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# Thermal Conductivity and Viscosity of Ionanocolloids for Applications in Thermal Energy Systems

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***Abstract –*** The efficiencies of the heat transfer processes and systems are directly conditioned by the applied heat transfer fluid. Despite the great technological advances in energy-related areas, the performance of the conventional fluids is way below the required by demand and thus innovative and more efficient fluids must be developed. In this sense, the use of ionic liquids as base fluids combined with nanoparticles having excellent thermal conductivities emerge as attractive alternatives to replace the commonly used heat transfer fluids such as water or ethylene glycol. These new ionic liquid-based nanofluids, termed here as "ionanocolloids" have recently gained increasing attention and lot of research have been performed studying their thermophysical properties for applications in diverse energy fields. Ionanocolloids have the remarkable chemical and physical features of the ionic liquids, such as negligible vapor pressure, high ionic conductivity and thermal stability, that make them more sustainable, eco-friendly and of safer operation. Additionally, given the large variety of cations and the organic and inorganic anions available, there are infinite types of ionic liquids and they can be tailored to have specific desired characteristics.
In this work, an overview of the state of art concerning the thermal conductivity and viscosity of ionanocolloids has been done comparing the available literature results and providing a critical analysis of the impact of different operational conditions on each of these important properties. This systematic evaluation gives extreme valuable insights about the behaviour of different ionanocolloids under different conditions and it is essential for the consideration of the ionanocolloids for real-world applications, particularly in thermal energy systems.

***Keywords*:** ionic liquids, ionanocolloids, nanoparticles, thermal conductivity, viscosity

## 1. Introduction

It is well known that the addition of nanoparticles into conventional fluids enhance their thermophysical properties. Because of their remarkable thermal conductivity, much superior to the liquids, even very low concentrations of nanoparticles can promote considerable improvement in thermal performance of the fluids. Numerous works have been focused on study of nanofluids and their advantages and challenges [1,2]. More recently, a new class of liquids named ionic liquids has been mixed with nanoparticles to produce ionic liquid-based nanofluids, that we termed "ionanocolloids".

Ionic liquids are molten salts with remarkable chemical and thermal properties, such as negligible vapour pressure, high electrical conductivity, high solvating potential and recyclability [3]. Because of their low volatility they are of safer operation, are non-flammable, eco-friendly, and more sustainable than any other conventional fluids [4]. The infinite options of cations and anions available allow to customize the ionic liquids to posse specific desired features for a determined application. The dispersion of nanoparticles into ionic liquids lead to better thermal performances, which make the ionanocolloids excellent options for heat transfer applications. When compared with nanofluids, they possess higher thermal stability, allowing them to operate under high temperature conditions where only oil-based fluids can operate without degrade, however, these oil-based fluids have high viscosities, low heat capacities, and may be toxic and flammable [3].

The most relevant features to take into consideration in selecting a heat transfer fluid (HTF) are its viscosity in the entire operating range, that is highly related with pumping power and overall energy spent in the process, thermal conductivity that dictates the efficiency of the system, the lifetime of the fluid, which should not be bellow 35000 working hours, and the maximum operating temperature, which is conditioned by the thermal stability of the HTF [3,5].

In this work, an overview of recent literature on ionanocolloids applied in thermal energy-related areas was done, with focus on their viscosities and thermal conductivities. The main goals of this article are: (i) to provide an overview of these properties compared under the same room temperature; (ii) evaluate and discuss the impact of nanoparticles concentration and temperature on these properties, and (iii) give insights to the readers about the best choice of an ionanocolloid for heat transfer processes and systems.

## 2. Preparation methods of ionanocolloids

Preparation of ionanocolloids in one of the most important and challenging tasks regarding their study. In nanotechnology, the obtention of a stable solution for a long period of time or under high temperatures is not simple, due to the high tendency of the nanoparticles to form aggregates. The two main approaches for the ionanocolloids preparation are one-step method and two-step method (see Fig. 1). The one-step method involves the simultaneous preparation and mixing of nanoparticles with the ionic liquid. With this method the suspension obtained is more stable, *i.e.*, the clustering formation is lower due to the evasion of drying, storage, and transportation processes. However, the main drawback of this method is the difficult of large scaling, and for that reason this is not as much applied as the two-step method [6].

