INVESTIGATION OF NANOFLUIDS BEHAVIOR IN HEAT EXCHANGERS

Dadui Guerrieri*[1], guerrieri@cefet-rj.br
Fabio Viana, fabio.viana.abreu@gmail.com
Saulo Carvalho Fragoso, saulocfragoso@yahoo.com.br
Mauro C. L. Souza*[2], mauro@lin.ufrj.br
Mila R. Avelino*[3], mila@uerj.br
State University of Rio de Janeiro, Rua Fonseca Teles, nº 121. São Cristóvão - Rio de Janeiro, Brazil. 20940-200.

Abstract. *The purpose of this paper is to present this new class of fluid called nanofluid and its feasibility for use in industrial heat exchangers. Aiming to analyse the behaviour of the thermophysical properties of nanofluids of alumina oxide and nanofluids copper oxide. Also, checking the reduction in the proposed design of a heat exchanger, hoping to find a good reduction in the use of this novel class of fluid.*

Keywords*: Nanofluid, Heat Transfer, Reduce Heat Exchangers.*

1. INTRODUCTION

The effort of researchers by improving the thermal systems has reached very high levels as the materials and processes. This has made the search for new and better working fluids arise a field with significant projected development. Therefore, the application of nanoparticles in fluids of low thermal properties to intensify them has generated encouraging results.

In recent years, a large number of publications on nanofluids has been increasing. This shows the growing interest of many researchers in a subject that can contribute to a major advance in heat transfer equipment, a fact that motivated the making of this work in order to deepen the knowledge a little more in an area with a future as promising.

It is expected that in the near future, nanofluid open doors for a major technological breakthrough in industrial applications such as oil & gas, food, chemical, and industries that operate in the system of heating, ventilation and air conditioning for buildings.

2. NANOFLUIDS

Conventional fluids such as water, ethylene glycol and oil, widely used in various branches of industry as coolants, have deficiencies among which include the low evaporation temperature, as water, and low thermal conductivity in the case of oils and ethylene glycol.

The addition of nanoparticles in the fluid changes the flow structure, so that besides increasing the thermal conductivity, chaotic motion, dispersion and fluctuation of the nanoparticles especially near the tube wall of a heat exchanger leads to an increase in the rate of energy exchange and increases heat transfer between the fluid and the tube wall. Furthermore, at high flow rates, the effects on dispersion and chaotic motion of nanoparticles enhance mixing fluctuations and changes in temperature profile to a flatter profile similar to turbulent flow and causes an increase in the coefficient of heat transfer. And in low Peclet number, a lower rate of heat transfer can be observed at low temperature flow and agglomeration of nanoparticles may exist in the flow nanofluid.

For a theoretical modeling, the nanofluid can be defined as a mixture consisting of a continuous component base fluid called "matrix" and a discontinuous solid component called "particles". The properties especially the thermal conductivity and viscosity, depend on their microstructures such as the properties of components, volume concentration of the component, particle size, particle shape, particle distribution, particle movement, and the purpose of matrix-particle interface.

The calculation of the effective density (ρ_e) and the specific heat effective (C_{pe}) of a nanofluid can be estimated based on the physical principle of the rule of mixture as:

$$\rho_e = \left(\frac{m}{V}\right)_e = \frac{m_m + m_p}{V_m + V_p} = \frac{\rho_m V_m + \rho_p V_p}{V_m + V_p} = (1 - \nu_p)\rho_m + \nu_p \rho_p \qquad (1)$$

*[1] Also Professor at CEFET – UnED Itaguaí. Rodovia Mário Covas, lote J2, quadra J - CEP: 23810-000. Itaguaí – RJ
*[2] Also Professor at UEZO
*[3] Also Researcher at Inmetro. National Institute of Metrology, Quality and Technology. Av. Nossa Senhora das Graças, 50 - Xerém, 25250-020 Duque de Caxias. Rio de Janeiro. RJ. Brazil. MRAvelino@Inmetro.gov.br

$$\left(\rho C_p\right)_e = \rho_e \left(\frac{Q}{m\Delta T}\right)_e = \rho_e \frac{Q_m + Q_p}{(m_m + m_p)\Delta T} = \rho_e \frac{\left(mC_p\right)_m \Delta T + \left(mC_p\right)_p \Delta T}{(m_m + m_p)\Delta T} \quad (2)$$

$$= \rho_e \frac{\left(\rho C_p\right)_m V_m + \left(\rho C_p\right)_p V_p}{\rho_m V_m + \rho_p V_p} = (1 - v_p)\left(\rho C_p\right)_m + v_p\left(\rho C_p\right)_p \quad (3)$$

