Annexure–IX

PROJECT COMPLETION REPORT

UNIVERSITY GRANTS COMMISSION
BAHADURSHAH ZAFAR MARG
NEWDELHI–110002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING THE FINAL REPORT OF THE WORK DONE ON THE PROJECT

1.	**Title of the Project**	Characterization and Hydrodynamic study on nanofluids
2.	**Name and Address of the Principal Investigator**	Prof. Ritu Gupta Dr. S.S. Bhatnagar University Institute of Chemical Engineering & Technology, Panjab University, Sector 14, Chandigarh, 160014
3.	**Name and Address of the Institution**	ENERGY RESEARCH CENTRE, Panjab University, Chandigarh
4.	**UGC Approval Letter Number and Date**	F No. 40-7/2011 (SR) dated 29 June 2011
5.	**Date of Implementation**	1.7.2011
6.	**Tenure of the Project**	Three years, 1.7.2011 to 30.6.2014
7.	**Total Grant Allocated**	Rs. 12,36,787/-
8.	**Total Grant Received**	Rs. 11,82,888/-
9.	**Final Expenditure**	Rs. 11,54,082/-
10.	**Title of the Project**	Characterization and Hydrodynamic study on nanofluids
11.	**Objectives of the Project**	(a) Synthesis of nanofluids by the two step process. (b) Characterization of nanofluids in terms of

their volumetric property and transport properties.
(c) Measurement of pressure drop per unit length through straight tubes and helical coils for the synthesized nanofluids.

12.	**Whether Objectives were achieved**	Yes
13.	**Achievements of the Findings**	Annexure 1 attached
14.	**Summary of the Findings**	Annexure 2 attached
15.	**Contribution to the Society**	If commercialized, nanofluids can be used in industrial applications
16.	**Whether any Ph.D. enrolled /produced out of the Project**	Yes, One
17.	**Number of Publications out of the Project**	03 (Three), Reprints attached.

11.09.2019
Dr.(Ms.) Ritu Gupta
(Principal Investigator)
Dr. RITU GUPTA

(Registrar, P.U.)
14/10/19
Registrar
Panjab University
Chandigarh

- Effect of different base fluids viz. water, EG/water (60:40), PG/water(60:40) on the pressure drop of nanofluids through straight tubes and helical coilswas studied.
- Various metal oxide nanoparticles like Al_2O_3, CuO and MgO with primary particle size less than 50 nm was considered for measuring pressure drop of nanofluids.
- Various geometries of test section, i.e., straight tubes & helical coils having different inside diameters, coil diameters and pitch were used for pressure drop measurement so as to cover a wide range of Reynolds number.
- Effect of varying particle volume concentration of nanoparticles in the range 0-2.5 vol.% on pressure drop of nanofluids through straight tubes and helical coils was elucidated.
- Comparison of experimental data with the predicted values determined from the various models available in literature was done.
- Development of a new model/correlation for nanofluid flowing through straight tubes and helical coils was also done.

Synthesis and characterization of metal and non-metal oxide based nanofluids with different particle volume concentrations in the temperature range of 10 to 40^{0}C has been carried out. Distilled water and aqueous ethylene glycol (in 60:40 weight ratio) were used as the base fluids.TiO_2, SiO_2 and Al_2O_3 nanoparticles were used for the preparation of nanofluids. TiO_2 nanofluid was prepared using water as base fluid in the concentration range of 0.3-2.5 vol.%. The thermophysical properties of TiO_2-water nanofluid were determined in the temperature range of 10-40^{0}C. The flow characteristics of TiO_2-water nanofluid through straight horizontal tube were then investigated for 0.3-1.5 vol.%. The effect of percentage volume fraction of suspended nanoparticles and Reynolds number on fanning friction factor has been studied. For NRe < 1000, there was a fairly good agreement between the friction factor predicted using the conventional correlation (f = (16/NRe)) and the experimentally measured value of friction factor. However, for NRe> 1000, deviation from the Newtonian behavior has been observed. With increasing Reynolds number, the divergence becomes significant and is believed to be a function of percentage volume fraction of TiO_2 in the nanofluid. Correlations for predicting the fanning friction factor for TiO_2-water nanofluids as a function of particle volume concentration have been developed for laminar as well as turbulent flow regions. These correlations predict the present experimental data well within ±10%. SiO_2 nanofluid was prepared using 60:40 ethylene glycol-water as the base fluid with concentration 1, 1.5 and 2 vol.%. The prepared SiO_2 nanofluid was then characterized in terms of thermophysical properties in the temperature range 10 to 40^{0}C.

