Correlation between the thermal and rheological behavior of nanofluids based carbon nanotube and glycerol

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Abstract :

The main objective of this work consists in characterizing the thermal and rheological behavior of nanofluids based on NTC carbon nanotubes used in order to quantify the main parameters influencing their thermo-physical properties and the physical phenomena governing the intensification of heat transfers induced by these nanofluids. An analysis of previous research work was carried out in order to overcome the various parameters that can influence the thermal and rheological behavior of nanofluids, including parameters related to the composition of nanofluids: CNT volume fraction, temperature and base fluid.

Keywords:

Rheology, Nanofluid, carbon nanotube, empirical law, heat exchanger

1 Introduction

Significant progress has made since the late 1990s to synthesize nano-sized particles, which, dispersed in a carrier liquid, form nanofluids. Their synthesis meets the need to improve the thermal properties of heat transfer fluids by inserting a solid phase of very high thermal conductivity [3].

The main objective of this work is to characterize the thermal and rheological behavior of nanofluids based on NTC carbon nanotubes [4] used in order to quantify the main parameters influencing their thermo-physical properties and the physical phenomena governing the intensification of heat transfers induced by these nanofluids. An analysis of previous research work was carried out in order to overcome the various parameters that can influence the thermal and rheological behavior of nanofluids, including parameters related to the composition of nanofluids: CNT volume fraction, temperature and base fluid.

In the field of heat transfer, the use of the properties of rheological behavior inherent in suspensions of nanoparticles in heat transfer fluids has been the subject of several studies over the past thirty years. Our study concerns the particular case of suspensions of multilayer carbon nanotubes (MNTCs) in glycerol. We highlight in one hand the effects of the mass fraction φ of (MNTCs) varying between 0.1% ≤ φ ≤1 % and in the hand the effect of the temperature [30-80°C] on the rheological behavior of the solutions considered in a rotary rheometer.

The experimental results obtained consider the rheological behavior described by viscoplastic models for which the yield stress increases with φ. We then propose a polynomial evolution law of apparent viscosity as a function of the volume fraction for each shear rate value varying from 0s-1 to 100s-1.

Following this work, we conducted an experimental approach on the thermo-physical properties of the nanofluids tested and on the other hand, we conducted studies on the thermal performance in a double-jacketed heat exchanger.

We have set as operating mode; the fluid that circulates in the heating coil involves water at a temperature of 70°C for the heat transfer and for the tank. We have taken two cases for the cold fluid the first involves water and the second the nanofluid with the carbon nanotube and glycerol whose concentration varies between 0.3% and 0.7% with a constant flow of 0.6 l / min with agitation.

We also presented an analysis of the results in order to study the influence of the parameters mentioned above. The results obtained are compared and are discussed with existing conventional models.

In order to quantify and refine the analysis on the improvement of heat exchange provided by the use of the studied nanofluids, the evolution of the convective exchange coefficient and the Nusselt number associated with the central tube as a function of the Reynolds number were investigated. The objective is to characterize the thermal performance in order to study the effects of the various parameters that can influence the thermal behavior of nanofluids in the heat exchanger, including the effect of the flow regime or Reynolds number and the effects related to the composition of nanofluids: the concentration of NTC.

2. Raw materials and materials

2.1 Raw materials

For the development of nanofluids tested in this work, we consider the following products:
Multi-Walled carbon nanotube (MWCNT) with> 95% purity, a length that varies from 5 µm, an outside diameter of 6 to 9 nm, Melting point / freezing point is 3.652 - 3.697 ° C and density: 0.22 kg / m3
Glycerol is a basic fluid that serves to stabilize nanoparticles due to its high viscosity

2.2 Protocol of elaboration

The nanofluid obtained from the following steps:
Addition of the carbon nanotube powder in glycerol while continuing to heat and stir in the presence of a magnetic stirring of 10 revolutions / sec for 1 hour according to the different fractions desired volume: [0.1% -1%] and the different temperatures [30-80 ° C].
The suspension is subjected to magnetic stirring using a thermostated bath of carbon nanotubes dispersed in glycerol.

2.3 Materials and methods

-For the rheological characterization:
The rheological tests are conducted as part of this study using a HAAKE RHEOSTRESS 1 rotary rheometer with a plane-plane geometry, for the tests carried out as part of this work, the configurations are selected are: a quasi-stationary configuration for monitoring the rheological behavior of the nanofluid, an oscillatory configuration for determining the critical frequency.

