LAMPIRAN A

(Submission & Nomor Registrasi Artikel)

I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

Jepter <jepter@itmo.by> 31 Juli 2019 pukul 13.26
Balas Ke: jepter@itmo.by
Kepada: I Made Arsana <madearsana@unesa.ac.id>

Dear Dr. I Made Arsana,

This is to confirm the receipt of your paper "Enhanced Heat Transfer Effectiveness Using Low Concentration SiO_2@TiO_2 Core-Shell Nanofluid in Water/Ethylene Glycol Mixture" (reg. number 163-2019). The paper will be sent to the referees for their comments. We'll communicate with you as we have the referees' comments.

With best wishes,

Managing Editor

Larissa Shemet

From: I Made Arsana [mailto:madearsana@unesa.ac.id]
Sent: Tuesday, July 30, 2019 5:29 PM
To: jepter@itmo.by
Subject: Manuscript Submission

July 30, 2019

Editorial Board of Journal of Engineering Physics and Thermophysics
P. Brovka Street 15
220072 Minsk
Belarus

Dear Editor,

I am submitting a manuscript for consideration of publication in Journal of Engineering Physics and Thermophysics. The manuscript is entitled "Enhanced Heat Transfer Effectiveness Using Low Concentration SiO_2@TiO_2 Core-Shell Nanofluid in Water/Ethylene Glycol Mixture".

It has not been published elsewhere and it has not been submitted simultaneously for publication elsewhere.

This paper assesses the heat transfer performance of nanofluids containing low concentration of core-shell structure of SiO2@TiO2 nanoparticles in a mixture of water and ethylene glycol (EG) in a commercially available heat exchanger.. Its heat transfer performance written in detail explanation and equipped by graphic to help explaining the correlation between parameters. It may bring benefit to Journal of Engineering Physics and Thermophysics .

Thank you very much for your consideration, we really expect that my manuscript could be published in your journal.

Yours Sincerely,
Dr. I Made Arsana
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Phone : +62 812 3000 4262

LAMPIRAN B

(Feedback Revisi Penulisan Manuskrip dari Editor Naskah)

I Made Arsana <madearsana@unesa.ac.id>

Manuscript Submission

Jepter <jepter@itmo.by> 5 September 2019 pukul 19.17
Balas Ke: jepter@itmo.by
Kepada: I Made Arsana <madearsana@unesa.ac.id>

Dear Dr. Arsana,

We, Editors of the Journal of Engineering Physics and Thermophysics, considered your (in coauthorship) paper "Enhanced Heat Transfer Effectiveness Using Low Concentration SiO_2@TiO_2 Core-Shell Nanofluid in Water/Ethylene Glycol Mixture" (No. 163-2019) and concluded that it can be published in the Journal. However, we would like to inform you that:

1) the Journal of Engineering Physics and Thermophysics is a translation of Inzhenerno-Fizicheskii Zhurnal (a publication of the Academy of Sciences of Belarus). Most of the papers published in the Zhurnal are sent to the Editorial Board in Russian, and only two–three papers submitted in English are published in each issue. We have a very long queue of submitted papers in English, so that your paper cannot be published in the nearest future;

2) the paper should be prepared according to the attached Rules of the Journal;

3) in the paper, dimensionality of the thermal conductivity is presented incorrectly: it should be $W \ m^{-1} \ K^{-1}$.

Best regards,

Editors

Rules.doc
39K

Information for authors of the **Journal of Engineering Physics and Thermophysics** (a translation of Inzhenerno-Fizicheskii Zhurnal (IFZh), a publication of the Academy of Sciences of Belarus which is published bimonthly)

1. The paper in **WORD format** should be submitted by email. The length of the paper should not exceed 15 typed pages (**27,000 symbols** (with gaps) including References and captions to figures).

2. The material should be presented in the following order: a) the UDC (universal decimal classification) number; b) the initials and names of the **authors**; c) the **title** of the paper; d) the **abstract** (not exceeding **150 words**) which should be most informative, giving a clear indication of the nature of the paper and the results obtained in it, and should not duplicate Conclusions; e) **keywords** (no more than 10); f) the body of the **text**; g) the section **Notation** with the complete list of symbols (first **Latin** symbols in alphabetical order, then **Greek** ones, also in alphabetical order) and sub- and superscripts with explanation of their origin; h) **references**; i) **tables**; j) **captions** to figures with all dimensions indicated; k) **figures**.

3. The section **Notation** should be given as, for example:

$A_{\rm s}$, $A_{\rm cr}$, heat sink surface area and cross-sectional area of the minichannel heat sink, m^2; C_p, specific heat, kJ/(kg$\cdot$K); $d_{\rm h}$, hydraulic diameter of the minichannel, m; f_x, $f_{\rm m,ave}$, local and average friction factors; h, heat transfer coefficient at the interface between the nanofluid and heat sink, W/(m$^2\cdot$K); Nu, Nusselt number;...; λ, thermal conductivity, W/(m$\cdot$K); μ, viscosity, kg/(m$\cdot$s); ρ, density, kg/m^3; ... Indices: i, initial; w, at the wall;...

