EXPERIMENTAL INVESTIGATION ON FORCED CONVECTION HEAT TRANSFER OF WATER – ETHYLENE GLYCOL BASED TIO_2 NANOFLUID

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LIST OF SYMBOLS

A	Area
C_{bf}	Specific heat of base fluid
C_{nf}	Specific heat of nanofluid
C_p	Specific heat of particle
d	Diameter
d_i	Inner diameter
d_o	Outer diameter
ΔV	Additional volume
ΔP	Pressure drop
ΔP_{exp}	Experimental pressure drop
ΔP_{theory}	Theoretical pressure drop
f	Friction factor
$f_{Blasius}$	Blasius friction factor
f_{exp}	Experimental friction factor
ϕ	Volume concentration
ϕ_1	Initial volume concentration
ϕ_2	Final volume concentration
φ	Volume fraction
h	Heat transfer coefficient
h_{exp}	Experimental heat transfer coefficient

I	Current
k	Thermal conductivity
k_{bf}	Thermal conductivity of base fluid
k_{nf}	Thermal conductivity of nanofluid
L	Length
L_h	Hydrodynamic length
μ	Viscosity
μ_{bf}	Viscosity of base fluid
μ_{nf}	Viscosity of nanofluid
$\dot{m}$	Mass flow rate
Nu	Nusselt number
Nu_{DB}	Nusselt number of Dittus-Boelter
Nu_G	Nusselt number of Gnielinski
Nu_{exp}	Experimental Nusselt number
Nu_{nf}	Nusselt number of nanofluid
ω	Weight concentration
Pr	Prandtl number
Pr_{nf}	Prandtl number of nanofluid
Q	Heat
Re	Reynolds number
ρ	Density
ρ_{bf}	Density of base fluid

ρ_{nf}	Density of nanofluid
ρ_p	Density of particle
T	Temperature
T_b	Bulk temperature
T_s	Surface temperature
v	Velocity
V_t	Voltage
V	Volume
V_1	Initial volume
V_2	Final volume
V_b	Bulk volume

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium oxide
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
CHF	Critical heat flux
CNT	Carbon nano-tube
CTAB	Cetyl trimethyl ammonium bromide
CPU	Central processing unit
CuO	Copper oxide
DSC	Differential scanning calorimeter
EC	Electrical conductivity
EG	Ethylene glycol
FCNT	Functionalized carbon nanotube
FESEM	Field Emission Scanning Electron Microscopy
FKM	Fakulti Kejuruteraan Mekanikal
GO	Graphene oxide
HP	Horse power
IUPAC	International Union of Pure and Applied Chemistry
KPS	Potassium persulfate
LPM	Liter per minute
MSDS	Material safety data sheet
MWCNT	Multi walled carbon nanotube
NA	Not available
PG	Propylene glycol

PVD	Physical vapor deposition
RMS	Root mean square
RPM	Rotation per minute
SDBS	Sodium dodecyl benzene sulfonate
SDS	Sodium dodecyl sulphate
SiC	Silicon carbide
SiO_2	Silicon dioxide
SnO_2	Tin dioxide
TEM	Transmission Electron Microscopy
TiO_2	Titanium oxide
UMP	Universiti Malaysia Pahang
W	Water
W/EG	Water/Ethylene glycol
ZrO_2	Zirconium dioxide

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ABSTRACT

Nanofluid as a new heat transfer fluid have overcome the limitations in thermal performance faced by conventional fluids such as water (W), ethylene glycol (EG) and oil based fluids. However, researches conducted on nanofluid with specific liquid mixture based such as water/EG are limited. In conjunction with that, experimental investigations using nanofluid in mixture base fluid are required for determination on heat transfer performance. The objective of the study is to investigate the thermo-physical properties and the heat transfer performance of TiO_2 nanofluid in a base fluid composed of mixture of water and EG at three different operating temperatures. The nanofluid was prepared by dispersing TiO_2 of 50 nm in size in the base fluid (60W:40EG) for volume concentrations in the range of 0.5 to 1.5%. The nanofluid thermal conductivity and viscosity were measured using analytical laboratory equipment, whereas the density and specific heat were obtained using mixture formula. The forced convection heat transfer investigation was conducted using the existing experimental set up at Reynolds number that ranges from 3,000 to 24,000 for bulk temperature of 30, 50 and 70^{o}C under constant heat flux boundary conditions. The measurements of the properties indicated that the thermal conductivity of nanofluid increased with the increase of temperature and concentration. The maximum enhancement of thermal conductivity achieved was 15.4% at 1.5% volume concentration, compared to the base fluid. On the other hand, the nanofluid dynamic viscosity increased with increase in volume concentration but decreased exponentially with temperature. The maximum enhancement in nanofluid viscosity was observed to be 33.3% for the concentration of 1.5%, compared to the base fluid. The heat transfer coefficients of the nanofluid increased with the increase of Reynolds number at concentrations of 1.3% and 1.5% for a working temperature of 30^{o}C. The enhancements in heat transfer coefficient at this condition were 7.2% and 9.7%, respectively. However, most enhancements in heat transfer coefficient for nanofluid concentrations in the range of 0.5% to 1.0% showed negative values. The heat transfer coefficient for the range of concentrations studied with temperatures of 50^{o}C and 70^{o}C showed an enhancement compared to the base fluid. The maximum enhancements were found to be 22.8% and 28.9% for temperatures of 50^{o}C and 70^{o}C, respectively. The friction factor for nanofluid is slightly increased with the increase of concentration at about 1.1 times of the base fluid. The heat transfer performance evaluated through the Performance Energetic Criterion (PEC) of TiO_2 nanofluid showed that the effect of high temperature is dominant at concentrations greater than 1%. It is recommended to use TiO_2 nanofluid in a mixture of water and EG (60W:40EG) based at a high temperature of 70^{o}C and concentrations of 1.5% for various heat transfer applications.