-For the thermal characterization:

The thermal tests are conducted using a double jacket heat exchanger to detect the heat gain.

3 Results and discussion

3.1 Rheological behavior

Effect of the volume fraction [0.1% -1%]:

Two types of flow regime are retained:

- In quasi-stationary mode:

We initially focused on the evolution of shear stress and viscosity as a function of shear rate. We will take from RheoStress 1 a set of rheograms that allow highlighting the effect of the concentration on apparent viscosity.

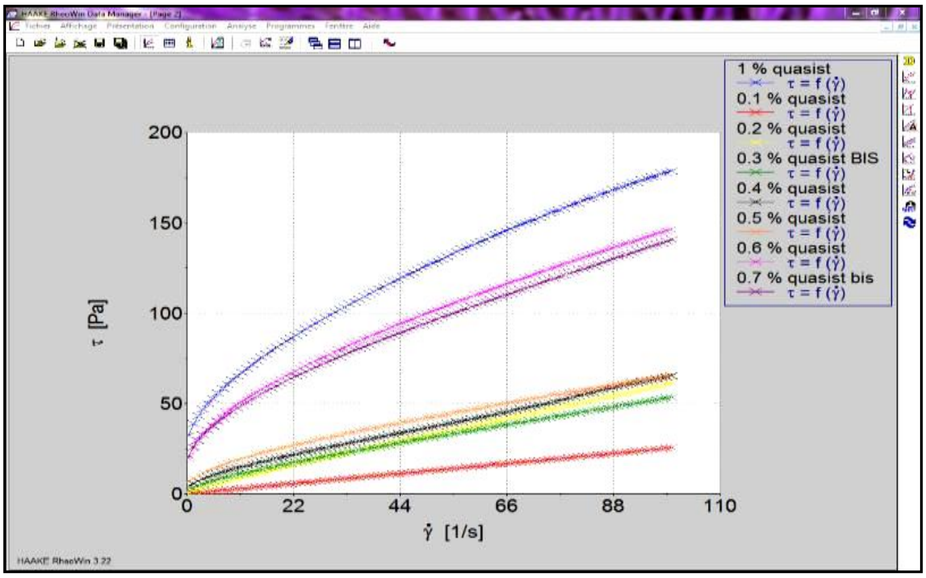

Fig. 1. The shear stress versus nanofluid shear rate for different Fraction

From the measurement of the rheological properties of carbon nanotubes-glycerol, we can draw the following conclusions:

- According to the rheogram which relates the shear stress as a function of the shear rate of the different mass fractions. We notice that there are three distinct zones such that the first one presents the Newtonian behavior of 0.1% and for the values of the mass fractions [0.2%, 0.3%, 0.4%, 0.5%] the rheological behavior becomes Herschel Bulkley one with a low yield stress and for [0.6%, 1%], it's a Herschel Bulkley model with a remarkable yield stress.

-According to the underside curve, the mass fraction affects strongly the rheological parameters, the graphs show that the yield stress, and the consistency increase when the fraction increases. On the other hand, the index of the flow decreases.