The hydrodynamic characteristics for the laminar flow of 60:40 (w/w) EG-W based Al_2O_3 nanofluids through straight tube and helical coils were experimentally investigated. Three straight tubes with different inside diameters and 4 helical coils with different combinations of curvature ratio and pitch ratio were used as the experimental test section. Four different volume concentrations (0.6, 0.9, 1.2 and 1.5 vol.%) of alumina nanofluid were prepared. Pure ethylene glycol (Rankem make, 99.0 % assay) was used for the preparation of base fluid. Glycol / water mixture was prepared by the addition of distilled water in small quantities to the pure glycol along with mechanical stirring. The alumina nanoparticles with an average size of 55 nm were procured from Nanoshel. The two step method was ollowed for the preparation of nanofluids. The amount of nanoparticles required for the preparation of nanofluid was calculated and was slowly added to the base fluid along with magnetic stirring. The fluid was then homogenized and ultrasonicated.The nanofluid was made stable by pH adjustment. The highest concentration was diluted to prepare the lower concentrations. The prepared nanofluids were observed to be stable for seven days. The density of base fluid was measured at 20, 25, 30, 35^{0}C using Anton Paar, DMA 48 density meter with an accuracy of ±0.6 %. The viscosity of base fluid was measured at 20-35^{0}C using Ubbelohde viscometer with an accuracy of ±1.3 %. After the measurement of density and viscosity of base fluid, the transport properties of alumina nanofluid were measured for all the particle volume concentrations at all the working temperatures. The straight tube and helical coil setup were then calibrated using base fluid over a wide range of Reynolds number. After establishing the reliability of the experimental setup, the pressure drop measurements were carried out for alumina nanofluid through straight tube and helical coils for all the concentrations under the laminar flow regime. Friction factor of nanofluids was found to be greater than that of the base fluid for both the straight tubes as well as helical coils. For each system, observed pressure drop or friction factor increased with increase in particle volume fraction. The friction factor of nanofluids could not be estimated using standard friction factor correlations available in literature for flow through straight tubes and coils. Thus, a correlation has been proposed to estimate the friction factor for laminar flow of alumina nanofluids through straight tubes as a function of particle volume fraction. This correlation is valid for water as well as glycol water based alumina nanofluids with $0 \leq \Phi \leq 1.5\%$. The coil friction factor was found to be influenced by both the curvature ratio and coil pitch.The combined effect of both these parameters is well quantified in terms of Germano number. A correlation to estimate the coil friction factor for laminar flow of base fluid as well as alumina nanofluid has been proposed. This correlation is valid for $0 \leq \Phi \leq 1.5\%$ and $0.7 \leq Gn \leq 12$.Both the correlations predict the experimental data well within ±10%.

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Hydrodynamic studies on glycol based Al_2O_3 nanofluid flowing through straight tubes and coils

Puja Sharma , Ritu Gupta * , Ravinder Kumar Wanchoo

Energy Research Centre, Panjab University, Chandigarh 160014, India
University Institute of Chemical Engineering and Technology, Panjab University, Chandigarh 160014, India

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ABSTRACT

Laminar flow hydrodynamic characteristics of alumina based nanofluids (0–2.5 vol.%) flowing through straight tubes and helical coils with different combinati... of curvature and pitch ratio have been studied. Two types of glycol-water based mixtures, ethylene glycol/water (EG/W) and propylene glycol/water (PG/W) in 60:40 wt ratio, were used as the base fluids. ... friction factor of nanofluids was found to be higher than that of the base fluids for both the straight tubes as well as helical coil geometry, which further increased with increase in nanoparticle volume concentration. At the same Reynolds number, friction factor increased with nanoparticle concentration in the base fluid, which could be due to the presence of Brownian motion and increased collision rate of nanop... Two new correlations to predict the friction factor for the laminar flow of alumina nanofluids through straight tubes and helical coils have been proposed.