So,

$$C_{pe} = \frac{(1 - v_p)\left(\rho C_p\right)_m + v_p\left(\rho C_p\right)_p}{(1 - v_p)\rho_m + v_p \rho_p} \quad (4)$$

3. Increase in Heat Transfer in Turbulent Flow

The results of heat transfer were available for turbulent flow of nanofluids just two groups. The results from the increased heat transfer that are shown in Figure 1, Figure 2, Figure 3 are for water-based nanofluids containing TiO2 and Al2O3 particles and Cu, respectively. Trends are similar for all three figures. There is little or no effect of Reynolds number on increasing heat transfer and thermal conductivity increases with increased particle concentration by volume. The heat transfer is greatest for particles of Cu, followed by TiO2 particles and Al2O3em concentration levels with the same volume. From the viewpoint of thermal conductivity, it is not surprising that the Cu-water nanofluid shows a greater increase in heat transfer.

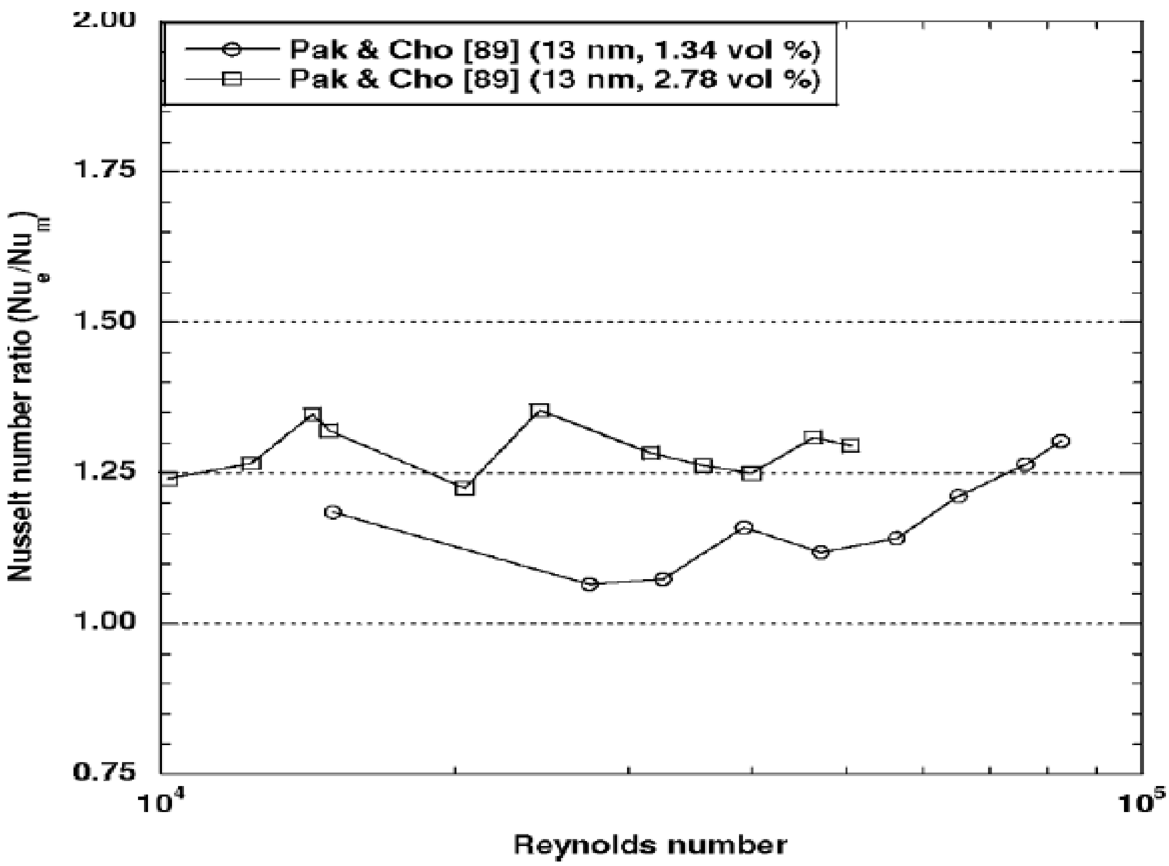

Figure 1. Heat transfer in turbulent flow of Al_2O_3 in water.