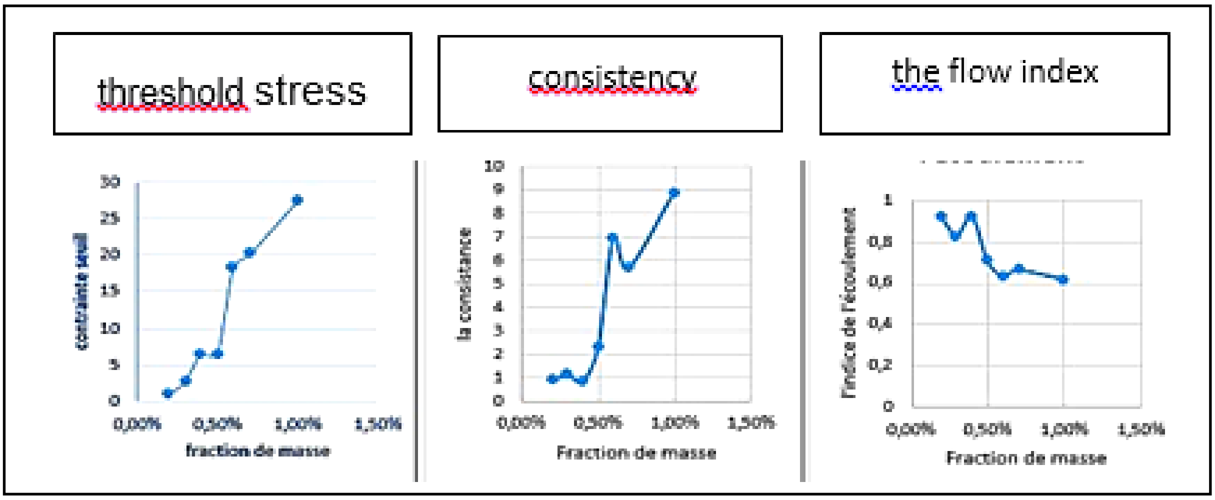

Fig. 2. The rheological parameters of the nanofluid

Several theoretical models have been developed to predict the evolution of the dynamic viscosity of suspensions under certain conditions.

In this part, we will focus on the theoretical models most adapted to our different Mass Fractions.

Law of evolution of the apparent viscosity as a function of the volume fraction for each value of the shear rate varying from 10s-1 to 80s-1.

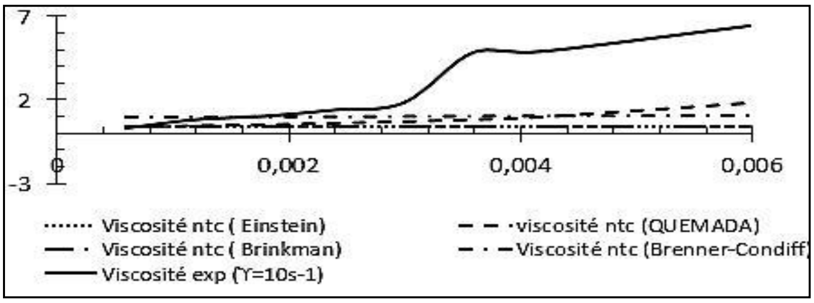

Figure. 3: Estimation of the relative macroscopic viscosity as a function of the particulate volume fraction for the suspensions of carbon nanotubes.

The model closest to our case in different shear rates is the model of QUEMADA according to theoretical calculations for volume fractions ranging from 0.000600591 to 0.00299576.

Beyond 0.003 to 0.006, there are no theoretical models that quantify the non-Newtonian behavior, so we have drawn from the experimental results the established relation (1) which describes the law is the polynomial law of order2 is given as follows:

$$\eta = a\phi_v^{\,2} + b\phi_v + C \qquad (1)$$

The coefficients of the polynomial were determined by the least squares method and removed by the experimental results;

We take:

σ= b/a≈ -0.01 and β= c/a≈ 2*⟦10⟧^ (-5)

So: the polynomial law of order 2 for the fractions volumetric beyond 0.003 established is:

$$\eta = a(\Upsilon) * (\phi_v^{\,2} - 0.01 * \phi_v + 2 * 10^{-5}) \quad (2)$$

Hence: ϕ_v: Volume fraction,

η: Viscosity

a: Coefficient of the order polynomial (2)

With the help of this expression, one comes to consolidate the protocols in quasi-stationary mode on the one hand and to optimize the processes of their use in industrial environment on the other hand.

- **In oscillating mode:**

For this regime, we studied the evolution of conservation modules G 'and loss G' 'as well as the evolution of the critical frequency with the concentration for a frequency range varying from 1 to 10 Hz and an imposed constraint of 1Pa, for concentrations [0.1% -1%].

For a concentration of 0.1%, the curves below show the G 'which characterizes the conservation and the G' 'which expresses the losses. We notice that the G' 'is the dominant for a certain frequency range which is the Viscous behavior of the aqueous solution of the carbon nanotube with glycerol, the conservation factor prevails from a frequency of 4 Hz can close.
Hence the point of intersection between G 'and G' 'at a critical value, fc≈4.601 Hz