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1. Introduction

Due to a rapid rise in energy costs, there is a great need for new types of heating & cooling medium so as to minimize the energy consumption by increasing the overall thermal efficiency. Ethylene or propylene glycol mixed with water in 60:40 wt ratio is commonly used heat transfer fluid in heat exchangers, industrial plants, automobiles etc. . The main reason to use glycol mixtures is their ability to decrease the freezing point of the heat transfer medium with lower corrosivity and low volatility.

The transport properties of these fluids can further be improved by the use of additives called nanoparticles with particle size and concentration less than 100 nm and 5 vol.% respectively, resulting in stable suspensions termed as nanofluids . Nanofluids possess a higher thermal conductivity resulting in increased heat transfer rate as compared to that of the base fluid . However, addition of nanoparticles also causes an increase in the density and viscosity of the fluid thereby increasing the pumping power required to pump the fluid. Baratpour et al. examined the dynamic viscosity of single-wall carbon nanotubes/EG nanofluid (0.0125–0.1 vol.%) from 30 °C to 60 °C. They observed that the nanofluid viscosity increased to 3.18 times that of the base fluid at 30 °C for 0.1 vol.%. Afrand et al. experimentally investigated the dynamic viscosity of SiO_2-multi walled carbon nanotubes/engine oil hybrid nanofluid (0–1 vol.%) from 25 °C to 60 °C. They reported a maximum enhancement of 37.4% in the viscosity of hybrid nanofluid. Some of the authors ... have studied the rheological behavior of nanofluids and report... non-Newtonian behavior of nanofluid... Hemmat Esfe et al. experimentally studied the flow ... multi-walled carbon nanotubes/water nanofluid through a double tube heat exchanger (0 ... 1 vol.%) under turbulent conditions. The authors reported an average increase of 78% in heat transfer coefficient for 1 vol.% whereas a penalty of 27.3% was observed in pressure drop. Thus, the pressure drop studies need to be carried out to estimate the frictional pressure drop and hence the power required to pump the nanofluid. The literature available on the flow of nanofluids through different geometrical configurations has been extensively reviewed in the subsequent section.

1.1. Flow of nanofluids through straight tubes

Several experimental studies have been reported on flow of Al_2O_3 based nanofluids through straight tubes. Alumina nanoparticles have a good thermal conductivity (36 W/m K) and are ... available.

Some of the authors ... studied the laminar flow of alumina nanofluids through straight tubes and reported an in... in the pressure drop o... nanofluids. While several other investigators ... observed ... significant increase in the pressur...

* Corresponding author.
E-mail address: ... (R. Gupta).

and PG-W and their corresponding alumina nanofluids. is modified to extend its applicability for predicting the ction factor of nanofluids as well, in the following form:

$$\frac{f}{f} = 1 + \frac{A\,BGn}{1+(BGn)^{C}} \quad (20)$$

Here f for nanofluid is given by Eq.

The values of parameters A, B and C are the same as obtained for base fluids. Eq. is applicable for the prediction of coil friction factor of water, glycol-water mixture base fluid and alumina nanofluids with nanoparticle volume concentration ranging from 0 to 2.5 and Gn 12.

shows the comparison of experimental data for base fluids as well as nanofluids with the proposed correlation, Eq. . As can be seen, the data is reasonably distributed around the proposed correlation. shows the comparison between the measured friction factor ratio and the calculated friction factor ratio based on the proposed correlation in terms of parity plot. The present proposed correlation, Eq. predicts the experimental data well within ±10%.