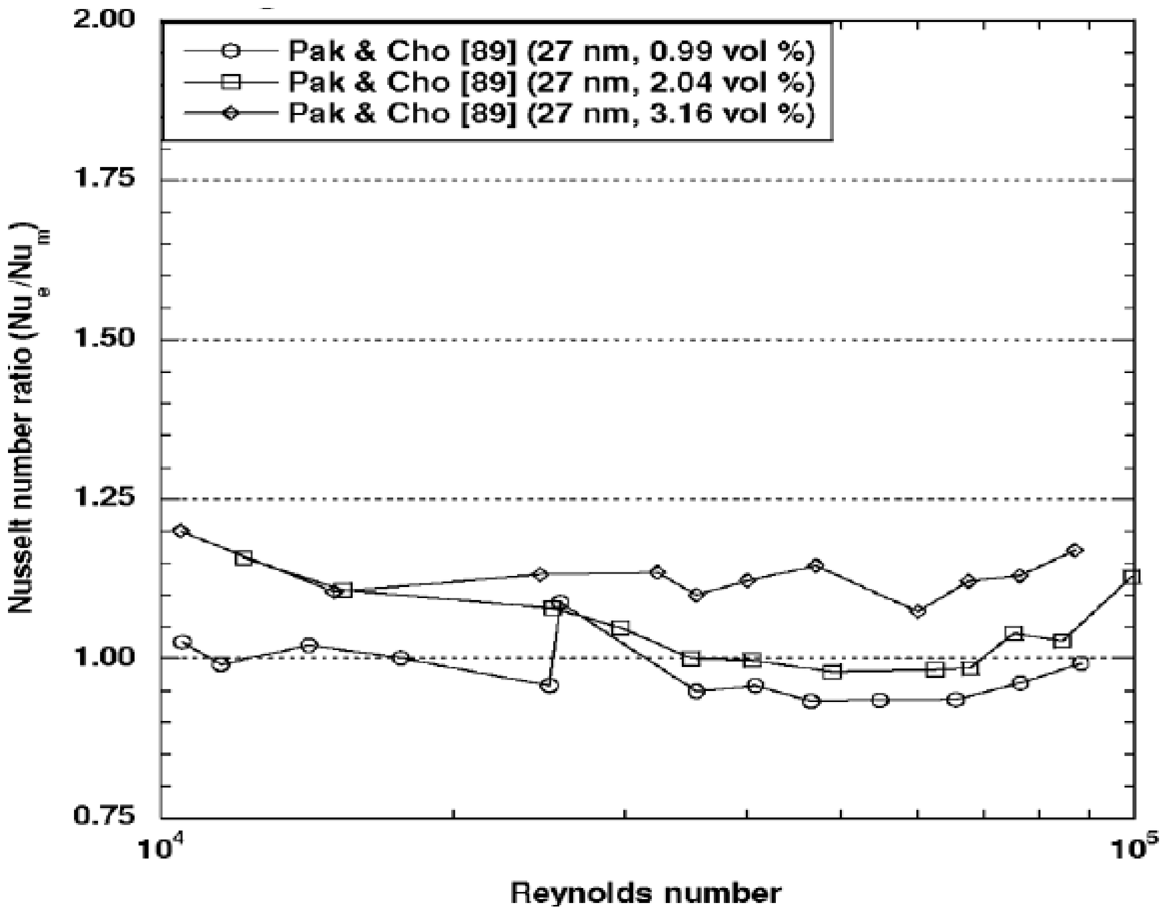

Figure 2. Heat transfer in turbulent flow of TiO_2 in water.

For turbulent flow, some researchers have used a correlation calculation to compare the increase in heat transfer to improve the thermal conductivity. By using a correlation transfer of heat to long turbulent flow as the correlation Dittus-Boelter, one can predict the Nusselt number of base fluid with reasonable accuracy.

