar system, based on a single effect absorption chiller (15 kW of power), is fully modelled in TRNSYS with weather data of Naples as the reference climate data. The ETSCs, a storage tank, a hydraulic pump and a controller are considered for the hot loop. Physical properties of the Al₂O₃ nanoparticles and water such as thermal conductivity, specific heat capacity, density and dynamic viscosity are evaluated from literature. Thermal efficiency solar collector equations are given in Ghaderian and Sidik [2].

RESULTS AND CONCLUSIONS: Simulations are performed for the whole summer season, i.e. from June to September. The nanofluid flows into the collectors and reaches a hot storage tank at temperature $T_{coll,o}$ by means of a pump. In the tank nanofluid heats water at temperature $T_{st,o}$, which is lower than 90°C. Hence, the ETSCs work isolated from the chiller and the loop of the first part of the system continues until the water inside the storage tank reaches the required working temperature. The TRNSYS simulation was run with 1-hour time step. The selected system successfully maintained the room temperature below the set point value of 26 °C, even when the ambient temperature was more than 32 °C during peak summer season, Figure 1.

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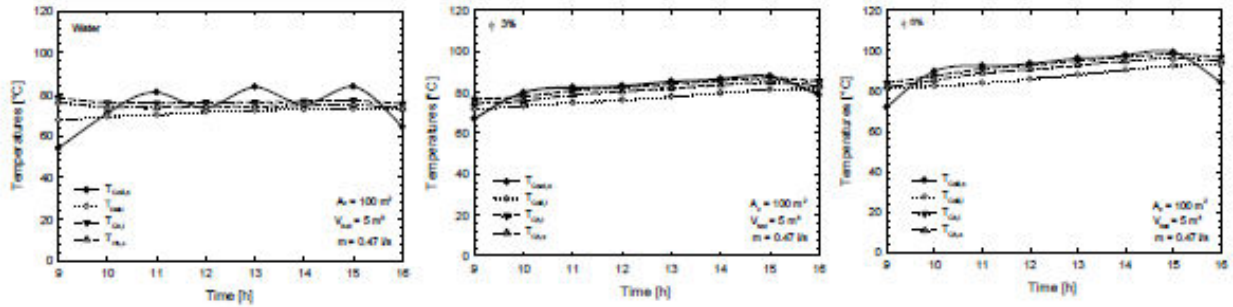


Figure 1. Temperatures profile in a typical summer day (30 July)

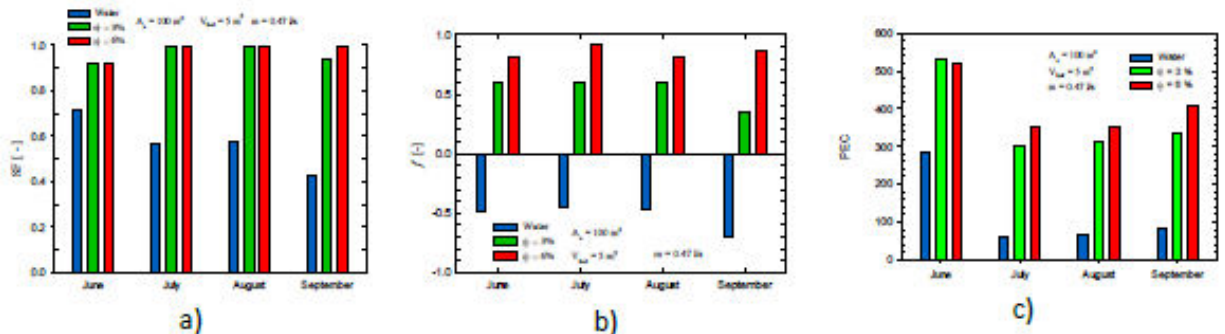


Figure 2. Performance results vs month: a) solar fraction; b) primary energy savings; c) PEC

In terms of SF (Solar Fraction), Figure 2a, configuration with nanoparticles is better for whole cooling season, obtaining SF=1 in July, August, September and July and August for $\phi=6\%$ and 3% , respectively. Considering the fractional energy savings, f , configuration with $\phi=6\%$ offers greater savings than pure water. Finally, the configuration with particle concentration of $\phi=3\%$ presents higher pumping energy consumption than the other two. Compared with pure water, the pumping energy consumption is higher because the viscosity of the fluid is higher. Compared with nanofluid with $\phi=6\%$, the pumping energy consumption for lower concentration is higher because the effect of outlet hot water temperature from absorption chiller on temperature of the storage tank is greater, thus the pump remains on for longer. However, the difference is minimum in terms of energy cost so PEC for collectors which use nanofluids with $\phi=6\%$ is higher in summer season.

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Overcoming Barriers to Nanofluids Market Uptake

Towards highly stable nanofluids for Concentrating Solar Power

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Keywords: Nanofluid, Stability, Concentrating Solar Power.