4. Both figures and photographs (but **no more than 15**) should be presented in an electronic form not in the text, but **as individual files** in one of **graphic formats** (tif, gif, jpg, cdr). Figures should have clear lines, figures, and symbols and photographs should be contrast. Printing of color figures is left to the Editorial Office's discretion.

5. Equations should be presented in **MathType**. Vectors should be presented as **q**, **H** and criteria as Re, Sc, Pr instead of *Re, Sc, Pr*.

6. References to cited literature should be grouped in numerical order of appearance. References to articles and books should include the initials and names of all authors and be given, for example, as

1. **A. J. Reynolds**, The prediction of turbulent Prandtl and Schmidt numbers, *Int. J. Heat Mass Transfer*, **18**, No. 6, 1055–1069 (1975).

2. **G. K. Batchelor**, *An Introduction to Fluid Dynamics*, Cambridge Univ. Press, Cambridge (1967).

3. **O. Matvienko, J. Duck, and Th. Neesse**, Hydrodynamics and particle separation in the hydrocyclone, in: *Proc. 2nd Int. Symp. on Two-Phase Flow Predictions and Experimentation,* May 23–26, 1999, Pisa, Italy (1999), Vol. 2, pp. 923–929.

7. The authors are requested to give the following information: the first name, second name and patronymic, affiliation, exact mailing address, and email address.

LAMPIRAN B – 1

NASKAH ARTIKEL VERSI PERTAMA (30 JULI 2019)

Enhanced Heat Transfer Effectiveness Using Low Concentration $SiO_2@TiO_2$ Core-Shell Nanofluid in Water/Ethylene Glycol Mixture

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Abstract. This paper assesses the heat transfer performance of nanofluids containing low concentration of core-shell structure of $SiO_2@TiO_2$ nanoparticles in a mixture of water and ethylene glycol (EG) in a commercially available heat exchanger. $SiO_2@TiO_2$ core-shell nanoparticles were prepared using modified Stöber method and characterized by using SEM, XRD, FTIR. Thermal properties of $SiO_2@TiO_2$ nanofluids, *i.e.* thermal conductivity, was determined by using transient hot wire experiments. For heat transfer analyses, 0 – 0.025% of $SiO_2@TiO_2$ nanofluids was employed in a finned-tube cross flow heat exchanger (automobile radiator kit). The results indicate that $SiO_2@TiO_2$ has an amorphous structure and is able to increase thermal conductivity as the fraction increases up to 0.04%. The thermofluid characteristics of nanofluid (Re, Nu, and Pr) increases leading to an increasing the convection coefficient. As the thermal conductivity and the convection coefficient increases, the total heat transfer coefficient improves. Finally, the heat transfer effectiveness increases linearly by 21% (from 0.203 to 0.246) upon using 0.025% mass fraction of $SiO_2@TiO_2$ to water/EG base fluid.

Key words Nanofluid, $SiO_2@TiO_2$ core shell, water – ethylene glycol mixture, automobile radiator, heat transfer

NOMENCLATURE			
φ	Mass fraction $SiO_2@TiO_2$ to water/EG	T_h	Temperature of hot nanofluids
V	Flow rate (m/s)	T_c	Temperature of cold nanofluids
D_h	Hydraulic diamater (m)	**Greek Symbols**	
Nu	Nusselt number	ρ	Density (kg/m^3)
Re	Reynold number	μ	Dynamic viscosity (Ns/m^2)
Pr	Prandtl number	**Subscripts**	
k	Conduction coefficient	nf	Nanofluid
h	Convection coefficient	bf	Base fluid
Q	Heat	in	inlet
U	Overall heat transfer coefficient	out	outlet
ε	Effectiveness		
ΔT_{LMTD}	Log mean temperature different		

1. INTRODUCTION

Operational of heat exchanger in industry is often facing less optimal thermal properties of the working fluid used, such as water, ethylene glycol, or oil, leading to the lower heat transfer effectiveness [1,2]. Increasing the overall heat exchanger performance can be achieved by improving the thermal properties of working fluids, one of which is by adding micrometer or nanometer-sized particles into the working fluid [3,4]. However, blockages in the heat transfer process can occur in heat exchanger tubes when using working fluids with large particles and high particle concentrations [5,6]. Therefore, the use of nanoparticles dispersed in the base fluid (nanofluid) is considered an alternative solution that not only increases the thermal conductivity of the working fluid but also increases the long-term stability and mantains a low pressure drop [7]. The utilization of nanofluids enable the enhancement of heat transfer effectiveness in laminar flow as increasing concentration of nanofluids also increase the Reynolds number [3-7]. This suggests an increasing the nanofluid convection coefficient.

Recent studies have been carried out to investigate the improved heat transfer mechanism in nanofluids bearing various metal oxide semiconductor nanomaterial, for example, TiO_2, Al_2O_3, CuO, and SiO_2 [3-12]. Amongst these nanomaterial, TiO_2 is one of the widely explored nanomaterials for the purpose of increasing heat transfer effectiveness due to its excellent chemical and thermophysical stability [6-11]. TiO_2 nanoparticles dispersed in various base fluids are widely used in various forms of heat exchangers. In addition, TiO_2 nanoparticles are cost-effective and commercially available. Increasing the concentration of TiO_2 is followed by an increase in the value of

Nusselt numbers and without an increase in pressure drop to a concentration of 0.25% [12]. Beside the n-type semiconductor TiO_2, other metal oxide such as SiO_2 which is more electrically insulator in an oil emulsion based nanofluids also exhibits promising heat transfer effectiveness[13-19]. It is found that increasing the concentration of SiO_2 nanofluid leads to the enhanced thermal conductivity without much changing its viscosity [14]. With concentration of only 0.5-3% SiO_2, it is already found to increase the heat transfer effectiveness by 43.75%.