Then, using the increased thermal conductivity of the correlation nanofluid For turbulent flows heated fluid from the base, the Nusselt number is proportional to the thermal conductivity to the power of 0.6. Thus, even though the reasons for improving the thermal conductivity and the Nusselt number were the same, the actual heat transfer exceeds the correlation of the prediction heat transfer, since the thermal conductivity seems that power is only 0.6 . Taking into account the range of values expected for the thermal conductivity of the class of considered liquids and making appropriate corrections measurements were made under the following working conditions:

- The heating current was set at 300 mA. Depending on the nature of the test sample, this level of current can produce a temperature rise of up to 14 K, which is estimated as an upper limit assigned to protect the test cell damage from overheating. At temperatures greater protection against overload is activated and the test cell is disconnected from the source. In liquids investigated in the experiments, the total increase in temperature during a test ranged from approximately 1.5 to approximately 6 K K;

- The duration of the test was set at 2 seconds. The time is actually the time window tw, in the diagram of Figure 7. Considering the constraints assumed for the testing time, as they were expressed in relation (3), and taking into account the constructive characteristics of the test cell, it was discovered that a lower limit of the order of hundreds of ms, and an upper limit of order of tens of seconds cover very well the experimental conditions. We investigated liquids with varying thermal conductivity of 0.256 Wm-1K-1 (pure ethylene glycol) to 0.6 Wm-1K-1 (deionized water). Therefore the test time of 2 seconds was considered sufficiently good approximation to ensure the elimination of the effect of thermal convection;

- The sampling time was set at 40 ms, 50 resulting temperature readings throughout the test. Thus, sufficient data have been obtained to take comprehensive information on the transient thermal process, resulting in accurate estimation of the thermal conductivity.

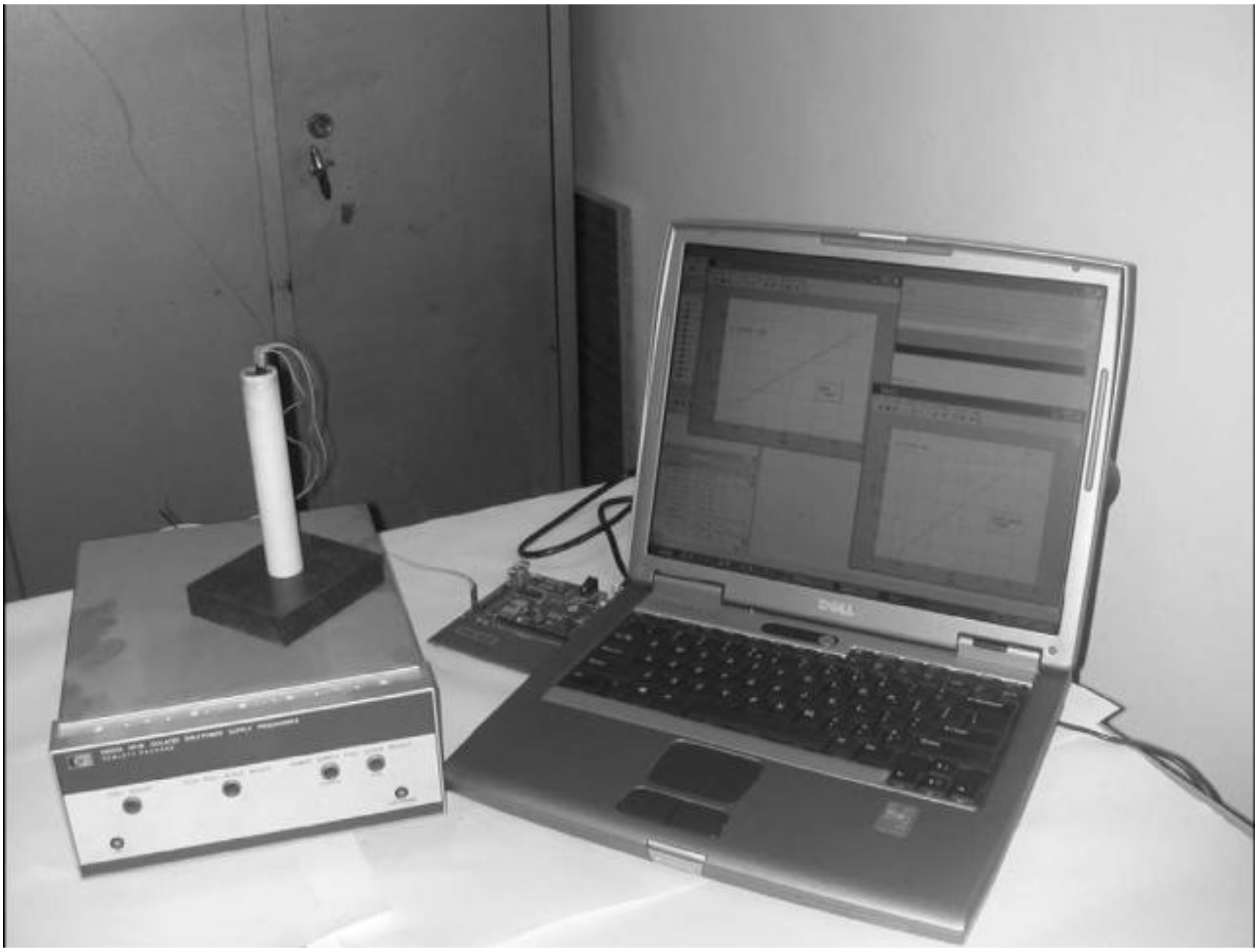
Figura 11. Instalação experimental para a medição da condutividade térmica.