INTRODUCTION: The colloidal suspension of a nanomaterial in a base fluid, typically called nano-colloids or nanofluid, is an emerging system that can be used as heat transfer fluid (HTF) due to the enhanced thermophysical properties with respect to the conventional fluids, such as air, water, ethylene glycol, or synthetic oils [1-4]. That is why nanofluids are considered as potential HTFs which will improve the efficiency of the exchangers involved in renewable power generation [5]. But stabilization of nanofluids is one of the main requirements for this kind of systems, since high stability leads to good and sustainable thermal properties [6]. Therefore, the use of 2D nanomaterials could be a major advance in these systems since these nanomaterials present good physical stability, which is reflected in low sedimentation levels when they are in colloidal suspension due to the higher planar surface. Furthermore, these 2D structures usually show high intrinsic thermal conductivity values. But really, to our knowledge, there is not a systematic methodology for preparing nanofluids with high stability.

METHODS: This study involved the preparation of nanofluids based on the eutectic mixture of diphenyl oxide and biphenyl as the base fluid, this being a typical HTF used in Concentrating Solar Power (CSP) plants that use parabolic trough technology (PTC). MoS₂ nanostructures were used to prepare the nanofluids. But the most important contribution in this work is the introduction for the first time of a systematic methodology to prepare stable and improved nanofluids. A rationalized procedure is presented for defining beforehand the composition of a stable nanofluid; the method determines the appropriate amounts of surfactant and nanomaterial and makes it possible to control the morphology of the nanostructures.

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Also, stability of the nanofluids were determined from UV-vis spectroscopy for evaluating the sedimentation process, and from particle size measurements using the Dynamic Light Scattering technique. Moreover, thermal properties were evaluated. Isobaric specific heat was measured using the Temperature-Modulated Differential Scanning Calorimetry (TMDSC) technique. Also, thermal conductivity was obtaining from diffusivity measurements using light flash technique.

RESULTS AND CONCLUSIONS: Different nanostructures were obtained in function of the surfactant used. But, nanofluids prepared were stable after few days. Particle size were about 500 nm. Also, an increase of isobaric specific heat up to 7.5% was obtained. Also, an increase of thermal conductivity up to 57% was found for nanofluids based on 2D nanostructures.

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NANOUP TAKE COST ACTION (CA15119)

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NANOTENSION

Round robin test for surface tension and contact angle of nanofluids

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Keywords: nanofluids, surface tension, contact angle, round robin test

NENOTENSION joins ten European institutions in a round robin test for measuring surface tension and contact angle of nanofluids. So far four different nanofluids – all water based – are experimentally investigated. The talk will present first results and data analysis.

GEOAIR

H2020 proposal – First experiences

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Keywords: nanofluids, surface tension, contact angle, round robin test

The main objective of GEOAIR is to develop passive long-distance heat transfer systems to employ geothermal heat for the air-conditioning of multi-family residential buildings. The project incorporates an approach to increase the power output of the photovoltaic system of such a building. GEOAIR combines these two renewables with local heat storage to achieve an enhanced decarbonisation.

The proposal was launched January 2018 by a group of five NANOUP TAKE collaborators and three additional partners. Nanofluids are proposed to be used as working fluids in novel types of thermosyphons.

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Experiment Investigation of Nanoparticle-assisted Enhanced Oil Recovery and Oil Reservoir Characterization

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Keywords: nanoparticle, enhanced oil recovery, subsurface sensor, nanoparticle transport

INTRODUCTION: Predictions have shown that our demand for oil and gas will continue to grow in the next decade, and future supply will become more reliant on tertiary recovery and from nonconventional resources. However, current reservoir characterization methodologies, such as well logs, cross-well electromagnetic imaging and seismic methods, have their individual limitations on detection range and resolution^{1,2}. Here we propose a pioneering way to use carbon quantum dots (CQDs) as nanoparticle tracers, which could not only transport through a reservoir functioning as conventional tracers, but also act as sensors to obtain useful information inside beyond tracers. These hydrothermally produced CQDs from Xylose possess excellent stability in high ionic strength solutions, durable absorbance and fluorescence ability due to multi high-polarity functional group on their surfaces. Our core-flooding results reveal that CQDs can transport easily through packed columns and reservoir core samples, showing tracer-like migration capability regardless of particle concentration and ionic strength, as detected by both UV-Vis (On-line) and CLSM (off-line) measurements. We also demonstrate that quantitative oil saturation detection in unknown core samples can be achieved by such CQDs based on its breakthrough properties influenced by the presence of oil phase.

METHODS: CQDs were facilely prepared by one-step hydrothermal carbonization of D-(+)-Xylose, an abundant and renewable precursor available in most biomass and agricultural waste materials, as shown in Fig. 1a. The obtained CQDs were first characterized by UV/Vis spectrometer and fluorescence spectroscopy to check their absorbance spectra over various light wavelengths together with their luminescent properties. Other characterization includes morphology and size by TEM, concentration derived from the fluorescent intensity, Raman spectra and FTIR. The transport properties of CQDs are checked both in column packed with glass beads, and sandstone core. The temperature are varied from ambient condition to 80

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°C, while the salinity was fixed at the level of API brine. Oil saturation was detected by the breakthrough curves (BTCs) of CQDs.

