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Heat Transfer Coefficients Investigation for TiO_2 Based Nanofluids

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ABSTRACT

From a regression analysis perspective, this paper focused on literature about TiO_2 nano particles. The particles on focus entailed those that had been suspended in ethylene glycol and water – at a ratio of 60:40. Indeed, regression analysis has gained application in contexts such as the turbulent Reynolds number, especially with the aim of establishing the impact of the ratio of the base fluid on heat transfer coefficients, as well as the target materials' thermal properties. From the findings, this study infers that when the water-ethylene glycol mixture is used at a ratio of 60:40, the rate of heat transfer is higher than that which is obtained when water is used solely. Additional findings established from the examination of the impact of material concentration and temperature on the rate of nanofluids' heat transfer suggested that as temperature increases, the rate of heat transfer decreases. However, it was noted that an increase in concentration exhibits a positive correlation with the nanofluids' rate of heat transfer whereby an increase in the former parameter (concentration) leads to an increase in the latter (rate of nanofluids heat transfer).

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NOMENCLATURE

Pr	w	g	Gravity(m/s^2)
Re	bf	**Subscripts**	
Nu	nf	Water	Particle Specific density
h	Heat transfer coffieicent	Base fluid	Horizontal components of velocity (m/s)
φ	Volume fraction	Nanofluid	Vertical components of velocity (m/s)
f_k^{eq}	Equilibrium distribution function	U_i, U_j	Random numbers between 0 and 1

1. INTRODUCTION

In the recent past, nanofluids have gained increasing popularity. Particularly, the interest has arisen from its beneficial effects felt in the field of energy. Particularly, nanofluids constitute suspended particles contained in base fluids. In most cases, they are distributed uniformly and contain metal oxides or metals that are nanometer-sized. Indeed, many scholarly investigations have focused on traditional base fluids. Examples include ethylene glycol and water, as well as the mixture ratios of these base fluids. The main objective has been to establish heat transfer characteristics and thermal properties with which these materials are associated, with nanofluids on focus. From the majority of the findings, scholarly studies demonstrate that ethylene glycol exhibits higher boiling point and lower freezing point than water. These mixed outcomes regarding the performance of water and that of ethylene glycol account for the increasing use of their mixture, with different ratios employed and dispersed via nanometer-sized particles. Specific parameters that have been investigated in relation to the mixture include heat transfer characteristics and thermal properties – when the materials operate under varying conditions of the Reynolds range.

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2. LITERATURE REVIEW

The heat transfer and thermal properties of nanoparticles dispersed in water such as TiO_2 [1-6], Al_2O_3 [7-9], CuO [10-12] and ZnO [13] and the thermal properties of nanoparticles suspended in EG as base fluid were investigated. Various nanoparticles were used, including TiO_2 [14, 15] Al_2O_3 [16-18] and CuO [19] are available in literature as stated. On the other hand, investigators have inclined towards EG-W 40-60 mixture ratio. In the experimental study by Vajjha et al. [20-22], the main aim was to find out the thermal properties of nanofluids, ZnO, SiO_2, CuO, and Al_2O_3. Also, Kulkarni et al. [23] and Sahoo et al. [24] performed experimental investigations with SiO2nanoparticles dispersed in EG-W 60-40 (E64) base fluid. Similarly, investigations were performed with nanoparticles dispersed in EG-W 40-60 (E46) as base fluid for TiO_2 [25-28] and Al_2O_3 [26, 28].

In the study by He et al. [29], experimental conditions were set in such a way that the Reynolds range was established between 2000 and 6500, with concentrations varying from 0.24 to 1.18 percent. In a related study, Duangthongsuk and Wongwises [30] focused on the parameters of the friction factor and HTC, with the nanofluids of concern being TiO_2/water (21nm). Also, the study established a maximum concentration, which was set at 2.0 percent, to gain insight into the impact of the factors mentioned above. It is also notable that temperatures were set at 25^{o}C, 20^{o}C, and 15^{o}C, with the range of the turbulent Reynolds number established between 3,000 and 18,000. Indeed, Duangthongsuk and Wongwises [3] conducted a similar study and strived to predict a Nusselt number – by concentrating on TiO_2/water nanofluids [29].

In the study by Usri et al. [31], the main aim was to predict the HTC connective of Al_2O_3 nano-particles. The study focused on E46 base fluid. Experimental conditions were set in such a way that 0.6 percent was the maximum volume concentration while 30-50nm range reflected the average size of the particles that were used. Also, the Reynolds range was set between 1,500 and 18,000, with 50^{o}C being the operating temperature[32-34].