The data were stored in data files created by the software Aspire, and are exported to MATLAB, to be processed interactively or later, and calculate the thermal conductivity.Figure shows the diagram of the temperature increase read every 40 ms time interval, while applying 2 second step of heating current .

It should be emphasized that in these experiments, the records of temperature rise for the first 200 ms of the test were not strongly affected by the disappearance of the heat capacity of the wire, and consequently major disturbances were seen in the graph in small time slots. This initial time period when errors occurred under the effect of self heating platinum wire, disturbing the measurement accuracy depends on the experimental conditions with respect to the heater and sensor characteristics of the material. In the graphical representation, this effect is reflected as a deviation from the ideal form of Figure 1 is reflected as a delay in temperature increase. To prevent this disruption affects the measurement results, these noisy initial values are not taken into account when the thermal conductivity is calculated. The pulse duration of the heating step, two seconds at the selected experiment may also vary as a function of the material under test.

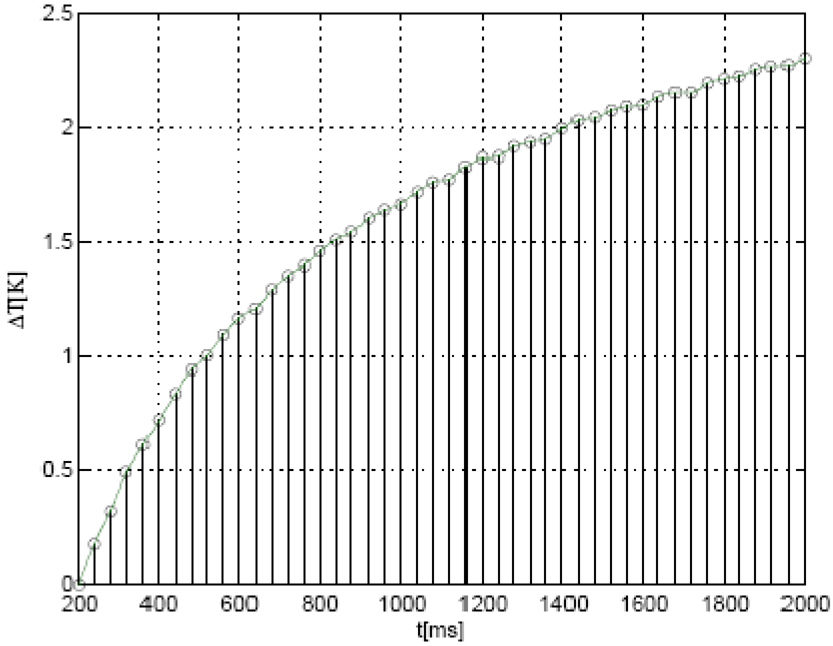

Figure 12. In MATLAB graphical representation of the temperature increase detected in each 40 ms interval of time during a test period of two seconds.

Figure 3.13 shows the results plotted on a logarithmic scale of time, to be obtained in the MATLAB graphics files. The slope of the curve having the equation shown in the graphs represents the thermal conductivity, as illustrated in figure 13.

