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(54) **Title**: A METHOD OF HEAT TRANSFER BETWEEN A METALLIC OR NON-METALLIC ITEM AND A HEAT TRANSFER FLUID

(57) **Abstract**: The present invention relates to a method of heat transfer between a metallic or non-metallic item and a heat transfer fluid comprising a fluid medium and nanoparticles wherein the thickness/lateral size ratio of such nanoparticles is below 0.00044.

A method of heat transfer between a metallic or non-metallic item and a heat transfer fluid

The present invention relates to a method of heat transfer between a metallic or non-metallic item and a heat transfer fluid comprising a fluid medium and nanoparticles having a specific thickness/lateral size ratio. In particular, it is well suited for steel, aluminum, stainless steel, copper, iron, copper alloys, titanium, cobalt, metal composite, nickel Industries or non-metallic industries such as plastics.

With a view of saving energy consumption, it is possible to improve the performance of heat exchangers systems and to introduce various heat transfer enhancement techniques. Some techniques have focused on electric or magnetic field application. Although an improvement in energy efficiency is possible from such points of view, an improvement can also be realized concerning the heat transfer fluid. Usually, fluids such as water, engine oil, ethylene glycol, etc. are used as heat transfer fluid. However, they have poor heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve required heat transfer. Among the efforts for enhancement of heat transfer, the application of additives to liquids is more noticeable.

For example, a surfactant such as LEVENOL C-421 which is polyoxyethylene mono- and di- glycerides, can be added into water for improving the heat transfer coefficient or at least the thermal conductivity. However, although the conductivity enhances in some cases, the presence of the surfactant results in the formation of foam. The presence of foam is a huge problem since it is really difficult to remove it, in particular in industrial scale. Moreover, the presence of a surfactant increases the corrosion of the heat transfer system, specially the pipe wherein the heat transfer fluid flows. Finally, scale can be formed particularly in the heat transfer system.

Recent investigations in nanotechnology have allowed the development of a new category of heat transfer fluid comprising nanoparticles. Such fluids also called “Nanofluid” are liquid suspension containing particles having at least one dimension below 100nm. These heat transfer fluids have usually an increased heat transfer coefficient.

The patent application US2014/0312263 discloses a heat transfer fluid comprising a fluid medium and an oxidized form of a material selected from the group of multilayer graphene nanoplatelets. It also discloses a method for manufacturing such fluid. The patent application describes that the oxidation of the multilayered graphene nano-platelets (GnPs) converts sp^2 graphite layers on the surface into OH^-, COO^- and CO groups. These groups create sufficient electrostatic charge at the nanoplatelet surface that keep the particles separated from each other due to repulsion and prevents particle agglomeration and settling. Thus, a good stability of graphitic nanofluids in a water or ethylene glycol/ water base fluid mixtures can be achieved and therefore a good dispersion.

It also discloses that suspensions with unmodified GnPs settle within a few hours. Suspensions stabilized with cationic or anionic surfactants show improvement in stability; however thermal conductivity of those suspensions is below the base fluid due to very low thermal conductivity of organic molecules compared to water. Thus, organic surfactants are detrimental for the thermal conductivity for the thermal conductivity of water based suspensions. Therefore, the use of non-surfactant approach to stabilizing dispersions of nanoparticles involves the oxidation of GnP, to clearly separate GnPs to individual nanoplatelets.

Finally, it discloses that oxidation of GnPs reduces the thermal conductivity enhancements in all tested grades. The ratio of heat transfer coefficients (h_{nf}/h_0) for the nanofluid (h_{nf}) and the base fluid (h_0), calculated for different temperatures, shows that the inclusion of graphitic nanoparticles in ethylene glycol/H_2O coolant can provide 75-90% improvement in heat transfer rates when used in laminar flow regime. Heat transfer coefficients in the turbulent flow regime show 30-40% improvement in heat transfer compared to the base fluid.

However, the oxidation or functionalization of GnPs necessitates an additional step in the process for the manufacture of the heat transfer fluid using strong acids, for example a mixture of concentrated sulfuric and nitric acids as in US2014/0312263. In industrial scale, this oxidation reaction produces waste products being difficult to manage. Additionally, this heat transfer fluid does not reach very high performance. For example, in steel making industry, during the cooling process in a hot rolling process, the run-out table cools the steel strip from approximately 800−950°C at the entrance to 450−600°C at the exit. Thus, for some steel grades, a heat transfer fluid having high heat transfer coefficient is needed.