A related investigation was conducted by Seshu et al. [35-40], who strived to analyze SiO_2 and Al_2O_3 nano-particles numerically. With their formulated equations, the researchers strived to predict the parameter of HTC in the E46 base fluid. In the investigation by Sharma et al. [37], a central motivation was to compare TiO_2 nano-particles' heat transfer coefficients in E46, as well as water as a base fluid. The experimental conditions were developed in such a way that 30nm was the average size of the particles while the range of temperature was set between 50^{o}C and 80^{o}C, with 0.0-0.4% being the volume concentration.

3. METHODOLOGY

The base fluid properties from the literature has been taken for water and EG and correlations were formulated using the regression analysis [38, 43]. Using the equations the thermal conductivity and viscosity values are predicted for TiO_2 based nanofluids.

Similarly, the heat transfer coefficients data from the literature has been used in regression for the formulation of correlations for Nusselt number [38, 43]. These correlations were used in prediction of heat transfer data and Nusselt number data which are in turn used in comparison of base fluid effect. The impact of base fluids i.e water and EG on the heat transfer characteristics of TiO_2 based nanofluids are analysed and represented.

3. 1. Base Fluid Properties and Nanofluid Properties

Sharma et al. [41] sought to investigate parameters of thermal conductivity, specific heat, viscosity, and density, having applying the equations developed by Seshu et al. [36].

The Nusselt number equation given for water by Sharma et al. [41] is given as follows:

$$Nu = \frac{h_{nf} D}{k_{nf}} = 0.023Re^{0.8}{Pr_w}^{0.4}\left(1 + Pr_{nf}\right)^{-0.012}(1 + \emptyset/100)^{0.23} \quad (1)$$

The Nusselt number equation given for E46 by Seshu et al. [36] is given below:

$$Nu = 0.0255Re^{0.8}{Pr_{bf}}^{0.4}\left(1 + Pr_{nf}\right)^{-0.02084}(1 + \emptyset/100)^{0.3373} \quad (2)$$

In this case, the Nusselt number is represented by Nu while the Reynolds number is represented by Re. Indeed, a 7-5-percent standard deviation and average deviation of 6.13% is linked o Equation (1). Also, there is a 20-percent deviation from the correlation in some of the exception data points. The specific temperature range in which the equation is worth applying is 20-90oC. Also, the diameter of the particles is expected to be less than or equal to 53nm, with four percent also expected to be the maximum concentration. Regarding Equation (2), the standard deviation lies at 9.3% while 7.8% reflects the average deviation. As such, Dittus-Boelter equation has been used to establish Equation (1) and Equation (2).
When substitutions are made such as Prnf= 0 and $\emptyset = 0$, the two equations translate into Equation (3), which is given below:

$$\mathrm{Nu} = 0.0257\mathrm{Re}^{0.8}{\mathrm{Pr}_{\mathrm{bf}}}^{0.4} \quad (3)$$

4. RESULTS AND DISCUSSIONS

Based on Sharma et al. [39, 41], E46-based nanofluids and water-based nanofluids are used to predict the thermal conductivity of TiO_2. From the results, E46-based nanofluids predict lower values of thermal conductivity compared to water-based nanofluids. It can also be seen that when water-based nanofluids are embraced, there is higher thermal conductivity. However, these higher heat transfer coefficients are seen to be achieved when E46-based nanofluids are used. It is also notable that E46-based nanofluids exhibit higher Nusselt numbers than TiO_2 nano-particles' water-based nanofluids. These results can be associated with or attributed to a combination of the effect of viscosity values and thermal conductivity values. The current study's findings suggest further that as temperature increases, the coefficients of heat transfer increase. As such, regions with lower temperature remain suitable and preferable for achieving higher heat transfer values. From Figures 3 and 4 (below), it is also worth indicating that the variables of heat transfer coefficient and volume concentration have a significant impact. This impact suggests the importance of increasing the nanofluids' volume concentration, a trend that is associated with the enhancement of the coefficients of heat transfer [39, 40].

Notably, the correlations presented by Sharma et al. [39, 4r1] governed the estimation of TiO_2 nanoparticles' viscosity values. Upon determining these values, the results were compared with E46- and water-based nanofluids. The comparative outcomes are presented in Figure 2 below. From the results indicated in Figure 2, water exhibits lower viscosity than E46. The eventuality is that lower viscosity values are likely to be predicted by water-based nanofluids compared to situations where E46-based nanofluids are used.

This study also employed Sharma et al.'s [39, 41] Nusselt equations for evaluating coefficients of heat transfer. Figure 3 illustrates the results plotted regarding and TiO_2-based nanofluids, especially regarding the effect of parameters of concentration and temperature. From the figure, the results obtained suggest that when temperatures are low, there is an increase in the coefficients of heat transfer. From these outcomes, this study infers that a decrease in temperature exhibits an inverse correlation with the coefficient of heat transfer whereby it leads to an increase in the former parameter (coefficient of heat transfer). Regarding the role of the variable of concentration, this study established that an increase in this parameter exhibits a direct relationship with the coefficient of heat transfer whereby an increase in the concentration causes an increase in the coefficient of heat transfer.