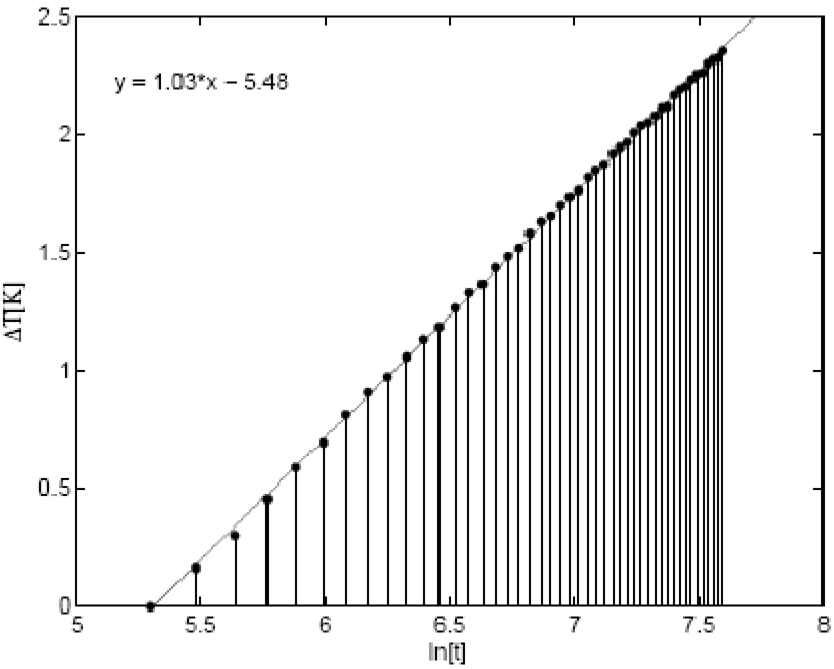

Figure 13. Graphing in MATLAB output data, together with the numerical values for the thermal conductivity (the slope) and thermal diffusivity (x-axis intercept).

This feature is very useful in comparing experiments requiring thermal conductivities of different liquids in order to evaluate their performance in heat transfer [36]. As mentioned earlier the Box and Tools Instrument Control in MATLAB can also perform and present statistical analyzes of the data. The graph provides the curve equation with the slope value expressing the thermal conductivity measurement. Figure 3.15 shows a small inset window that contains the results of statistical analyzes [36].