To check the validity of Eq. , the experimentally measured data of Wu et al. for the flow of alumina/water nanofluids in helical tubes was compared with the predictions of proposed correlation Eq. gives the comparison of present model

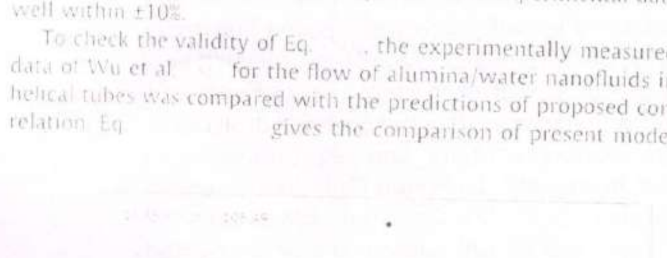

Fig. 22. Plot of 1 versus Germano number for combined base fluid and nanofluid data.

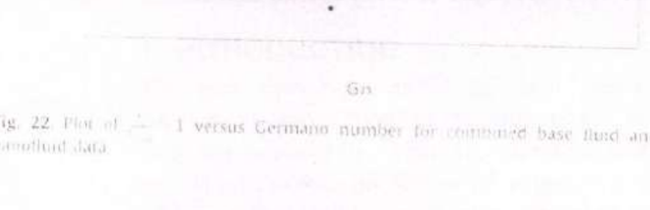

Fig. 23. Parity plot between (calculated) and (experimental).

Table 7
Statistical errors between the present proposed model, Eq. and data of Wu et al.

Author	ARE (%)	MRQE
Present exp. data	5.887	0.074
Wu et al.	8.663	0.098

Eq. (20) with the data of Wu et al. and present experimental data in terms of statistical errors.

The table shows that the present proposed correlation, Eq. (20) predicts the experimental data of Wu et al. well within ±10% for Gn ≤ 12.

6. Conclusion

The hydrodynamic characteristics of Al_2O_3/EG-W (0.6, 0.9, 1.2 & 1.5 vol.%) and Al_2O_3/PG-W nanofluids (1, 1.5, 2, 2.5 vol.%) flowing under laminar condition through straight tubes and coils were investigated. Friction factor of nanofluids was found to be greater than that of their corresponding base fluids for both the straight tube as well as helical coil. For each system, observed pressure drop or friction factor increased with increase in particle volume fraction. The percentage enhancement in friction factor in respect of base fluid, increases with increase in Reynolds number and also increases with increase in nanoparticle concentration. The presence of nanoparticles enhance the resistance to flow due to Brownian motion that results in increased collision rate at higher nanoparticle concentration. An empirical correlation, Eq. (17) has been proposed to estimate the friction factor for laminar flow of alumina nanofluids through straight tubes as a function of particle volume fraction. This correlation is valid for water as well as glycol-water based alumina nanofluids with $0 \le \phi \le 2.5\%$. The coil friction factor was found to be dependent on curvature ratio and coil pitch. The combined effect of both these parameters is well quantified in terms of Germano number Gn. An experimental correlation, Eq. has been proposed to estimate the coil friction factor for laminar flow of base fluids as well as alumina nanofluids. This correlation is valid for and $8.7 \le Gn \le 12$. The correlation proposed for straight tubes predicts the experimental data to within ±10% while the correlation proposed for coils predicts the experimental data to within ±5%. The proposed correlation, Eq. for flow through straight tubes predicts the available experimental data of other investigators [12,16,18–22,56] and proposed correlation, Eq. for flow through coils predicts the available experimental data of other investigators [52] with an accuracy of ±10%.

Acknowledgements

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Hydrodynamic Studies on MgO Nanofluid Flowing Through Straight Tubes and Coils

Puja Sharma[1], Parminder Singh[1], Ritu Gupta[2,*], and Ravinder Kumar Wanchoo[2]

[1]Energy Research Centre, Panjab University, Chandigarh 160014, India
[2]University Institute of Chemical Engineering and Technology, Panjab University, Chandigarh 160014, India

The laminar flow characteristics of magnesium oxide based nanofluid (0–0.66 vol.%) flowing through straight tubes and helical coils with different combinations of coil curvature and pitch ratio have been studied. A propylene glycol/water (PG-W) mixture (60:40 weight ratio) was used as the base fluid. The friction factor of nanofluid was found to be higher than that of the base fluid for both, the straight tube as well as helical coil geometry, which further increased with increase in nanoparticle volume%. In case of flow through straight tubes, observed pressure drop per unit length was observed to follow the power law correlation with fluid velocity for all concentrations of MgO nanofluid. The power law exponent (n) was close to 1 for the base fluid and increased with increase in volume fraction of MgO nanoparticles. Based on the observed data, empirical correlations have been proposed to predict the friction factor for the laminar flow of MgO nanofluid through straight tubes and helical coils. The proposed correlation for straight tubes, predicts the experimental data to within ±8%, while the correlation proposed for coils predicts the experimental data to within ±5%.