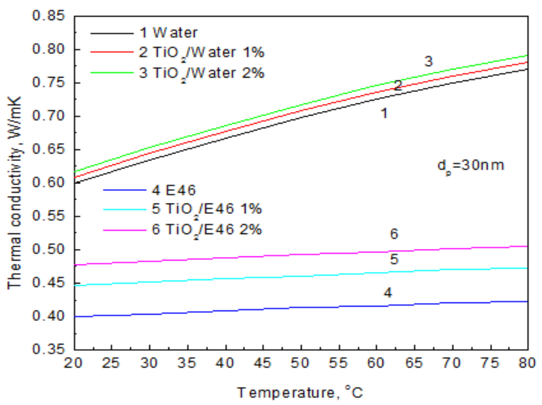

Figure 1. E46-based and water-based nanofluids' thermal conductivity prediction

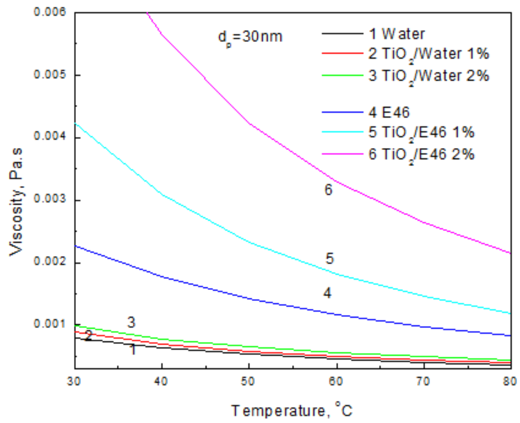

Figure 2. E46-based and water-based nanofluids' viscosity prediction

It is also notable that this study established similar results when E46- and TiO_2-based nanofluids were used. These findings are illustrated in Figure 4 and suggest that when temperature increases (and the concentration decreases), there is an increase in the coefficient of heat transfer. The latter results conformed to the standard equation concerning heat transfer.

In Figure 5, the results involve the relationship between TiO_2-based nanofluids' state of heat transfer and the nature or type of the base fluid. Based on the results obtained, it is evident that higher coefficients of heat transfer are likely to be obtained if E46-based nanofluids are employed. In the TiO_2-based nanoparticles, the results demonstrate that water-based nanofluids are likely to exhibit lower coefficients of heat transfer (compared to a case where E46-based nanofluids are used). Indeed, the results can be attributed to a combination of the impact of the selected nanofluids' viscosity and thermal conductivity.

From the results presented in Figure 6, this study strived to offer a comparison of E46 and water as base fluids, with the main objective being a comparison of TiO_2 nanofluids' Nusselt numbers. The figure builds on the results obtained in Figure 1, as well as those presented in Figure 5. From Figure 1, water-based nanofluids exhibit higher thermal conductivity. On the other hand, Figure 5 suggests that when water-based nanofluids are compared to E46-based nanofluids, the former predict lower coefficients of heat transfer (compared to the latter). Hence, Figure 6 proceeds to compare TiO_2 nanofluids' Nusselt numbers.