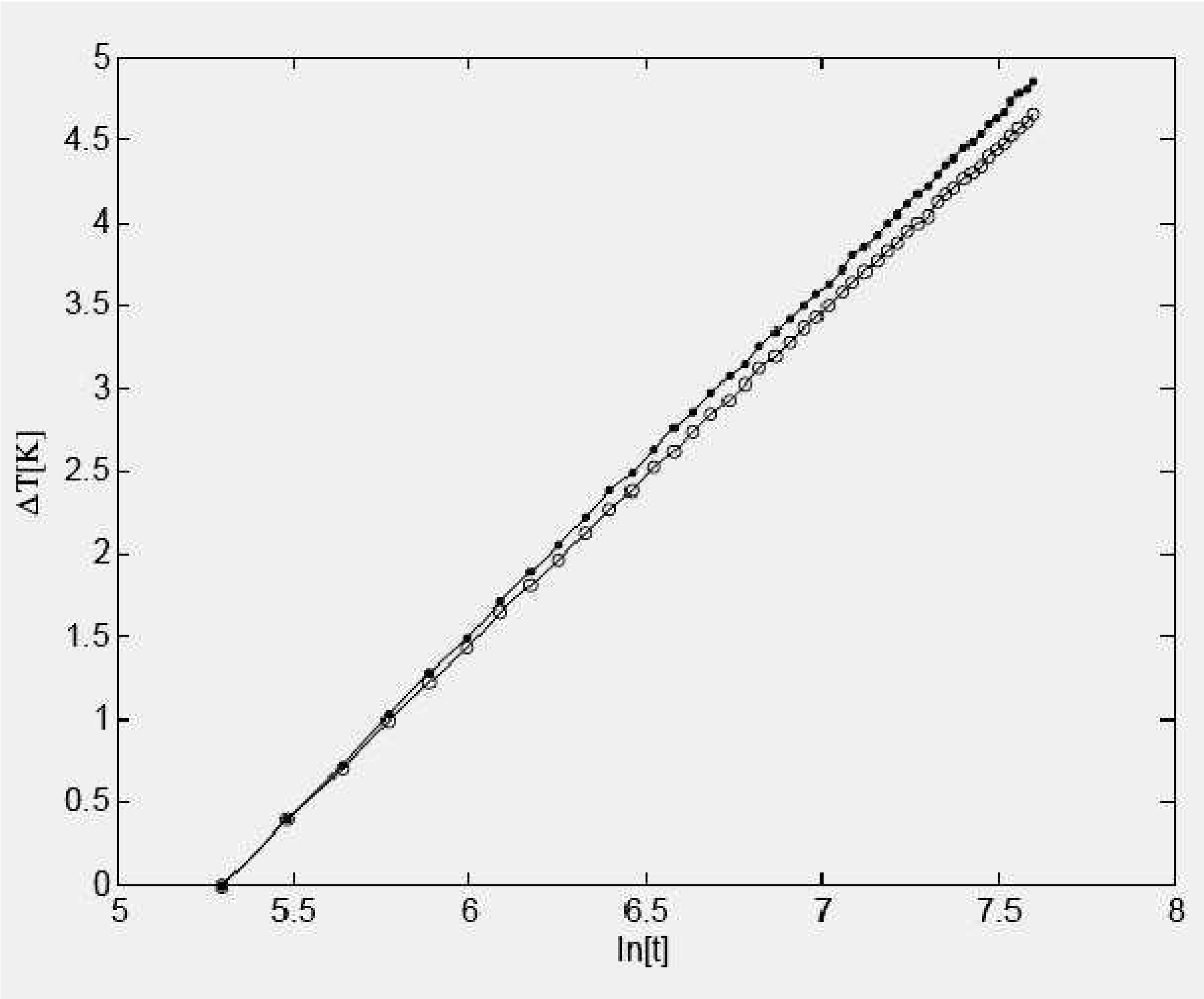

Figure 14. Graphing in MATLAB measuring two different samples. Was measured and the stored thermal conductivity of the pure base fluids, and the measured values of thermal conductivity of nanofluids were recorded experimentally prepared were stored in the corresponding files [36].