KEYWORDS: Nanofluid, Magnesium Oxide, Propylene Glycol, Helical Coil, Hydrodynamics.

1. INTRODUCTION

The unit operations involving heat transfer have a widespread application in various types of industries including automobiles, refining, chemical, manufacturing, etc. The desirable properties of a heat transfer fluid to achieve high rate of heat transfer, are high thermal conductivity, specific heat and low viscosity.[1] Glycol based mixtures are commonly used heat transfer fluids for low temperature applications. Ethylene or propylene glycol mixed with water in 60:40 weight ratio exhibits low volatility, lower corrosivity and can substantially lower the freezing point of the heat transfer medium.[2] Further, propylene glycol has the advantage of being non-toxic and chemically more stable over ethylene glycol as an antifreeze agent and provides a more stable suspension.[3,4] Thermal transport properties of these coolants can be further improved by the use of additives called nanoparticles with size <100 nm and concentration <5 vol.%. The resultant stable suspensions are called as nanofluids.[5] Nanofluids have interesting properties such as large specific surface area, high thermal conductivity, low erosion and long term stability.[6–10] Nanoparticles commonly used for the synthesis of nanofluids can be metals, metal oxides, carbides, nitrides, carbon nanotubes, etc. A nanomateria to be dispersed should be chemically stable material. Generally, metal oxide nanoparticles have a good stabil ity in polar liquids. MgO nanoparticles, having inherentl non-corrosive character, possess a good thermal conduc tivity of around 48.4 W/m · K and a density lower tha that of metal oxides like alumina, iron oxide, zinc oxid cupric oxide, etc. The lower density helps in improvin the stability of nanofluids and a lesser amount of MgO required to yield a particular volume fraction in compar son to other metal oxide nanoparticles.[1] However, additic of nanoparticles also causes an increase in the density ar viscosity of the fluid[9,11] thereby increasing the pumpi power required for transportation. Thus, the pressure dr studies need to be carried out to estimate the frictior pressure drop and hence the power required to pump t nanofluid. The literature available on the flow of Mg based nanofluids has been reviewed in the subseque section.

1.1. Flow of Nanofluids Through Straight Tubes

A few experimental studies have been reported on flow MgO based nanofluids through straight tubes. Meriläi et al.[12] experimentally investigated the influence of p ticle shape and size on friction factor characteristics water-based Al_2O_3, SiO_2 and MgO nanofluids in the bulent flow range with particle concentration up to 4 vo flowing inside a long annular tube with saturated ste

*Author to whom correspondence should be addressed.
Email: rit_gupta@yahoo.com
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Hydrodynamic Studies on MgO Nanofluid Flowing Through Straight Tubes and Coils

Puja Sharma[1], Parminder Singh[1], Ritu Gupta[2,*], and Ravinder Kumar Wanchoo[2]

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KEYWORDS: Nanofluid, Magnesium Oxide, Propylene Glycol, Helical Coil, Hydrodynamics.