The purpose of the invention is to provide an easy to implement method of heat transfer between a metallic or non-metallic item and a heat transfer fluid wherein the heat transfer fluid has a high heat transfer coefficient.

This is achieved by providing a method of heat transfer between a metallic or non-metallic item and a heat transfer fluid according to claim 1. The method can also comprise any characteristics of claims 2 to 26 taken alone or in combination.

The invention also covers a method for the manufacture of a heat transfer fluid according to claim 27.

The invention also covers a Heat transfer fluid according to claim 28.

The following terms are defined:

- heat transfer fluid comprising nanoparticles (so-called Nanofluid) means a liquid suspension containing particles having at least one dimension below 100nm,
- laminar flow means a flow with a Reynolds number below a critical value of approximately 2300,
- turbulent flow means a flow with a Reynolds number larger than a critical value of about 4000,
- Percolation threshold concentration is the concentration of nanoparticles above which they are connected forming a long-range network. For heat transfer applications, it is suitable that such network connects the hottest part, i.e. the part where the heat starts to flow, of the fluid and the coldest part of the fluid, i.e. the one where the heat is evacuated. In other words, below the Percolation threshold concentration, nanoparticles are not connected. When the Percolation threshold concentration is obtained, the network formed with nanoparticles, having higher thermal conductivity than the fluid medium, allows the heat carriers to take a path with much less thermal resistance, thus enhancing the thermal conductivity of the fluid, and therefore the heat transfer coefficient,
- vol.% means percentage by volume,
- wt.% means percentage by weight,
- Graphite nanoplatelets means a multilayered system of graphene sheets having a thickness around between 5 and 20nm,

- Few layers graphene means a multilayered system of graphene sheets having a thickness between 1 and 5 nm and

- Graphene means a single-atom-thick sheet of hexagonally arranged, bonded carbon atoms, presenting usually a thickness below 1nm.

Other characteristics and advantages of the invention will become apparent from the following detailed description of the invention.

The invention relates to a method of heat transfer between a metallic or non-metallic item and a heat transfer fluid comprising a fluid medium and nanoparticles wherein the thickness/lateral size ratio is below 0.00044.

Without willing to be bound by any theory, it seems that when the heat transfer fluid comprising nanoparticles having a thickness/lateral size ratio below 0.00044, the Percolation threshold concentration decreases. Consequently, fewer bridges are formed above percolation threshold concentration resulting in a decrease of viscosity. In addition, it is possible to obtain high thermal conductivity and therefore high heat transfer coefficient with low nanoparticles concentration especially in laminar flow.

According to the invention, the flow of the heat transfer fluid can be in a laminar or turbulent flow regime. In a laminar flow regime, the heat transfer coefficient is proportional to the thermal conductivity. On the contrary, in turbulent flow regime, the heat transfer coefficient depends on a set of thermo-physical properties such as viscosity.

Preferably, the heat transfer fluid comprises nanoparticles having a thickness/lateral size ratio below 0.00043, advantageously between 0.00010 and 0.00040, more preferably, between 0.00015 and 0.00035 or between 0.00020 and 0.00030.

Advantageously, the thickness of nanoparticles is between 1 and 99.99 nm, preferably between 5 to 50 nm and more preferably between 5 to 15 nm.

Preferably, the lateral size of the nanoparticle is between 26 and 50μm, advantageously, between 35 and 45μm.

Preferably, the nanoparticle concentration is between 0.01 wt.% and 12 wt.%, advantageously between 2 and 8 wt.% and more preferably between 4 and 7 wt.%.

In a preferred embodiment, the heat transfer fluid comprises nanoparticles being multilayered nanoplatelets. Indeed, without willing to be bound by any theory, it seems that to obtain nanoplatelets morphology, nanoparticles should have a multilayer structure with weak interaction between layers, i.e. Van der Waals, hydrogen bond, mechanical bond, halogen bond, pi stacking, cation/anion-pi bonds, intercalation, salt bridges and polar-pi. This weak bonding together with a good thermal conductivity of the nanoplatelets raises the possibility of improving heat transfer coefficient of a fluid.