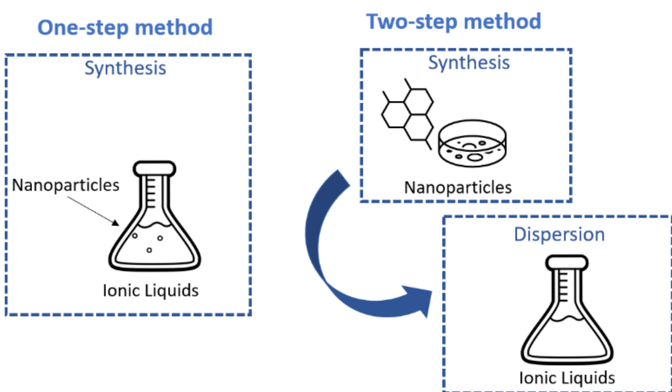

Fig. 1: Methods of preparation of ionanocolloids.

The two-step approach is more economic and more appropriate for industrial application. In this method, the nanoparticles are previously synthesized or purchased and are then dispersed into the base fluids using ultrasonicators, homogenizers, magnetic stirrers, etc. The nanoparticles can be synthesized by chemical, physical of biological processes that englobe a wide variety of techniques [6]. Although this method is less stable than the one-step method, it is more efficient in terms of heat transfer [7]. The agglomeration of nanoparticles, that are in powder form, may occur due to the Van der Walls force that promote a strong attraction between them [6].

When using nanoparticles, the biggest challenge is to get a well dispersed and stable nanofluids. In order to overcome this difficult, different techniques such as surfactant addition, modification of the nanoparticles surface or changes in the pH of the medium are commonly applied. The use of ionic liquids as base fluids may be of great value, because the ions in solution may interact with the nanoparticles surface creating an electrostatic layer surrounding them and avoiding the cluster formation [3].

## 3. Results and discussion

Thermal conductivity and viscosity of the ionanocolloids are strongly dependent of the ionic liquid and nanoparticle types and sizes as well as the conditions of the medium, such as temperature, concentration of nanoparticles, presence of dispersant agents, pH, etc. A careful evaluation of these variables is determinant to the performance of the ionanocolloids as heat transfer fluids.

In general, the addition of nanoparticles into ionic liquids improve their thermal conductivities, since nanoparticles have thermal conductivities orders of magnitude higher than the base fluids. For instance, multi-walled carbon nanotubes (MWCNT), have thermal conductivity of 3000 W/m-K [8], about 24000 times the thermal conductivity of [$C_4$mim][$NTf_2$] [9]. Fig. 2 displays the effect of the addition of different concentration of MWCNT into four ionic liquids on their thermal conductivities under room temperature. It is clear that nanoparticles enhance thermal conductivity, and it improves almost linearly by increasing concentration. Only 3 % wt. of MWCNT was responsible to enhance thermal conductivity of $[C_4mim][NTf_2]$ approximately 26 %. The impact of nanoparticle type has been reported as more significant than concentration [10], and it is conditioned by the thermal conductivity of the nanoparticle, which is lower for the metal oxides and higher for metals, graphene and carbon nanotubes [11]. Regarding the ionic liquid structure, both cation and anion influence on thermal conductivity, but there is an agreement between the authors that the anion nature is more impactful. The effect of temperature on thermal conductivity of ionanocolloids is still unclear and many divergencies remain in the reported researches, being not possible to establish a tendency.