In this study, we propose the utilization of SiO_2 and TiO_2 nanoparticles in the form of SiO_2@TiO_2 core-shell structure for nanofluids. Particularly, we evaluate the effect of low concentration of SiO_2@TiO_2 nanoparticles in water/ethylene glycol based nanofluid to the heat transfer effectiveness in cross-flow heat exchanger bearing finned tubes.

2. EXPERIMENTALS

2. 1. Synthesis of SiO_2@TiO_2 Core Shell Particle

Spherical SiO_2 particles were prepared using slightly modified Stöber method in a batch processed sol-precipitation. An amount of 2.725 mL TEOS were added drop wise under stirring at room temperature into a mixture of 180 mL ethanol, 30 mL saturated ammonia solution and 9 mL MilliQ water. The addition of TEOS was repeated four times every 12 h. After additional stirring for 6 h, 200 µL APTMS were added. The reaction solution was heated to reflux and kept stirring for 4 h. The particles where extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and re-dispersed in 25 mL ethanol by ultrasonication for 30 min. 100 mg of SiO_2 nanoparticles were dispersed in 100 mL ethanol by ultrasonication for 30 min. The nanoparticle solution was heated to reflux and a solution of 200 µL TTIP in 20 mL ethanol was added under stirring to the reaction solution with a dropping funnel. The mixture was kept under reflux for 2.5 h. The particles where extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and re-dispersed in 25 mL water by ultrasonication for 30 min.

2. 2. Characterization of SiO_2@TiO_2 Core Shell Particle

The micromorphology of SiO_2@TiO_2 core-shell particles was analyzed by Scanning Electron Microscopy (SEM) FEI Inspect-S50 operating at 20.0 kV accelerating voltage. The crystal structure of nanoparticles was determined by powder X-ray diffraction (XRD) with PANalytical X-pert MPD. The diffractometer was operated at 40kV and 20mA using a Cu-Kα radiation (λ = 0.15406 nm). The thermal conductivity of the nanofluids was assessed by using the transient hot wire technique.

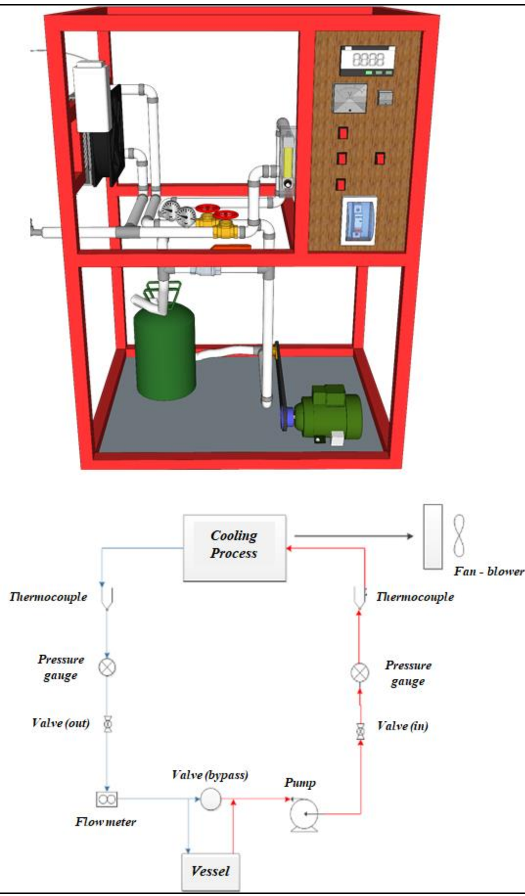

Figure 1. (*top*) The heat exchanger apparatus and (*bottom)* the schematic its component.

2.3. Heat Transfer Apparatus and Analysis

The effectiveness of heat transfer was assessed in the experimental heat transfer system, *i.e.*, automobile radiator training kit, including a closed loop of hot and cold flow (Fig. 1). The heat exchanger was finned-tube cross flow heat exchanger (Suzuki). The SiO_2@TiO_2 in a mixture of EG:water (1:1 v/v) nanofluid was employed as the hot fluid in the system. The concentration was varied in the range of 0 – 0.025% mass fraction of SiO_2@TiO_2 to EG:water base fluids. The system was functionalized with the calibrated thermocouples, flow meter and pressure gauges. The schematic diagram of the automobile radiator training kit is shown in Fig. 1.