ABSTRAK

Sebagai cecair pemindahan haba yang baru, bendalir nano telah dapat mengatasi batasan prestasi haba yang dihadapi oleh bendalir konvensional seperti air (W), etilena glikol (EG) dan cecair berasaskan minyak. Walau bagaimanapun, kajian yang dijalankan ke atas bendalir nano menggunakan cecair asas campuran tertentu seperti air/EG adalah terhad Sehubungan dengan itu, ujikaji eksperimen menggunakan bendalir nano dalam cecair asas campuran diperlukan untuk menentukan prestasi pemindahan haba. Objektif kajian ini adalah untuk mengkaji sifat-sifat terma-fizikal dan prestasi pemindahan haba bendalir nano TiO_2 dalam cecair asas campuran menggunakan air dan EG pada tiga suhu operasi yang berbeza. Bendalir nano dihasilkan menggunakan TiO_2 bersaiz 50 nm dimasukkan ke dalam cecair asas (60W:40EG) untuk kepekatan isipadu bermula 0.5 sehingga 1.5%. Pekali kekonduksian haba dan kelikatan bendalir nano diukur menggunakan peralatan analisis makmal, manakala ketumpatan dan pekali haba tentu diperolehi melalui formula campuran. Ujikaji olakan secara paksaan dijalankan menggunakan peralatan eksperimen sedia ada; untuk nombor Reynolds daripada 3,000 sehingga 24,000 pada suhu 30, 50 dan 70^{o}C dengan fluks haba yang tetap. Pengukuran sifat-sifat bendalir menunjukkan bahawa pekali kekonduksian haba bendalir nano meningkat dengan kenaikan suhu dan kepekatan. Peningkatan maksimum bagi pekali kekonduksian haba adalah 15.4% pada kepekatan isipadu 1.5%, berbanding cecair asas. Sebaliknya kelikatan bendalir nano meningkat dengan pertambahan kepekatan isipadu tetapi menurun secara eksponen dengan suhu. Peningkatan maksimum bagi kelikatan bendalir nano adalah 33.3% pada kepekatan 1.5%, berbanding cecair asas. Pekali pemindahan haba bendalir nano meningkat dengan peningkatan nombor Reynolds pada kepekatan 1.3% dan 1.5% pada suhu operasi 30^{o}C. Peningkatan dalam pekali pemindahan haba pada kepekatan ini adalah masing-masing 7.2% dan 9.7%. Walau bagaimanapun, kebanyakan peningkatan pekali pemindahan haba pada kepekatan bendalir nano bermula 0.5% sehingga 1.0% menunjukkan penurunan berbanding cecair asas. Pekali pemindahan haba pada suhu 50^{o}C dan 70^{o}C menunjukkan peningkatan berbanding cecair asas untuk semua julat kepekatan. Peningkatan maksimum yang diperolehi sebanyak 22.8% dan 28.9% masing-masing pada suhu 50^{o}C dan 70^{o}C. Pekali geseran bendalir nano meningkat sedikit dengan pertambahan kepekatan sebanyak 1.1 kali lebih tinggi berbanding cecair asas. Prestasi pemindahan haba ditentukan melalui Kriteria Prestasi Tenaga (PEC) bagi bendalir nano TiO_2 dan menunjukkan kesan yang lebih baik untuk suhu tinggi serta pada kepekatan lebih besar daripada 1%. Oleh itu, dicadangkan bendalir nano TiO_2 bagi asas campuran air dan EG (60W:40EG) pada suhu 70^{o}C dan kepekatan 1.5% digunakan dalam pelbagai aplikasi yang berkaitan dengan pemindahan haba.