Preferably, nanoparticles are chosen from graphite nanoplatelets, graphene, few layers graphene , TiO_2, ZnO_2, ZnO, Boron-nitride, copper, silica, montmorillonite, zeolite clipnoptilolite, wollastonite, mica, zeolite 4A, Al_2O_3, silicate, pumice, calcium oxide and carbon nanotubes.

In a preferred embodiment, the heat transfer fluid further comprises a dispersing agent. The dispersing agent can be a non-surface active polymer, a surfactant or a mixture thereof. The surfactant can be cationic, anionic, amphoteric or non-ionic.

For example, the dispersant agent can be polyvinnylpyrrolidone, polysaccharides, sulphated polysaccharides, linear alkylbenzene sulfonates, lignin sulfonates, di-alkyl sulfosuccinates, quaternary ammonium compounds, sodium stearate or a mixture thereof.

Preferably, the nanoparticles concentration / dispersing agent concentration ratio is between 3 and 18. More preferably, the nanoparticles concentration / dispersing agent concentration ratio is between 4 and 15, advantageously between 4 and 8 and preferably being between 4 and 6.

Without willing to be bound by any theory, it seems that when the above ratio is controlled and the Percolation threshold concentration reached, the heat transfer fluid according to the invention allows for a higher thermal conductivity and therefore a higher heat transfer coefficient. Indeed, the dispersing agent would be able to avoid deposition and agglomeration of nanoparticles. For instance, if the dispersing agent is a surfactant, the nanoparticle would be enclosed by a micelle consisting in a core of hydrophobic molecules and a shell of hydrophilic molecules. Such micelle structure allows dispersing nanoparticles within the fluid. However to obtain percolation, in other words the formation of the long-range network formed by the nanoparticles, the degree of dispersion of nanoparticles has to be limited.

Preferably, the heat transfer fluid comprises a fluid medium chosen from water, ethylene glycol, ethanol, oil, methanol, silicone, propylene glycol, alkylated aromatics, liquid Ga, liquid In, liquid Sn , potassium formate and a mixture thereof. Gallium, Indium and Tin can be used as heat transfer fluid, in particular for the cooling of a metallic item. Indeed, the melting point of gallium is of 30°C, the one of indium is 157°C and the one of tin is of 232°C. For example, they can be used to cool down computer chips or laboratory equipments such as neutron sources.

According to the invention, the heat transfer method is between a metallic or non-metallic item and the heat transfer fluid. Preferably, the metallic item, being for example a metallic substrate, is made of aluminum, steel, stainless steel, copper, iron, copper alloys, titanium, cobalt, metal composite, nickel and the non-metallic is made of plastics.

In the prior art, the heat transferring using water as fluid medium can usually be realized by 2 different modes. The first mode is called “non-contact water” which means that water is kept in a circuit without being shot towards the object, off-gases or fluids to cool or to heat. This mode uses indirect cooling or heating systems or non-contact cooling or heating systems, in particular through heat exchangers. The second mode is called “contact water” which means that water is used to cool or heat an object by being in direct contact with it.

According to one preferred embodiment of the invention, the item, being metallic, is a heat exchanger and the heat transfer is realized with a fluid being inside the heat exchanger.

In particular, in the steel making industry, the heat transfer using a heat exchanger can be implemented in coke oven gas treatment, blast furnaces, basic oxygen furnaces, electric arc furnaces, continuous casting, hot-rolling operations, cold-rolling operations, boilers, annealing furnaces and coating, pickling or sinter lines. The cooling in such processes is needed for maintain performance of processing equipment.

According to one preferred embodiment of the invention, the item is a metallic substrate and the heat transfer fluid is directly in contact with it. In this case, the heat transfer can be realized by jet impingement cooling, pool boiling, spray cooling or micro-channel cooling.

For example, in the steel making industry, the heat transfer by contact water cooling can be implemented:

- in sprays chambers of continuous casters and hot rolling process such as the cooling process on the run-out table,
- In coke ovens for gas treatment and quenching of coke,
- during the slag quenching in blast furnaces, basic oxygen furnaces and electric arc furnaces.

The heat transfer fluid is preferably manufactured by the following steps:

A. the provision of nanoparticles according to the present invention,
B. the provision of a fluid medium,
C. the adjustment of the nanoparticle concentration in order to achieve percolation and
D. the mixing of the nanoparticles with the fluid medium.