Performance of heat exchanger using different concentration of SiO_2@TiO_2 was evaluated by the heat tranfer effectiveness. Heat transfer parameters of nanofluids were determined by joint experimental and theoretical approach, *i.e.* only conductivity is directly determined from transient hot wire measurements. The other parameters are determined as follows [1,2,17-22]:

- Density of nanofluids

$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{bf}$	(1)

- Viscosity of nanofluids (Einstein equation)

$\mu_{nf} = (1+2,5\varphi)\mu_{bf}$	(2)

- Reynold number (Re)

$\mathrm{Re} = \dfrac{\rho \times V \times D_h}{\mu}$	(3)

- Nusselt number (*Nu*) of external flow

$$Nu = 0,683 \times \mathrm{Re}^{0,38} \times \mathrm{Pr}^{0,37} \times \left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s} \right)^{0,25} \qquad (4)$$

- Nusselt number (*Nu*) of internal flow

$$Nu = 0,0265 \times \mathrm{Re}^{0,8}\, \mathrm{Pr}^{0,36} \qquad (5)$$

- Convection coefficient (h_{nf}) of nanofluids

$$h_{nf} = 0,295 \left(\frac{k_w}{D_h} \right) \mathrm{Re}^{0,64}\, \mathrm{Pr}^{0,32} \left(\frac{\pi}{2} \right) \qquad (6)$$

- Convection coefficient (*h*) of air

$$h = \frac{Nu \times k_f}{D_h} \qquad (7)$$

Once all above parameters were determined, the overal heat transfer coefficient (*U*) was estimated. For a single tube heat exchanger, *U* was determined as follows:

$$U = \frac{1}{\frac{1}{h_i} + \frac{\Delta x}{k_w} + \frac{1}{h_o}} \qquad (8)$$

Finally, the heat transfer rate which involves convection and conduction was evaluated by the following:

$$Q = U \times \mathrm{A} \times \Delta \mathrm{T}_{LMTD} \qquad (9)$$

$$\Delta \mathrm{T}_{LMTD} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln \left[\frac{(T_{h,in} - T_{c,out})}{(T_{h,out} - T_{c,in})} \right]} \qquad (10)$$

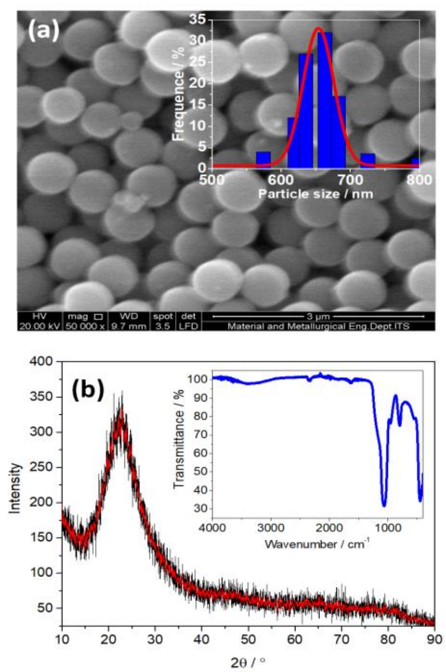

Figure 2. (a) Scanning electron micrograph and (b) XRD pattern of $SiO_2@TiO_2$. Inset of (b) indicates FTIR spectra of

SiO$_2$@TiO$_2$.

3. RESULTS AND DISCUSSION

3.1. Physical Properties of SiO$_2$@TiO$_2$ Core Shell Particle

The morphology of SiO$_2$@TiO$_2$ core-shell particles is displayed in Fig. 2a. The average size of SiO$_2$@TiO$_2$ is 640 nm and the particle size distribution indicates that the resulting SiO$_2$@TiO$_2$ particles is considered monodisperse. To understand the underlying structure of SiO$_2$@TiO$_2$ core-shell particles XRD patterns of the SiO$_2$@TiO$_2$ core-shell and TiO$_2$ after calcination at 500◦C for 3 h are recored (Fig. 2b). All the SiO$_2$/TiO$_2$ core-shell particles started to show clear anatase peaks corresponding to the planes (1 0 1), (0 0 4), and (200) at 2θ = 25.3, 37.8, and 48.1, respectively. With increasing the number of coating steps, the FWHM (full width at half max-imum) of anatase peaks decreased indicating larger crystallite sizes. Nonetheless, higher X-ray diffraction background indicates that the nanoparticle is amorphous. Inset of Fig. 2b shows FT-IR patterns of SiO$_2$@TiO$_2$ core-shell particles. The absorption band at 460 cm^{-1} is assigned for Si-O-Si bending modes which appears in the same range of Ti-O-Ti band (400–600 cm^{-1}) for SiO$_2$@TiO$_2$ core-shell particles. The absorption peak at 940 cm^{-1} is observed in the spectrum of SiO$_2$@TiO$_2$ core-shell particles indicating the characteristic vibration of Ti-O-Si.

3.2. Thermal Properties of SiO$_2$@TiO$_2$ Nanofluids

To aid the heat transfer analysis, the thermal conductivity of the prepared SiO$_2$@TiO$_2$ core-shell nanofluids is assessed by transient hot-wire measurements and summarized in Fig. 3. The thermal conductivity of water-EG mixture is 13.2 W·m^{-2}·K^{-1} and increases by 19.7% with inclining mass fraction of SiO$_2$@TiO$_2$ core-shell nanoparticle up to 0.04%. However, the thermal conductivity further decreases upon higher fraction of SiO$_2$@TiO$_2$ core-shell nanoparticle.