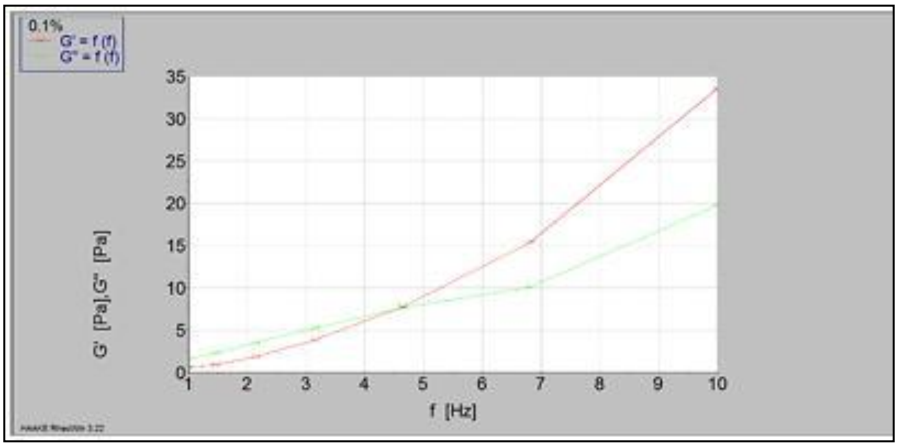

Figure 4: Viscoelastic properties of the solution for a concentration of 0.1%.

A behavior similar to this one is observed for a concentration a concentration of (0.2% -1%) where fc≈6.335 Hz as shown in figure 2.

It emerges from this analysis that the evolution of the value of fc, which corresponds to the case where G 'and G' 'are comparable, is inversely proportional to the concentration. This consolidates the control protocols of aqueous solutions of carbon nanotubes with glycerol in oscillating mode and allows to optimize the processes of their use in an industrial environment.

The curve below shows the frequency as a function of the concentration these frequencies are taken for the loss module equal to the conservation module:

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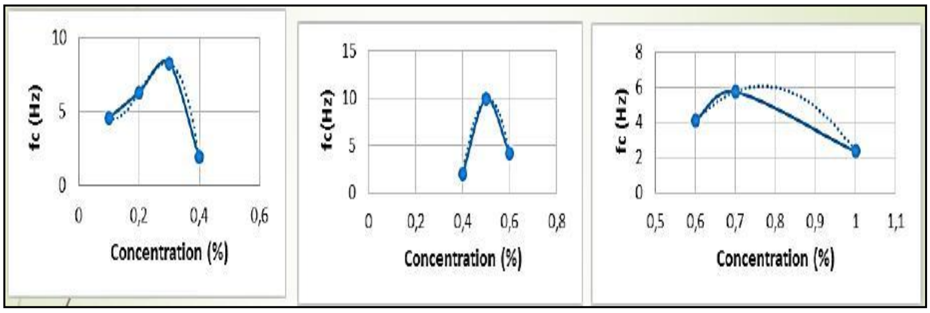

Figure5.a *Figure5.b* *Figure5.c*

Figure5: Curve shows the evolution of the frequency according to the concentration

a-For [0.1-0.4%],

$$fc = -1411.2 * X^3 + 856.45 * X^2 - 140.81 * X + 11.529 \quad (3)$$

b-For [0.4-0.6%],

$$fc = -684.55 * X^2 + 695.28 * X - 166.66 \quad (4)$$

c-For [0,6-1%],

$$fc = -69.65 * X^2 + 107.11 * X - 35.123 \quad (5)$$

This result is, in our opinion, an additional contribution to the control of the evolution of the flow of carbon nanotubes.

Effect of temperature [30-80°C]:

We will take from RheoStress 1 a set of rheograms that show the effect of the temperature [30-80° C] on the apparent viscosity.

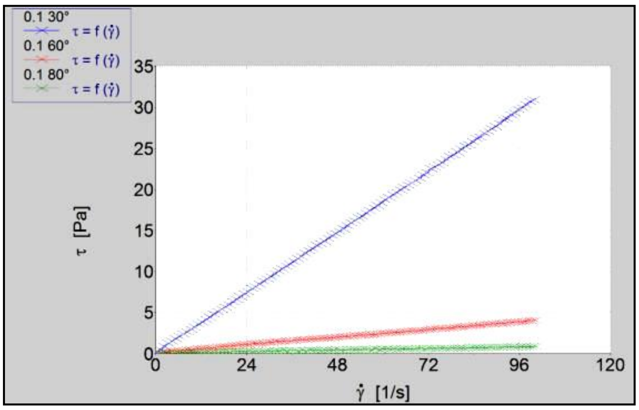

Fig. 6. Shear stress versus shear rate of carbon nanotube nanofluids-glycerol for different temperatures.