1. INTRODUCTION

The unit operations involving heat transfer have a widespread application in various types of industries including automobiles, refining, chemical, manufacturing, etc. The desirable properties of a heat transfer fluid to achieve high rate of heat transfer, are high thermal conductivity, specific heat and low viscosity.[1] Glycol based mixtures are commonly used heat transfer fluids for low temperature applications. Ethylene or propylene glycol mixed with water in 60:40 weight ratio exhibits low volatility, lower corrosivity and can substantially lower the freezing point of the heat transfer medium.[2] Further, propylene glycol has the advantage of being non-toxic and chemically more stable over ethylene glycol as an antifreeze agent and provides a more stable suspension.[3,4] Thermal transport properties of these coolants can be further improved by the use of additives called nanoparticles with size <100 nm and concentration <5 vol.%. The resultant stable suspensions are called as nanofluids.[5] Nanofluids have interesting properties such as large specific surface area, high thermal conductivity, low erosion and long term stability.[6–10] Nanoparticles commonly used for the synthesis of nanofluids can be metals, metal oxides, carbides, nitrides, carbon nanotubes, etc. A nanomaterial to be dispersed should be chemically stable material.[1] Generally, metal oxide nanoparticles have a good stability in polar liquids. MgO nanoparticles, having inherently non-corrosive character, possess a good thermal conductivity of around 48.4 W/m · K and a density lower than that of metal oxides like alumina, iron oxide, zinc oxide, cupric oxide, etc. The lower density helps in improving the stability of nanofluids and a lesser amount of MgO is required to yield a particular volume fraction in comparison to other metal oxide nanoparticles.[1] However, addition of nanoparticles also causes an increase in the density and viscosity of the fluid[9,11] thereby increasing the pumping power required for transportation. Thus, the pressure drop studies need to be carried out to estimate the frictional pressure drop and hence the power required to pump the nanofluid. The literature available on the flow of MgO based nanofluids has been reviewed in the subsequent section.

1.1. Flow of Nanofluids Through Straight Tubes

A few experimental studies have been reported on flow of MgO based nanofluids through straight tubes. Meriläinen et al.[12] experimentally investigated the influence of particle shape and size on friction factor characteristics of water-based Al_2O_3, SiO_2 and MgO nanofluids in the turbulent flow range with particle concentration up to 4 vol.% flowing inside a long annular tube with saturated steam

*Author to whom correspondence should be addressed.
Email: rit_gupta@yahoo.com
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the proposed correlation. The present proposed Eq. (18) predicts the experimental data well within ±5%.

6. CONCLUSION

The hydrodynamic characteristics for the laminar flow of 0.3 and 0.66 vol.% MgO nanofluid through straight tubes and coils were investigated. Friction factor of nanofluids was found to be greater than that of the base fluid for both the straight tube as well as helical coils. For each system, observed pressure drop or friction factor increased with increase in particle volume fraction. The percentage enhancement in friction factor in respect of base fluid, increases with increase in Reynolds number and also increases with increase in nanoparticle volume%. An empirical correlation, Eq. (16) has been proposed to estimate the friction factor for laminar flow of MgO nanofluids through straight tubes as a function of particle volume fraction. This correlation is valid for water as well as propylene glycol-water based MgO nanofluids with $0 \leq \phi \leq 0.66\%$. The coil friction factor was found to be dependent on curvature ratio and the coil pitch. The combined effect of both these parameters is well quantified in terms of Germano number, Gn. An experimental correlation, Eq. (17) has been proposed to estimate the coil friction factor for laminar flow of base fluid as well as MgO nanofluid. This correlation is valid for $0 \leq \phi \leq 0.66\%$ and $0.7 \leq$ Gn ≤ 12. The correlation proposed for straight tubes predicts the experimental data to within ±8%, while the correlation proposed for coils predicts the experimental data to well within ±5%.

Acknowledgment: One of the authors (Puja Sharma) acknowledges the financial assistance provided by UGC (File no. 40-7/2011 (SR)), DST-PURSE-II (Ref. no. 79-81/RPC) and CSIR (File no. 09/135/(0013)/2015-EMR-I) in the form of fellowship to carry out her research work. The authors are also thankful to PURSE-II and TEQIP-II, Dr. SSBUICET, PU, Chandigarh for providing grants for purchase of chemicals.