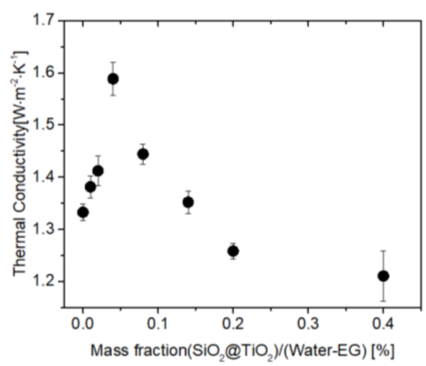

Figure 3. Thermal conductivity of SiO$_2$@TiO$_2$ nanofluids determined from transient hot wire measurements.

The increasing and decreasing thermal conductivtiy in SiO$_2$@TiO$_2$ nanofluid can be described as follows: The nanoparticles, which has large surface area for energy exchange, acts as energy absorber and storage which are transported by diffusion or forced convection (flow). Therefore, a maximum thermal transport will be achieved when sufficient amount of SiO$_2$@TiO$_2$ particles, whose thermal conductivity and heat capacity is higher than the base fluid, is reached. Nonetheless, the there is saturated concentration of nanoparticles in nanofluid which behaves like turning point (global maximum), in which higher concentration of nanoparticles will result in the worse particle diffusion and possible agglomeration/aggregation and hence, reduces the overal thermal conductance of the nanoparticle/fluid system.

3.3. Heat Transfer Analysis

The heat transfer performance of SiO$_2$@TiO$_2$ nanofluids can be indirectly assessed by dynamic of temperature changes in the hot (T_h) and cold (T_c) stream upon varying the nanofluid concentration, *i.e.* mass fraction of SiO$_2$@TiO$_2$ to water/ethylene glycol, from 0 – 0.025% as shown in Fig. 4. The results show that outflow of T_h and T_c is decreasing and increasing, respectively, with increasing concentration of SiO$_2$@TiO$_2$ nanofluids. This further indicates that the higher the concentration of nanofluids, the higher the heat is transferred. In addition, this seemingly increasing heat transfer upon increasing nanofluid concentration up to 0025% is in a good agreement with the thermal properties of investigated nanofluids as discussed earlier. It should be noted that the thermal conductivity of $SiO_2@TiO_2$ increases up to 0.040% mass fraction.

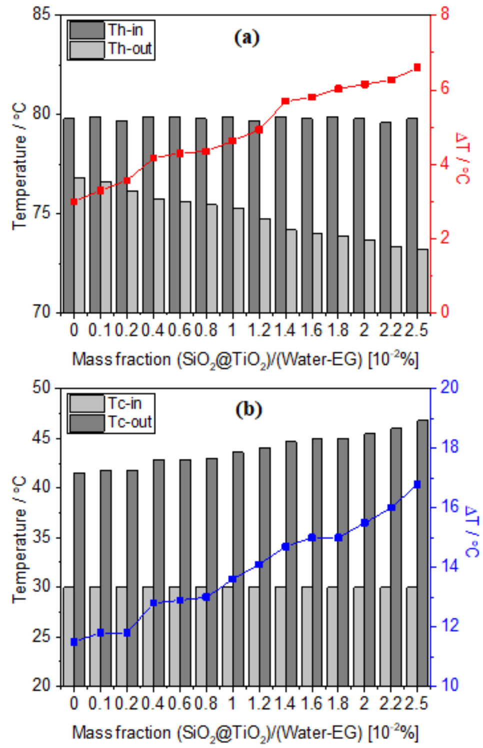

Figure 4. Inlet and outlet temperature of (a) hot and (b) cold stream of nanofluids in heat exchanger apparatus.

The $SiO_2@TiO_2$ nanoparticles also affects the density of nanofluid determining the Reynold number (Re). Higher Re implies a dominant inertial force which speeds up the movement of molecules accelerating the rate of heat transfer. In addition, thermal conductivity depends on the mass fraction of the nanofluid, the size and morphology of the particles, and the base fluid characteristics. The addition of $SiO_2@TiO_2$ nanoparticles results in an increase in the work surface of the heat transfer area. Nonetheless, agglomeration of nanoparticles should be avoided in practical application [20-22], since this can change the thermal characteristics of the nanoparticles themselves, which affects the heat transfer process.

The external forced convection in this study is supported by blowers with an average speed of 6.8 $m \cdot s^{-1}$ and a temperature of 30°C. Addition of $SiO_2@TiO_2$ mass fraction to the base fluid can result in an increase in the value of the convection coefficient of nanofluid (Fig. 5). Furthermore, the change in fraction affects the convection coefficient of the air since there is a change in temperature indicating an increasing contact surface area during the heat transfer process. The addition of $SiO_2@TiO_2$ nanoparticles at a concentration of 0.025% can increase the heat transfer coefficient by up to 9.15%. The convection coefficient increases with increasing mass fraction of nanoparticles is also reported by other study [6]. The earlier study indicates that the convection coefficient is improvey by 6.6% at a TiO_2 mass fraction of 0.3%.