We studied the effect of temperature on the rheological behavior of the nanofluid. For this, we represent the evolution of the apparent viscosity as a function of temperature at different volume fractions (0.1-1%)).

It is observed from Figures 2 that the apparent viscosity of the nanofluid decreases as the temperature increases in the temperature range studied (between 30 and 80 ° C) and a constant shear rate.

Table1: effect of the parameters on the rheological and thermal behavior

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Viscosité	γ̇(s-1)	T °C	fm %	Nanofluide
0,325	48,61	30	0,10%	Glycérol+NTC
0,0475	48,65	60		
0,01114	48,66	80		
0,557	48,59	30	0,20%	Glycérol+NTC
0,0706	48,58	60		
0,04814	48,59	80		
0,387	48,57	30	0,30%	Glycérol+NTC
0,02408	48,54	60		
0,0139	48,73	80		
0,492	48,58	30	0,40%	Glycérol+NTC
0,483	48,47	60		
0,08673	48,6	80		
0,09182	48,59	30	0,50%	Glycérol+NTC
0,05178	48,47	60		
0,02779	48,6	80		
0,03512	48,49	30	0,60%	Glycérol+NTC
0,001578	48,66	60		
0,002212	48,71	80		
0,07833	48,5	30	0,70%	Glycérol+NTC
0,05436	48,59	60		
0,04844	48,59	80		
0,267	48,5	30	1,00%	Glycérol+NTC
0,293	48,59	60		
0,383	48,59	80		

The temperature has a strong effect on the rheological properties of the CNT. The viscosity of NTC decreases significantly with increasing temperature.

3.2 Thermal behavior

The thermal behavioral research was led by a heat exchanger to double envelope and it is due to its advantages such as the precise regulation of the temperature of the product with a homogeneous distribution of the temperatures.

We set as modus operandi, the fluid that circulates in the heating serpentine involves of the water with temperature 70°C for the heat transmission and for the reservoir. We took two cases for the cold fluid the first one involves some water and the second the nanofluid with the nanotube of carbon and the glycerin the concentration between 0.3 % and 0.7 % of which we varied with a constant debit of 0.6l / min with agitation.

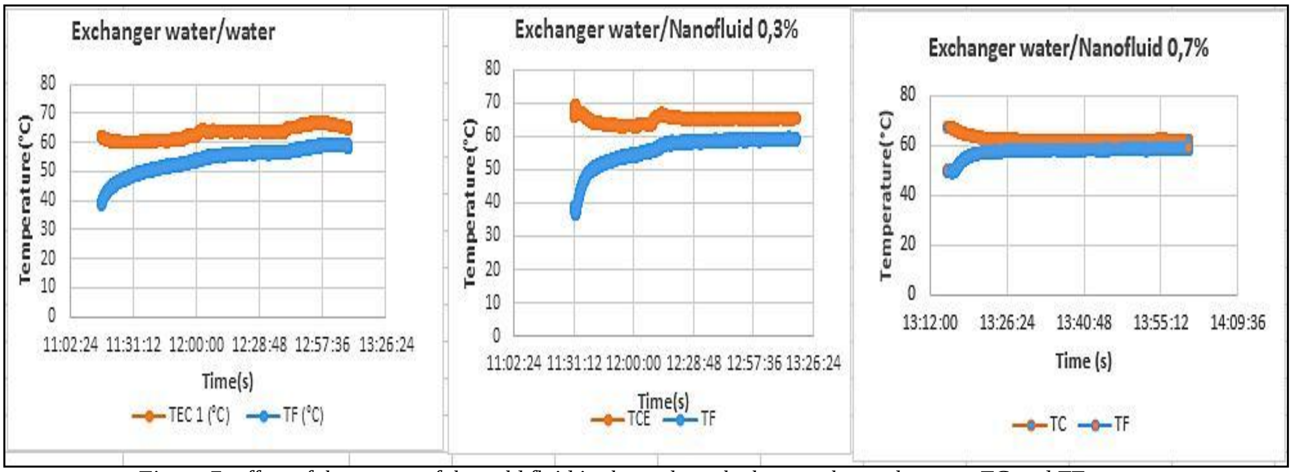

Figure.7: effect of the nature of the cold fluid in the tank on the heat exchange between TC and TF

It is noted that the heat exchange is affected by the nature of the cold fluid in the tank. It is observed that, when it is an exchange between the water and the nanofluid with 0.3% of carbon nanotube, the exchange is done quickly and the temperatures of the hot and cold fluid tend to the same value. This is confirmed in the case of the exchange between water and the nanofluid based on 0.7% of carbon nanotube. It should be noted that when the concentration of carbon nanotube increases the heat exchange increases.