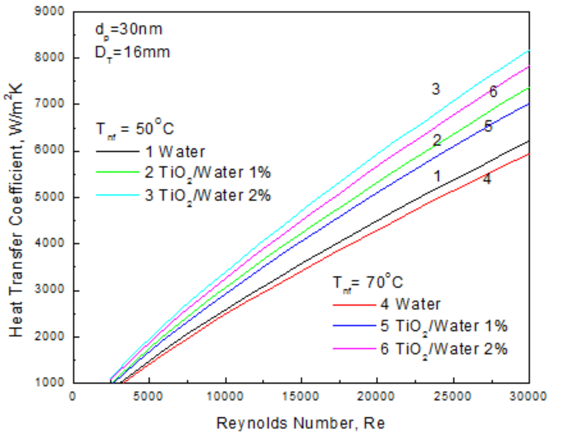

Figure 3. TiO_2/Water-based nanofluids' coefficients of heat transfer

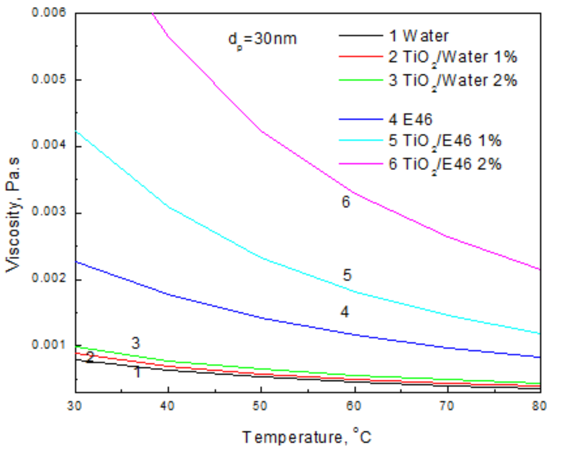

Figure 4. TiO_2/E46-based nanofluids' coefficients of heat transfer

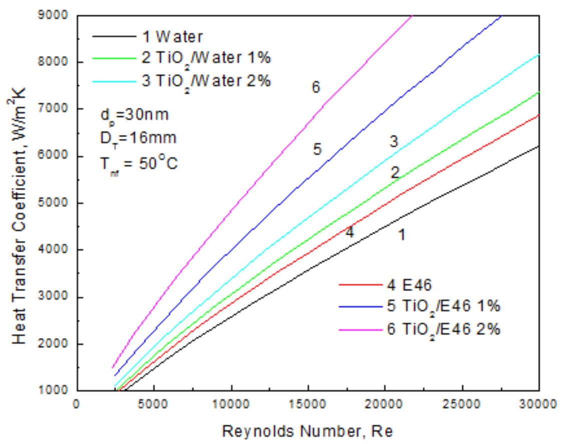

Figure 5. Comparing the TiO_2 nanofluids' coefficients of heat transfer

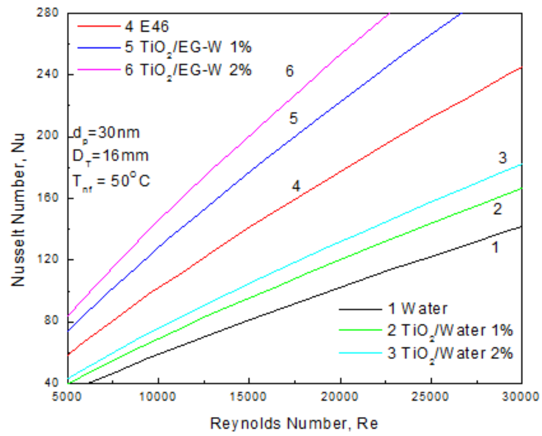

Figure 6. Comparing the TiO_2 nanofluids' Nusselt number

5. CONCLUSION

Based on the insights gained from the current literature, it is evident that higher thermal conductivity is achieved when water-based nanofluids are used. However, the results demonstrate that higher coefficients of heat transfer are associated with E46-based nanofluids. This study has also established that the latter materials exhibit higher Nusselt numbers when compared to experimental results obtained when TiO_2 nano particles' water-based nanofluids are used. Notably, the outcomes or the perceived performance is linked to the combined effect of viscosity values and thermal conductivity values. It is also evident that as temperature increases, the coefficients of heat transfer increase. Hence, regions with lower temperature remain suitable and preferable for achieving higher heat transfer values. From figures 3 and 4, it is also inferable that the parameters of heat transfer coefficient and volume concentration pose a significant impact, pointing to the criticality of increasing the nanofluids' volume concentration – to ensure that the heat transfer coefficients are enhanced.

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چکیده

از دیدگاه تحلیل رگرسیون ، این مقاله به ادبیات مربوط به ذرات نانو TiO_2 پرداخته است. ذرات تمرکز شامل مواردی هستند که در اتیلن گلیکول و آب به حالت تعلیق درآمده می باشد – با نسبت ٤٠:٦٠. در واقع ، تجزیه و تحلیل رگرسیون در زمینه هایی مانند تعداد آشفتگی رینولدز توربیولنت ، بخصوص با هدف تعیین تأثیر نسبت سیال پایه بر ضرایب انتقال حرارت و همچنین خصوصیات حرارتی مواد مورد استفاده ، ارائه داده است . از یافته های این مطالعه این استنتاج می شود که هنگامی که از مخلوط آب اتیلن گلیکول با نسبت ٤٠:٦٠ استفاده می شود ، میزان انتقال حرارت بالاتر از آن است که هنگام استفاده از آب فقط حاصل می شود. یافته های اضافی حاصل از بررسی تأثیر غلظت مواد و درجه حرارت بر سرعت انتقال حرارت نانوسیالات بیانگر این است که با افزایش دما ، سرعت انتقال حرارت کاهش می یابد. با این حال ، قابل توجه است که افزایش غلظت با میزان انتقال حرارت نانوسیالات ارتباط مثبت دارد و در نتیجه افزایش پارامتر قبلی (غلظت) منجر به افزایش در حالت دوم (سرعت انتقال حرارت نانوسیالات) می شود.

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