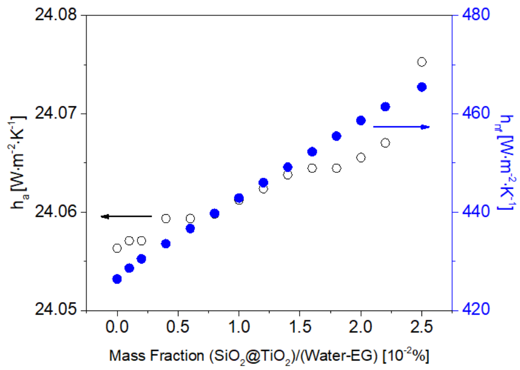

Figure 5. The estimated convection coefficient of air (h_a) and $SiO_2@TiO_2$ nanofluids (h_{nf}).

Referring to the calculation of thermal conductivity and convection coefficient in the earlier discussion, the total heat transfer coefficient value is evaluated and the results are described as follows: The total heat transfer coefficient does not significantly increase, that is ca. 0.03-0.07% for each increment of mass fraction. This results is also in line with other study [8], that the total heat transfer coefficients in the fractions of 0.3%, 0.8%, and 1.5% (at a certain Re) only slightly increases. The overall heat transfer evaluation is based on the Newton equation. As the heat exchanger used in this study using cross-flow configuration, the log man temperature difference (ΔT_{LMTD}) is used to calculate the heat transfer rate (Fig. 6).

At the same flow rate, *i.e.* 8 litre per min (LPM), increasing the concentration of $SiO_2@TiO_2$ nanoparticles up to 0.025% results in an increase of heat transfer rate up to 18.11% (from 2168 $W{\cdot}m^{-2}$ to 2344 $W{\cdot}m^{-2}$). This result is found higher than the heat transfer rate of water based nanofluid containing TiO_2 nanoparticles: At a concentration of 0.25%, the heat transfer rate is only enhanced by 11% [22]. Other study reported that at the flowrate of 1.8 LPM the TiO^2-based nanofluids are able to produce a heat transfer rate of around 5000 $W{\cdot}m^{-2}$ and increased to 8000 $W{\cdot}m^{-2}$ when the flowrate is doubled. This implies that the heat transfer rate of the investigated low concentration $SiO_2@TiO_2$ nanofluids can be improved by increasing the flowrate of nanofluids in the heat exchanger.

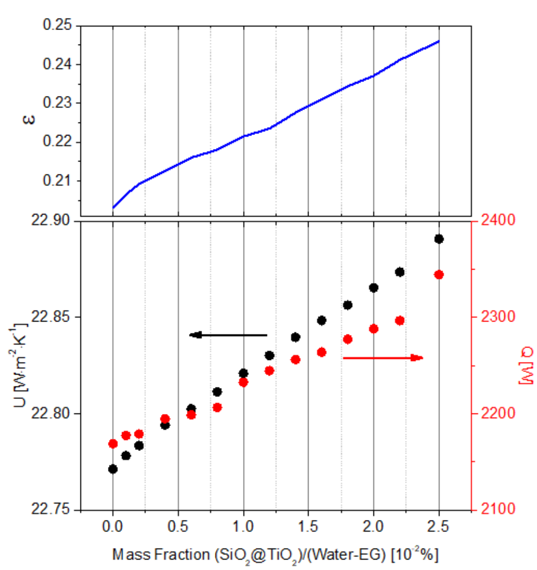

Figure 6. The overal heat transfer coefficient (U), heat rate (W), and heat transfer effectiveness (ε) in heat exchanger using different concentration of $SiO_2@TiO_2$ nanofluids.

In general, according to the energy conservation law, the effectiveness of heat transfer using different $SiO_2@TiO_2$ concentration is linearly enhanced when the mass fraction of nanoparticles to base fluid is increased [Fig. 6]. It is shown that the effectiveness of heat transfer increases by 1.6 - 2% for increasisng mass fraction by 0.005%. Overall, there is an increase in the effectiveness of heat transfer by 21%, *i.e.* from 0.203 to 0.246, when the concentration of 0% is added to 0.025%. The results at hand indicate that the investigated system, *i.e.* EG:water based nanofluid containing $SiO_2@TiO_2$ nanopartices, is better than other study using EG:water (3:2) based nanofluid containing 0.02% TiO_2 which is only able to increase the effectiveness of heat transfer by 13% [19].

4. CONCLUSIONS

It has been successfully prepared and evaluated EG:water based nanofluids containing $SiO_2@TiO_2$ core-shell nanoparticles for application of finned tube cross-flow heat exchanger. Increasing mass fraction of $SiO_2@TiO_2$ nanoparticles to EG:water base fluid can improve the thermophysical characteristics and thermal characteristics of nanofluid. The saturation concentration of $SiO_2@TiO_2$ nanoparticles in nanofluid is 0.04%. From the mass fraction of 0% to 0.025%, the total heat transfer coefficient increases from 22.77 $W\cdot m^{-2}\cdot K^{-1}$ to 22.89 $W\cdot m^{-2}\cdot K^{-1}$ resulting in the enhancing heat transfer rate in the exchanger from 2168 $W\cdot m^{-2}$ to 2344 $W\cdot m^{-2}$. Furthermore, the effectiveness of heat transfer also increases from 0.203 to 0.246.