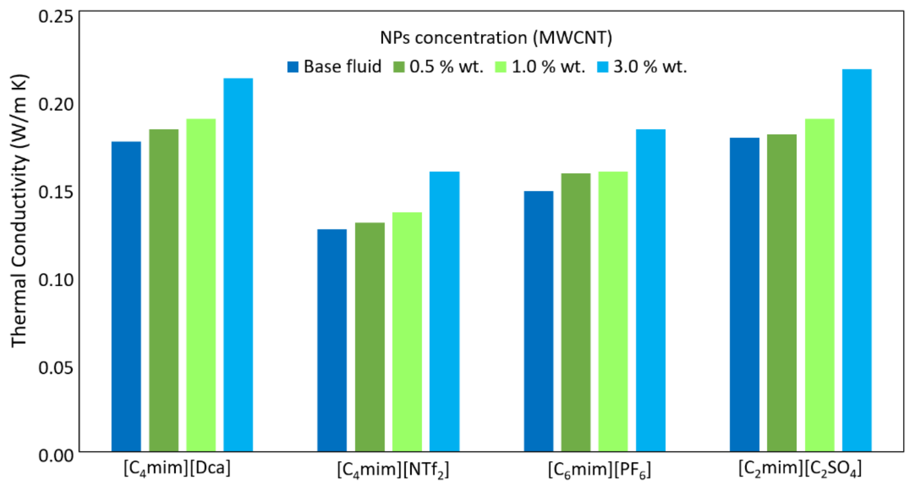

Fig 2. Effect of MWCNT concentration on thermal conductivity of different ionic liquids under room temperature. Data adapted from [9].

The viscosity of the ionanocolloids is influenced by several factors, as may cite, nanoparticles type and concentration, temperature, ionic liquids nature and shear rate, among others. The dispersion of nanoparticles into base fluids is so complex that in some cases may promote a change in the fluid flow to non-Newtonian behaviour [12]. This phenomena can be explained by the transition between ordering and disordering of the molecules [12]. However, the understanding of the viscosity of ionanofluids is still a challenge because of the overlap of different factors that significantly affect this property. The structure of the ionic liquids exerts high influence on viscosity of the ionanocolloids at lower temperatures. Cations containing substituents groups of alkyl, bulky phenyl or hydroxyl exhibit higher viscosity, while the anion nature decreases viscosity in the following order: $[Cl]^- > [PF_6]^- > [NO_3]^- > [BF_4]^- > [TfO]^- > [CF_3CO_2]^- > [Tf_2N]^- > [(NC)_2N]^- > [(NC)_3C]^-$ [4].

Temperature effect is very relevant when considering application of an ionanocolloid. Its impact on viscosity is remarkable as it is presented in Fig 3. Ionanocolloids have high viscosity at room temperatures, but as temperature increases it drastically drops, and there is almost no differentiation of the ionic liquids above 360 K. This decrease in viscosity is ascribed to the higher motion of the molecules into solution [17].

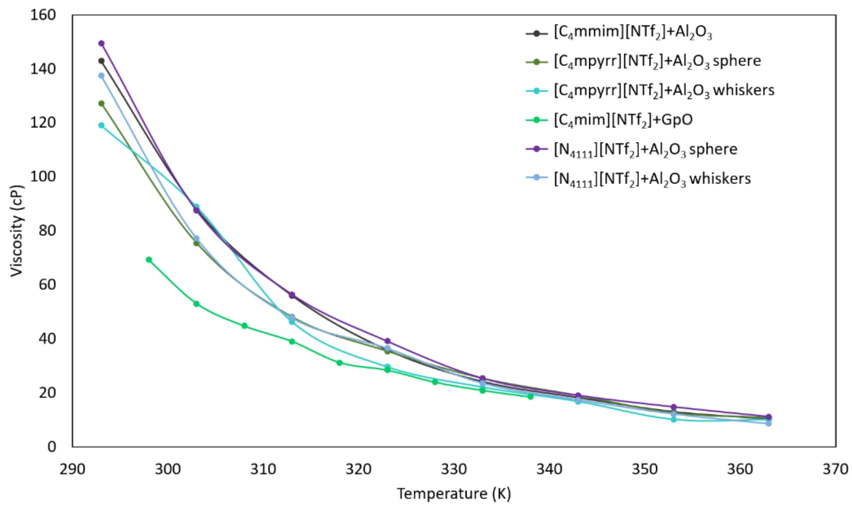


Fig 3. Influence of temperature on the viscosity of different ionanocolloids. $[C_4mmim][NTf_2] + Al_2O_3$ [13], $[C_4mpyrr][NTf_2] + Al_2O_3$ sphere [14], $[C_4mpyrr][NTf_2] + Al_2O_3$ whiskers [14], $[C_4mim][NTf_2]$ + graphene oxide (GpO) [15], $[N_{4111}][NTf_2] + Al_2O_3$ sphere [16], $[N_{4111}][NTf_2] + Al_2O_3$ whiskers [16].

