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Challenges in the development of a database of thermophysical properties of nanofluids

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Abstract: A comprehensive database of thermophysical properties of nanofluids composed of a base fluid and a single type of nanoparticle has been developed by collecting the available experimental data in published scientific literature. The database currently contains 5114 data records of thermophysical properties of nanofluids consisting of combinations of 12 base fluids and 18 nanoparticle types. The collected experimental data include a number of thermodynamic properties (i.e. density, heat capacity, vapor pressure) as well as transport properties (i.e. thermal conductivity, dynamic viscosity). The development process of the database and the faced challenges are described. Recommendations for reporting thermophysical properties of nanofluids are drawn, based on the current status of the available data.

Background: Since the introduction of the concept of nanofluids by Choi and Estman [1] in the early 90s as heat transfer fluids with substantially improved thermal properties, the research to explore their potential applications has increased exponentially. Over the last 10 years the number of scientific publications on nanofluids has multiplied by a factor of 20, being more than 1600 papers on nanofluids published only in 2018.

The properties which exhibit the most complex behavior and greatest interest for the scientific and engineering communities are their improved thermal conductivity [2] and their increased viscosity [3]. While the former brings up the attention on the potential use of nanofluids as heat transfer and/or working fluids, the later is of particular importance for the development of lubricants.

Despite the importance of an accurate determination of the thermal conductivity and dynamic viscosity of studied nanofluids, the experimental properties of similar systems

show large scatter of the property values [4,5]. A number of attempts have been made to develop correlations for the prediction of nanofluids' properties, accounting for the impact of different parameters (e.g. nanoparticle size, shape), but it has been observed that the developed correlations for thermal conductivity and dynamic viscosity perform well only for specific systems, or determined temperature ranges. Although a number of review papers have analyzed the thermophysical properties of nanofluids, covering specific types of nanofluids [6] or a broader group [7], a database gathering all the published experimental data of nanofluids is missing.

In order to overcome this gap in the field, a database collecting all of the published experimental data of thermophysical properties of nanofluids has been developed. The initial scope of the database focuses on nanofluids formed by a base fluid, and a single type of nanoparticle. Therefore, in this first stage of development of the database, hybrid nanofluids (i.e. containing more than one type of nanoparticle) or metal organic heat carriers (i.e. nanofluids containing metal organic frameworks) are not included. The considered thermophysical properties for which a high number of empirical data is available are the thermal conductivity (k), dynamic viscosity (μ), density (ρ), and isobaric heat capacity (c_p). Additionally, a few works analyzed the impact of nanoparticles in the vapor pressure (p_{sat}) of the base fluid, and its speed of sound (c). Because it is well known that some of these properties are sensitive to the nanoparticle shape and size, these data were also included in the database, if available in the sources.

Discussion and Results:

The developed database allows a comprehensive critical evaluation of the measured properties for selected base fluids, or nanoparticle material, and brings up insight on the significant scatter of some experimental data.

The development of this database provides two main contributions to the research in the field of thermophysical properties of nanofluids. First, during the data collection phase, the lack of a standard for the correct report of the experimental data of thermophysical properties of nanofluids has become patent. Second, the arrangement of all the experimental data available in the form of a database allows the quick comparison of existing data for different systems, thus facilitating the extraction of general conclusions.

With regards to the first contribution, it was observed that in many of the analyzed cases the reported data lack of enough quality as defined by Chirico et al. [8]. In this regard, the main inaccuracies found in the published literature on thermophysical properties of nanofluids are enumerated as follows by order of severity: i) experimental data reported only in the form of

plots (some with especial low resolution); ii) errors in the units of the reported values (especially in the case of dynamic viscosity); iii) describing the systems concentrations in volume basis; iv) incomplete definition of the characterized system (e.g. information on nanoparticle shape and dimensions missing); v) properties reported in the form of ratios with respect to the properties of the base fluid (in some cases for not well defined base fluids, such as lubrication oils).

The severity of the poor quality of some of the reported empirical data is here remarked, the thermophysical data of nanofluids can lead to overestimation of the thermal characteristics of the nanofluid, leading to under dimensioned heat exchangers, or failure in the design of lubricating systems.

When it comes to the second main contribution of the database, the organization and standardization of the available experimental data for different systems allows their straightforward comparison. This helps identifying trends on the impact of nanoparticles on different base fluids, recognizing discrepancies and outliers between data of the same or similar systems, or potential measurement errors. As an example of this feature, Figure 1 shows experimental dynamic viscosities of different authors versus temperature for the water/Al_2O_3 system. As it can be seen in Figure 1.a, the impact of small differences of the average diameter of the particles in the viscosity is not significant, but a larger difference in the nanoparticle size can have an important influence, even for low concentrations, as observed in Figure 1.b.

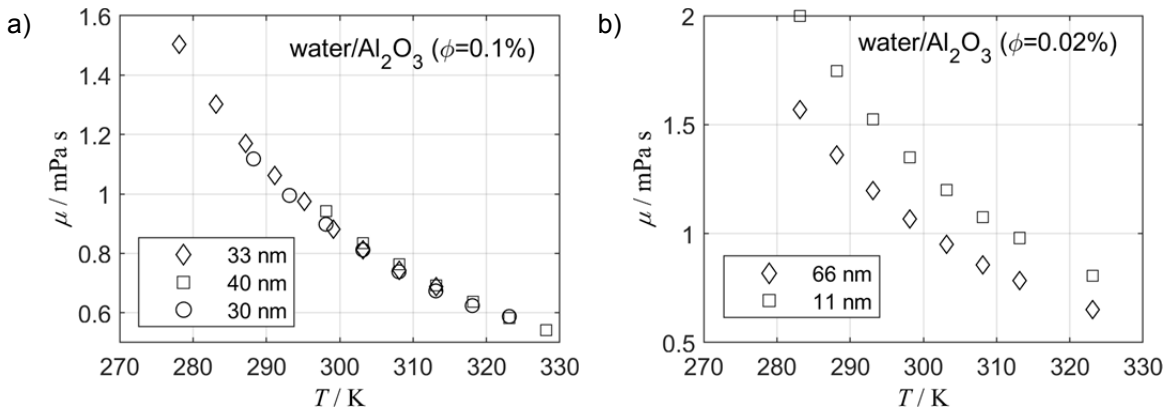

Figure 1. A comparison on the effect of particle size on dynamic viscosity.

Summary: A comprehensive database of experimental thermophysical property data of nanofluids consisting of a base fluid and a single type of nanoparticle has been developed. The database allows a comprehensive critical evaluation of the measured properties for

selected base fluids, nanoparticle material, or measurement conditions, and brings up insight on the significant scatter of some experimental data for specific similar systems.

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