5. ACKNOWLEDGMENT

Technical assistance for physical characterization of nanoparticles from the laboratory of material characterization, Institut Teknologi Sepuluh Nopember, is gratefully acknowledged. Authors also thank the heat transfer laboratory, Department of Mechanical Enigineering, Universitas Negeri Surabaya for using the facilities for carrying out this research work.

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LAMPIRAN B – 2

NASKAH ARTIKEL VERSI KEDUA

- **REVISI FORMAT**
- **REVISI SATUAN KONDUKTIVITAS**

[UDC 536+544]

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ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION $SiO_2@TiO_2$ CORE-SHELL NANOFLUID IN WATER/ETHYLENE GLYCOL MIXTURE

Abstract. This paper assesses the heat transfer performance of nanofluids containing low concentration of core-shell structure of $SiO_2@TiO_2$ nanoparticles in a mixture of water and ethylene glycol (EG) in a commercially available heat exchanger. For heat transfer analyses, 0 – 0.025% of $SiO_2@TiO_2$ nanofluids was employed in a finned-tube cross flow heat exchanger (automobile radiator kit). The results indicate that $SiO_2@TiO_2$ has an amorphous structure and enable increasing thermal conductivity as the fraction increases up to 0.04%. The thermofluid characteristics of nanofluid (Re, Nu, and Pr) increases leading to an increasing the convection coefficient. As the thermal conductivity and the convection coefficient increases, the total heat transfer coefficient improves. Finally, the heat transfer effectiveness increases linearly by 21% upon using 0.025% mass fraction of $SiO_2@TiO_2$ to water/EG base fluid.

Keywords: **Nanofluid, *$SiO_2@TiO_2$, EG/water mixture, Automobile radiator, Heat transfer.***

Introduction. Operational of heat exchanger in industry is often facing less optimal thermal properties of the working fluid used, such as water, ethylene glycol, or oil, leading to the lower heat transfer effectiveness [1,2]. Increasing the overall heat exchanger performance can be achieved by improving the thermal properties of working fluids, one of which is by adding micrometer or nanometer-sized particles into the working fluid [3,4]. However, blockages in the heat transfer process can occur in heat exchanger tubes when using working fluids with large particles and high particle concentrations [5,6]. Therefore, the use of nanoparticles dispersed in the base fluid (nanofluid) is considered an alternative solution that not only increases the thermal conductivity of the working fluid but also increases the long-term stability and mantains a low pressure drop [7]. The utilization of nanofluids enable the enhancement of heat transfer effectiveness in laminar flow as increasing concentration of nanofluids also increase the Reynolds number [3-7]. This suggests an increasing the nanofluid convection coefficient.

Recent studies have been carried out to investigate the improved heat transfer mechanism in nanofluids bearing various metal oxide semiconductor nanomaterial, for example, TiO_2, Al_2O_3, CuO, and SiO_2 [3-12]. Amongst these nanomaterials, TiO_2 is one of the widely explored nanomaterials for the purpose of increasing heat transfer effectiveness due to its excellent chemical and thermophysical stability [6-11]. TiO_2 nanoparticles dispersed in various base fluids are widely used in various forms of heat exchangers. In addition, TiO_2 nanoparticles are cost-effective and commercially available. Increasing the concentration of TiO_2 is followed by an increase in the value of Nusselt numbers and without an increase in pressure drop to a concentration of 0.25% [12]. Beside the n-type semiconductor TiO_2, other metal oxide such as SiO_2 which is more electrically insulator in an oil emulsion based nanofluids also exhibits promising heat transfer effectiveness [13-19]. It is found that increasing the concentration of SiO_2 nanofluid leads to the enhanced thermal conductivity without much changing its viscosity [14]. With concentration of only 0.5-3% SiO_2, it is already found to increase the heat transfer effectiveness by 43.75%.

In this study, we propose the utilization of SiO_2 and TiO_2 nanoparticles in the form of SiO_2@TiO_2 core-shell structure for nanofluids. Particularly, we evaluate the effect of low concentration of SiO_2@TiO_2 nanoparticles in water/ethylene glycol based nanofluid to the heat transfer effectiveness in cross-flow heat exchanger bearing finned tubes.

Materials and Method. Spherical SiO_2 particles were prepared using slightly modified Stöber method in a batch processed sol-precipitation. An amount of 2.725 mL TEOS were added drop wise under stirring at room temperature into a mixture of 180 mL ethanol, 30 mL saturated ammonia solution and 9 mL MilliQ water. The addition of TEOS was repeated four times every 12 h. After additional stirring for 6 h, 200 µL APTMS were added. The reaction solution was heated to reflux and kept stirring for 4 h. The particles where extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and re-dispersed in 25 mL ethanol by ultrasonication for 30 min. 100 mg of SiO_2 nanoparticles were dispersed in 100 mL ethanol by ultrasonication for 30 min. The nanoparticle solution was heated to reflux and a solution of 200 µL TTIP in 20 mL ethanol was added under stirring to the reaction solution with a dropping funnel. The mixture was kept under reflux for 2.5 h. The particles where extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and re-dispersed in 25 mL water by ultrasonication for 30 min. The micromorphology of SiO_2@TiO_2 core-shell particles was analyzed by Scanning Electron Microscopy (SEM) FEI Inspect-S50 operating at 20.0 kV accelerating voltage. The crystal structure of nanoparticles was determined by powder X-ray diffraction (XRD) with PANalytical X-pert MPD. The diffractometer was operated at 40kV and 20mA using a Cu-Kα radiation (λ = 0.15406 nm). The thermal conductivity of the nanofluids was assessed by using the transient hot wire technique.