- Determination of the Nusselt Number as a function of the Reynolds number:

In this part, we will carry out a numerical study on the characteristics of the NTC / Glycerol nanofluid, the type of NTC and the NC7000 of 9.2 nm with volume concentrations ranging from 0.1% up to 1%, in a heat exchanger serpentine from which the nanofluid is a cooling fluid under turbulent flow conditions.

To study the thermal performance of nanofluids, two approaches are proposed:

Conventional approach: A first approach, which consists in neglecting the effect of the thermal dispersion of the nanoparticles as well as the molecular effect and consequently the nanofluid is assimilated as a pure fluid.

In the turbulent regime, the number of Nusselt can be evaluated in a circular tube with the Colburn formula:

$$Nu_D = 0{,}023.Pr^{1/3}.Re_D{}^{0.8} \qquad (6)$$

The Nusselt number is calculated in a helical coil:

$$Nu_{ic,nf} = Nu_{inf}(1 + 3{,}5\frac{D}{D_H}) \qquad (7)$$

With D is the inside diameter of the coil and is its average diameter:

$$D = 30 \quad en\ (mm)$$
$$D_H = 267 \quad en\ (mm)$$

We will evaluate the number of Nusselt as a function of the Reynolds for different volume fractions of 0.0006% up to 0.006% for the nanofluid, comparing with pure water, to see the effect of the addition of NTC on thermal performance. in a coil heat exchanger.

Modified conventional approach : In this approach, we will take into account the effect of thermal dispersion and the molecular effect of carbon nanotubes to study the thermal performance of turbulent flow in a circular tube in a more relevant way. For that, we will work with Li Xuan's formula that evaluated the Nusselt number for nanofluids taking into account the effect of thermal dispersion of nanoparticles in a circular tube.
Li Xuan's formula:

$$Nu_D = 0{,}0059(1 + 7{,}6286\phi^{0{,}6886} Pe_d^{0{,}001})\ Pr^{0{,}9238}.Re_D^{0{,}4} \quad (8)$$

In this formula the number of Péclet describes the effect of thermal dispersion of nanoparticles.