Generally, the addition of nanoparticles increases the viscosity and the higher the concentration the higher viscosity. Fig 4. shows the increase in viscosity and thermal conductivity for different ionic liquids using different types and concentrations of nanoparticles. The evaluation of these two properties together is crucial for a proper choice of an ionanocolloid. From the engineering point of view, the best heat transfer fluid is the one with high thermal performance, and therefore high thermal conductivity, and lower energy consumption and hence, lower viscosity. It is easy to observe that the impact of improving nanoparticles concentration is much higher on viscosity than on thermal conductivity. The best choice of an ionanocolloid would be a fluid with intermediate concentration, for instance 1 % wt. that can have the benefits of thermal conductivity enhancement without needing much pumping power. Besides the combination of ionic liquid and nanoparticle is very particular and therefore it is essential to have a great knowledge of the main thermophysical and chemical properties of the ionanocolloids prior application in the industrial real-word.

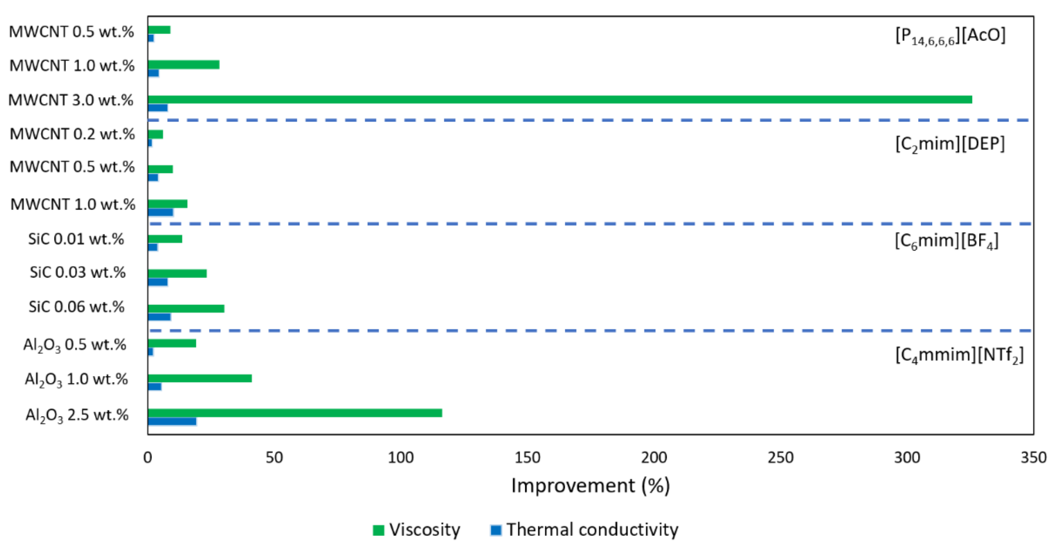


Fig. 4: Evaluation of improvement of viscosity and thermal conductivity for different ionanocolloids. $[P_{14,6,6,6}][AcO]$ [18], $[C_2mim][DEP]$ [19], $[C_6mim][BF_4]$ [20], $[C_4mmim][NTf_2]$ [13].

## 4. Conclusions

This work has evaluated and presented the potential of ionanocolloids to be used as heat transfer fluids. Overall, the addition of nanoparticles into ionic liquids showed significant improvement in thermal conductivity. However, attention should be paid to the resulting viscosity increments mainly at room temperature, when the ionic liquids are more different from each other. The great advantage of using ionanocolloids is probably their application at high temperatures, when the conventional fluids cannot be use without degrade and the ionanocolloids present low viscosity and great thermal performance. To conclude, these new types of fluids are excellent options to be successfully used in heat transfer processes.


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