The heat transfer fluid of the present invention has high heat transfer coefficient and preferably a good dispersion.

The invention will now be explained in trials carried out for information only. They are not limiting.

Examples: Heat transfer coefficient – Laminar flow

Example 1:

Trials 1 to 3 were prepared by mixing graphite nanoplatelets having a thickness/lateral size ratio of 0.00025, 0.001 and 0.005 with water.

For each trial, the thermal conductivity of the samples has been measured employing a DTC-25 thermal conductivity meter. The thermal conductivity enhancement was calculated with respect to the conductivity of water at room temperature, i.e. 20°C, the conductivity of water in such conditions being 0.67 W/mK.

Trials 4 to 6 are respectively samples A-GnP, B-GnP and C-GnP having functionalized nanoparticles of the Patent application US2014/0312263. The thickness/lateral size ratio is respectively of 0.001-0.009, 0.0005-0.008, and 0.00044-0.003.

For all the trials, in laminar flow, the heat transfer enhancement is proportional to the enhancement of thermal conductivity, so no calculation is needed to have the heat transfer enhancement in %.

Trials	Samples	Nanoparticles concentration (wt.%)	Thickness/lateral size ratio	Heat transfer enhancement (%)
1*	1	5	0.00025	203
2	2	5	0.001	31
3	3	5	0.005	10
4	4	5	0.001-0.05	6
5	5	5	0.0005-0.008	75
6	6	5	0.00044-0.005	85

*: according to the present invention.

Trial 1 has a high heat transfer enhancement when compared to Trials 2 to 6.

Example 2:

Trials 8 and 9 were prepared by mixing graphite nanoplatelets having a thickness/lateral size ratio of 0.00025 and 1 wt.% of polyvinnylpyrrolidone as dispersing agent with water.

The thermal conductivity of the samples has been measured employing a DTC-25 thermal conductivity meter. The thermal conductivity enhancement was calculated with respect the conductivity of water. In laminar flow, the heat transfer enhancement is proportional to the enhancement of thermal conductivity, so no calculation is needed to have the heat transfer enhancement in %.

Trials	Samples	Nanoparticles concentration (wt.%)	Dispersing agent (wt.%)	C_{nanoP} / C_{disp} ratio	Thickness/lateral size ratio	Heat transfer enhancement (%)
7*	1	5	-	-	0.00025	203
8*	7	7	1	7	0.00025	286
9*	8	10	1	10	0.00025	384

*: according to the present invention

Trials 8 and 9 having a dispersing agent have a higher heat transfer enhancement enhancement than Trial 7 without a dispersing agent.

CLAIMS

1. Method of heat transfer between a metallic or non-metallic item and a heat transfer fluid comprising a fluid medium and nanoparticles wherein the thickness/lateral size ratio of such nanoparticles is below 0.00044.

2. Method according to claim 1, wherein the thickness/lateral size ratio is below 0.00043.

3. Method according to claim 2, wherein the thickness/lateral size ratio is between 0.00010 and 0.00040.

4. Method according to claim 3, wherein the thickness/lateral size ratio is between 0.00015 and 0.00035.

5. Method according to claim 4, wherein the thickness/lateral size ratio is between 0.00020 and 0.00030.

6. Method according to anyone of claims 1 to 5, wherein the thickness of the nanoparticles is between 1 and 99.99 nm.

7. Method according to claim 6, wherein the thickness of the nanoparticles is between 5 to 50 nm.

8. Method according to claim 7, wherein the thickness of the nanoparticles is between 5 to 15 nm.

9. Method according to anyone of claims 1 to 8, wherein the lateral size of the nanoparticles is between 26 and 50μm.

10. Method according to claim 9, wherein the lateral size of the nanoparticles is between 35 and 45µm.

11. Method according to anyone of claims 1 to 10, wherein the nanoparticles concentration is between 0.01 – 12 wt.%.

12. Method according to claim 11, wherein the nanoparticles concentration is between 2 and 8 wt.%.

13. Method according to claim 12, wherein the nanoparticles concentration between 4 and 7 wt.%.

14. Method according to anyone of claims 1 to 13, wherein the nanoparticles are multilayered nanoplatelets.

15. Method according to anyone of claims 1 to 14, wherein, the nanoparticles are chosen from graphite nanoplatelets, graphene, few layers graphene, TiO_2, ZnO_2, ZnO, Boron- nitride, copper, silica, montmorillonite, zeolite clipnoptilolite, wollastonite, mica, zeolite 4A, Al_2O_3, silicate, pumice, calcium oxide and carbon nanotubes.