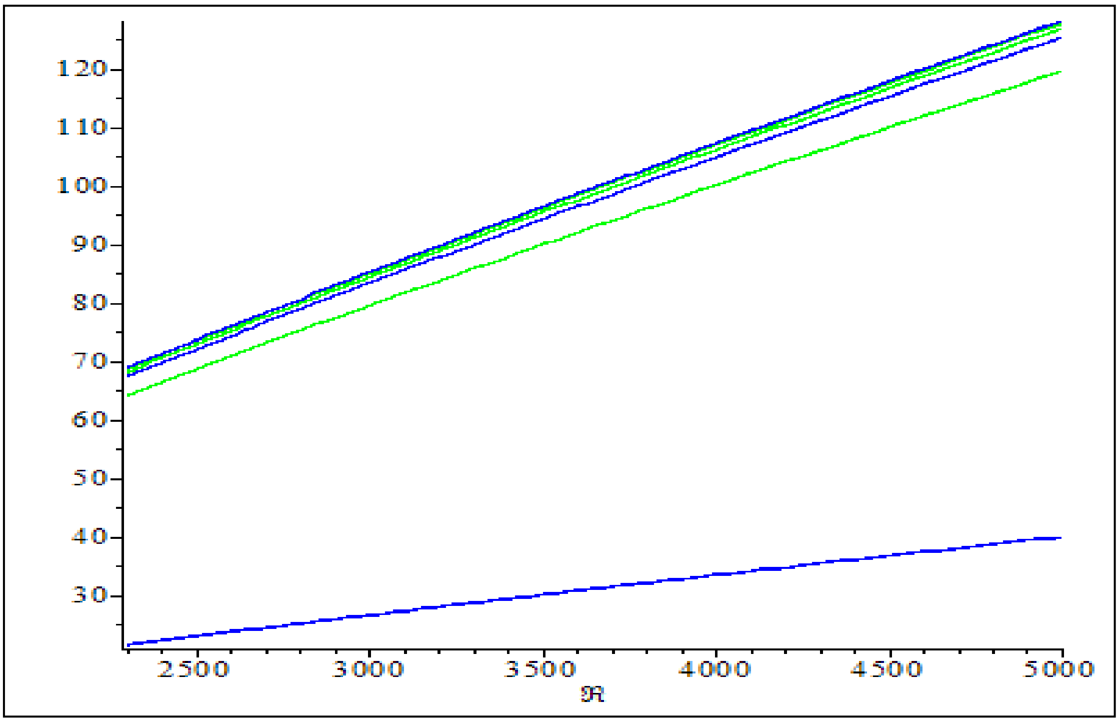

Figure 7 : Evolution of the Nusselt number according to the Reynolds for the nanofluid NTC / Glycerol for φ ranges from 0.1% up to 1%, and for pure water.

This numerical study considered a variation in the heat transfer fluid in a circular tube in a turbulent regime, of which two types of fluid could be compared:
→ Pure water
→ Nanofluid based on the carbon nanotube and glycerol, by varying the volume fraction from 0.1 to 1%
The curves show us that the change of heat transfer fluid strongly affects the increase of the Nusselt number according to Reynolds,

The first curve of the pure water shows us a small increase in the number of the Nu as a function of Re on the other hand with the nanofluid and with the increase of the volume fraction, we noticed a remarkable increase

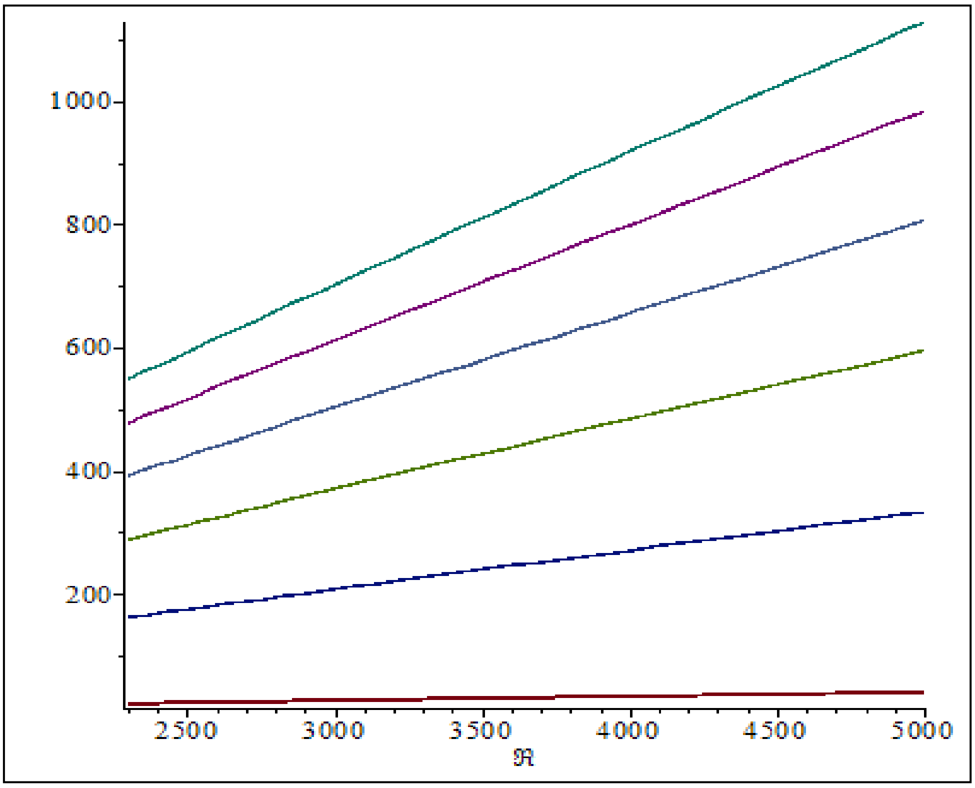

Figure 8 : Evolution du nombre de Nusselt en fonction du Reynolds pour le nanofluide NTC/Glycérol pour φ varie de 0.1% jusqu'à 1% en tenant compte d'effet de la dispersion thermique et pour l'eau pur.

Conclusion

The promising results of this study are very encouraging and show that the use of carbon nanotube-based nanofluids clearly offers an improvement in thermal performance over conventional base fluids. NTC-based nanofluids can thus constitute a promising outlet for heat transfer and offer good prospects and development.

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