RESULTS AND CONCLUSIONS: The results show that the CQDs have a good mobility at elevated salinity and temperature (Fig. 1 a&b). Based on the time (expressed in PV) when the CQDs breakthrough achieves 40%, 50% and 60%, the calibration curves (S_{or} against breakthrough time) are generated in Fig. 1d. The five-pointed star in Fig. 5d shows that by using calibration curve for 60% breakthrough, the calculated oil saturation is 24.0%, close to the real oil saturation of 25.1%.

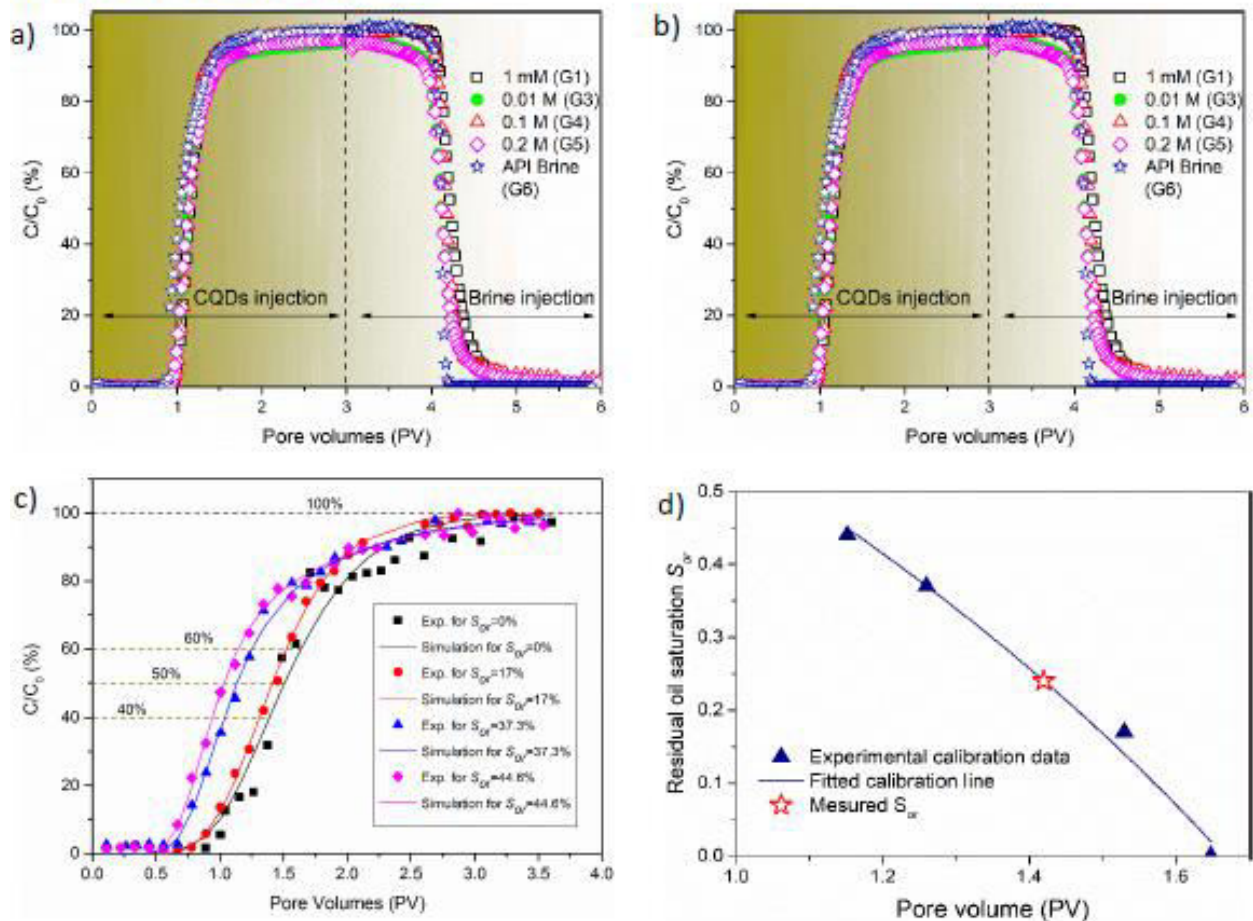


Figure 1. a) BTCs for CQDs (~10 ppm) at room temperature, with varying ionic strengths of the base electrolyte. b) BTCs for CQDs dispersed in API brine, and in glass bead column at elevated temperatures (25, 60 and 80 °C). c) BTCs as a function of injection time for samples containing different water fractions at S_{or} , when injecting CQD suspension at 0.5 mL/min into sandstone core. d) using the calibration curve to determine the oil saturation.

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