16. Method according to anyone of claims 1 to 15, wherein the heat transfer fluid further comprises a dispersing agent.

17. Method according to claim 16, wherein the dispersing agent is a non-surface active polymer or a surfactant or a mixture thereof.

18. Method according to claim 17, wherein the surfactant is a cationic, anionic, amphoteric or non-ionic one.

19. Method according to claim 18, wherein the dispersing agent is chosen from polyvinnylpyrrolidone, polysaccharides, sulphated polysaccharides, linear

alkylbenzene sulfonates, lignin sulfonates, di-alkyl sulfosuccinates, quaternary ammonium compounds and sodium stearate and a mixture thereof.

20. Method according to anyone of claims 16 to 19, wherein the nanoparticles concentration / dispersing agent concentration ratio is between 3 and 18.

21. Method according to anyone of claims 1 to 20, wherein the fluid medium is chosen among water, ethylene glycol, ethanol, oil, methanol, silicone, propylene glycol, alkylated aromatics, liquid Ga, liquid In, liquid Sn, potassium formate and a mixture thereof.

22. Method according to anyone of claims 1 to 21, wherein the heat transfer fluid is in laminar or turbulent regime flow.

23. Method according to anyone of claims 1 to 22, wherein the item, being metallic, is made of aluminum, steel, stainless steel, copper, iron, copper alloys, titanium, cobalt, metal composite or nickel.

24. Method according to anyone of claims 1 to 23, wherein the metallic item is a heat exchanger and the heat transfer is realized with the fluid being inside the heat exchanger.

25. Method according to anyone of claim 1 to 23, wherein the metallic item is a metallic substrate and the heat transfer is such that the heat transfer fluid is directly in contact with the metallic substrate.

26. Method according to claim 25, wherein the contact between the metallic substrate and the heat transfer fluid is realized though jet impingement cooling, pool boiling, spray cooling or micro-channel cooling.

27. Method for the manufacture of a heat transfer fluid comprising:

A. the provision of nanoparticles according to anyone of claims 1 to 20,

B. the provision of a fluid medium,

C. the adjustment of the nanoparticle concentration in order to achieve percolation and

D. the mixing of the nanoparticles with the fluid medium.

28. Heat transfer fluid according to anyone of claims 1 to 21 or obtainable according to the method of claim 27, to be used in the heat transfer method according to anyone of claims 1 to 26.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/002402

A. CLASSIFICATION OF SUBJECT MATTER
INV. C09K5/10 B22D11/124 C21D1/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C09K B22D C21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 8 834 739 B1 (CUMBERLAND ROBERT W [US] ET AL) 16 September 2014 (2014-09-16) column 5, line 4 - column 6, line 29 column 8, lines 29-54	1-28
X	GOPALAN RAMESH ET AL: "Review of thermo-physical properties, wetting and heat transfer characteristics of nanofluids and their applicability in industrial quench heat treatment", NANOSCALE RESEARCH LETTERS, vol. 6, no. 1, 1 January 2011 (2011-01-01), page 334, XP055297238, ISSN: 1556-276X, DOI: 10.2355/isijinternational.50.124 Introduction; Discussion; Specicif heat; Table 1	1-28

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/002402

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HAITAO ZHU ET AL: "Preparation and thermal conductivity of suspensions of graphite nanoparticles", CARBON., vol. 45, no. 1, 1 January 2007 (2007-01-01), pages 226-228, XP055297142, GB ISSN: 0008-6223, DOI: 10.1016/j.carbon.2006.07.005 the whole document -----	1-28
A	US 2009/065107 A1 (HO GEORGE [TW] ET AL) 12 March 2009 (2009-03-12) paragraphs [0002] - [0008], [0029] - [0032] -----	1-28
A	US 2013/341028 A1 (CHRISTIAN CHAD F [US] ET AL) 26 December 2013 (2013-12-26) paragraphs [0002], [0015], [0026], [0031], [0034], [0055], [0056] -----	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2015/002402

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			US	2009288743	A1	26-11-2009
US 2013341028	A1	26-12-2013	NONE			