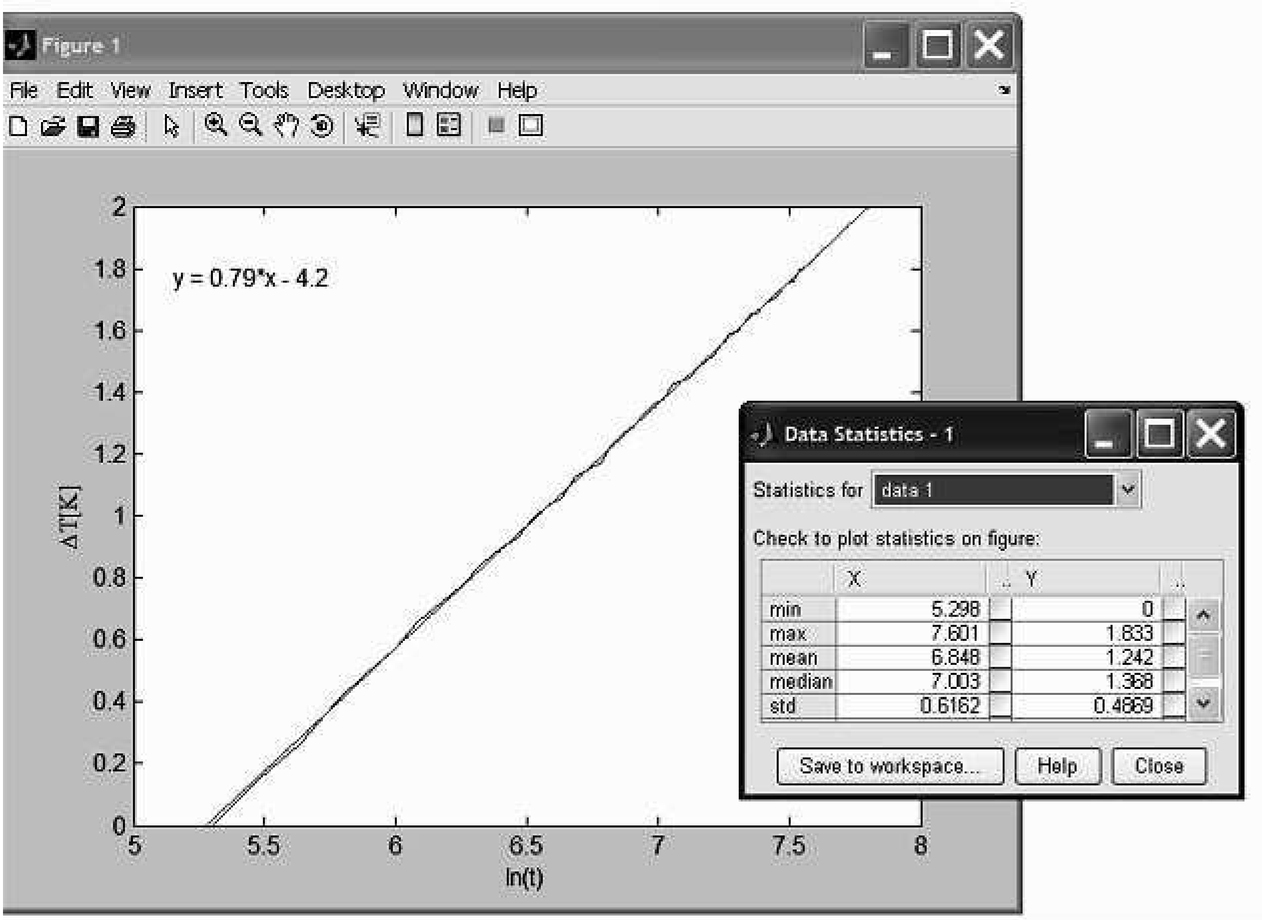

Figure 15. MATLAB Graphical representation and statistical data obtained after the test. To properly assess the value of the thermal conductivity of a particular material, it is necessary to calibrate the system [36].

4. CONCLUSIONS

The use of large-scale commercial nanofluids is not a reality next. Its development and production are under study. There are barriers to overcome the lack of a theoretical understanding of the mechanisms of heat transport, particle agglomeration and settling, should be studied in more detail.

Regarding the particle size, distribution and shape requires a greater consensus among investigators so that their characterization will become more accurate. While studies of nanofluids are still at an early stage, the results obtained by various researchers have been quite encouraging because, even with some differences, a common trend was manifested in its results: increasing the thermal conductivity of nanofluid heat transfer.

Despite the thermal conductivity is an important factor to be studied in the process of improvement in heat transfer, viscosity also deserves special attention for future studies. There is very comprehensive approach in the literature and has not been a major focus of research, but a more detailed study would be important due to the fact that the temperature and volume concentration of nanoparticles are important points to define the rheological behavior of nanofluids.

5. REFERENCES

Aparecido, J.B., 1988. Transformada Integral Generalizada no Escoamento Laminar e Transferência de Calor em Dutos Retilíneos de Geometria Arbitrária. Ph.D. thesis, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil.

Charoensupaya, D., 1986. Experimental and Analytical Investigations of Composite Desiccant Structures and Low Humidity Adsorption. Ph.D. thesis, Illinois Institute of Technology, Chicago, IL, USA.

Mikhailov, M.D. and Özisik, M.N., 1984. Unified Analysis and Solutions of Heat and Mass Diffusion. John Wiley & Sons, New York.

Özisik, M.N. and Murray, R.L., 1974. "On the solution of linear diffusion problems with variable boundary condition parameters". Journal of Heat Transfer (ASME), Vol. 96, pp. 48–51.

Panaras, G., Mathioulakis, E., Belessiotis, V. and Kyriakis, N., 2010. "Experimental validation of a simplified approach for a desiccant wheel model". Energy and Buildings, Vol. 42, No. 10, pp. 1719–1725.

Simonson, C.J. and Besant, R.W., 1999a. "Energy wheel effectiveness – part I: Development of dimensionless groups". International Journal of Heat and Mass Transfer, Vol. 42, pp. 2161–2170.

Simonson, C.J. and Besant, R.W., 1999b. "Energy wheel effectiveness – part II: Correlations". International Journal of Heat and Mass Transfer, Vol. 42, pp. 2171–2185.

Tuckerman, D.B. and Pease, R.F.W., 2011. "Microchannel heat transfer: early history, commercial applications, and emerging opportunities". In Proceedings of the ASME 2011 9th International Conference on Nanochannels, Microchannels, and Minichannels. Edmonton, Alberta, Canada. Paper no. 58308.

Vajjha, R.S. and Das, D.K., 2009. "Experimental determination of thermal conductivity of three nanofluids and develop- ment of new correlations". International Journal of Heat and Mass Transfer, Vol. 52, No. 21-22, pp. 4675–4682.

5. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.