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Hydrodynamic Studies on PG-W Based CuO Nanofluid Flowing Through Straight Tubes and Coils

Puja Sharma[1], Ritu Gupta[2,*], and Ravinder Kumar Wanchoo[2]

[1]Energy Research Centre, Panjab University, Chandigarh 160014, India
[2]University Institute of Chemical Engineering and Technology, Panjab University, Chandigarh 160014, India

The laminar flow characteristics of copper oxide based nanofluid (0–1 vol.%) flowing through straight tubes and helical coils with different combinations of coil curvature and pitch ratio have been studied. A propylene glycol/water mixture (60:40 weight ratio) was used as the base fluid. The friction factor of nanofluid was found to be higher than that of the base fluid for both the straight tube as well as helical coil geometry, which further increased with increase in nanoparticle volume concentration. In case of flow through straight tubes, observed pressure drop per unit length was observed to follow the power law correlation with fluid velocity for all concentrations of CuO/PG-W nanofluid. The power law exponent (n) was close to 1 for the base fluid and increased with increase in volume fraction of CuO nanoparticles. Experimental correlations to predict the friction factor for the laminar flow of CuO nanofluid through straight tubes and helical coils have been proposed. The correlation proposed for straight tubes predicts the experimental data to within ±4%, while the correlation proposed for coils predicts the experimental data to within ±6%. The proposed correlation for straight tubes predicts the available experimental data of other investigators with an accuracy of ±10%.

KEYWORDS: Nanofluid, Copper Oxide, Propylene Glycol, Helical Coil, Hydrodynamics.

1. INTRODUCTION

The unit operations involving heat transfer have a widespread application in various types of industries including automobiles, refining, chemical, manufacturing, etc. The desirable properties of a heat transfer fluid to achieve high rate of heat transfer are high thermal conductivity, specific heat and low viscosity.[1] Glycol based mixtures are commonly used heat transfer fluids for low temperature applications. Ethylene or propylene glycol mixed with water in 60:40 weight ratio exhibits low volatility, lower corrosivity and can substantially reduce the freezing point of the heat transfer medium.[2] Further, propylene glycol has the advantages of being non-toxic and chemically more stable over ethylene glycol as an antifreeze agent and provides a more stable suspension.[3,4] The transport properties of these coolants can be further improved by the use of additives called nanoparticles with size <100 nm and volume concentration <5 vol.%. The resultant stable suspensions are called as nanofluids.[5] Nanofluids can enhance heat transfer rate as compared to that of the base fluid as they possess a high thermal conductivity. Nanoparticles commonly used for the synthesis of nanofluids can be metals, metal oxides, carbides, nitrides, carbon nanotubes, etc. A nanomaterial to be dispersed should be chemically stable material.[1] Generally, metal oxide nanoparticles have a good stability in polar liquids. Copper oxide nanoparticles are easily available, possess a good thermal conductivity of around 76.5 W/m · K[6] and are used as additives in various types of industrial oils for removal of heat from high heat flux surfaces. Also, due to their spherical shape they exhibit anti-friction and anti-wear characteristics[7,8] and can significantly improve the heat transfer rate.[9] However, addition of nanoparticles also causes an increase in the density and viscosity of the fluid thereby increasing the pumping power required to pump the fluid. Nanofluids have the potential for commercial application only when the cost of increased pumping power is lesser as compared to the heat transfer enhancement. Thus, the pressure drop studies need to be carried out to estimate the frictional pressure drop and hence the power required to pump the nanofluid. The literature available on the flow of CuO based nanofluids has been reviewed in the subsequent section.

1.1. Flow of Nanofluids Through Straight Tubes

Vajjha et al.[10] numerically studied the laminar flow of 0–6 vol.% CuO dispersions in 60:40 EG/W through the

*Author to whom correspondence should be addressed.
Email: rit_gupta@yahoo.com
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of particle volume fraction. This correlation is valid for water, base oil as well as propylene glycol-water based CuO nanofluids with $0 \le \phi \le 1\%$. The coil friction factor was found to be dependent on curvature ratio and the coil pitch. The combined effect of both these parameters is well quantified in terms of Germano number, Gn. An experimental correlation, Eq. (18) has been proposed to estimate the coil friction factor for laminar flow of base fluid as well as CuO nanofluid. This correlation is valid for $0 \le \phi \le 1\%$ and $0.7 \le Gn \le 12$. The correlation proposed for straight tubes predicts the experimental data to within ±4%, while the correlation proposed for coils predicts the experimental data to within ±6%. The proposed correlation, Eq. (16) predicts the available experimental data of other investigators[12,14,15,37] with an accuracy of ±10%.

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