The effectiveness of heat transfer was assessed in the experimental heat transfer system, *i.e.*, automobile radiator training kit, including a closed loop of hot and cold flow (Fig. 1). The heat exchanger was finned-tube cross flow heat exchanger (Suzuki). The $SiO_2@TiO_2$ in a mixture of EG:water (1:1 v/v) nanofluid was employed as the hot fluid in the system. The concentration was varied in the range of 0 – 0.025% mass fraction of $SiO_2@TiO_2$ to EG:water base fluids. The system was functionalized with the calibrated thermocouples, flow meter and pressure gauges. The schematic diagram of the automobile radiator training kit is shown in Fig. 1. Performance of heat exchanger using different concentration of $SiO_2@TiO_2$ was evaluated by the heat tranfer effectiveness. Heat transfer parameters of nanofluids were determined by joint experimental and theoretical approach, *i.e.* only conductivity is directly determined from transient hot wire measurements. The other parameters are determined as follows [1,2,17-19]:

- Density of nanofluids

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{bf} \quad (1)$$

- Viscosity of nanofluids (Einstein equation)

$$\mu_{nf} = (1+2,5\varphi)\mu_{bf} \quad (2)$$

- Reynold number (Re)

$$\mathrm{Re} = \frac{\rho \times V \times D_h}{\mu} \quad (3)$$

- Nusselt number (*Nu*) of external flow

$$Nu = 0,683 \times \mathrm{Re}^{0,38} \times \mathrm{Pr}^{0,37} \times \left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s}\right)^{0,25} \quad (4)$$

- Nusselt number (*Nu*) of internal flow

$$Nu = 0,0265 \times \mathrm{Re}^{0,8}\,\mathrm{Pr}^{0,36} \quad (5)$$

- Convection coefficient (h_{nf}) of nanofluids

$$h_{nf} = 0,295\left(\frac{k_w}{D_h}\right)\mathrm{Re}^{0,64}\,\mathrm{Pr}^{0,32}\left(\frac{\pi}{2}\right) \quad (6)$$

- Convection coefficient (h) of air

$$h = \frac{Nu \times k_f}{D_h} \quad (7)$$

Once all above parameters were determined, the overal heat transfer coefficient (U) was estimated. For a single tube heat exchanger, U was determined as follows:

$$U = \frac{1}{\frac{1}{h_i} + \frac{\Delta x}{k_w} + \frac{1}{h_o}} \quad (8)$$

Finally, the heat transfer rate which involves convection and conduction was evaluated by the following:

$$Q = U \times \mathrm{A} \times \Delta \mathrm{T}_{LMTD} \quad (9)$$

where

$$\Delta \mathrm{T}_{LMTD} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left[\frac{(T_{h,in} - T_{c,out})}{(T_{h,out} - T_{c,in})}\right]} \quad (10)$$

Physical Properties of SiO_2@TiO_2 Core Shell Particle. The morphology of SiO_2@TiO_2 core-shell particles is displayed in Fig. 2a. The average size of SiO_2@TiO_2 is 640 nm and the particle size distribution indicate that the resulting SiO_2@TiO_2 particles is considered monodisperse. To understand the underlying structure of SiO_2@TiO_2 core-shell particles XRD patterns of the SiO_2@TiO_2 core-shell and TiO_2 after calcination at 500◦C for 3 h are recored (Fig. 2b). All the SiO_2/TiO_2 core-shell particles started to show clear anatase peaks corresponding to the planes (1 0 1), (0 0 4), and (200) at 2θ = 25.3, 37.8, and 48.1, respectively. With increasing the number of coating steps, the FWHM (full width at half maximum) of anatase peaks decreased indicating larger crystallite sizes. Nonetheless, higher X-ray diffraction background indicates that the nanoparticle is amorphous. Inset of Fig. 2b shows FT-IR patterns of SiO_2@TiO_2 core-shell particles. The absorption band at 460 cm^{-1} is assigned for Si-O-Si bending modes which appears in the same range of Ti-O-Ti band (400–600 cm^{-1}) for SiO_2@TiO_2 core-shell particles [20,21]. The absorption peak at 940 cm^{-1} is observed in the spectrum of SiO_2@TiO_2 core-shell particles indicating the characteristic vibration of Ti-O-Si.

Thermal Properties of SiO_2@TiO_2 Nanofluids. To aid the heat transfer analysis, the thermal conductivity of the prepared SiO_2@TiO_2 core-shell nanofluids is assessed by transient hot-wire measurements and summarized in Fig. 3. The thermal conductivity of water-EG mixture is 13.2 $W \cdot m^{-1} \cdot K^{-1}$ and increases by 19.7% with inclining mass fraction of SiO_2@TiO_2 core-shell nanoparticle up to 0.04%. However, the thermal conductivity further decreases upon higher fraction of SiO_2@TiO_2 core-shell nanoparticle. The increasing and decreasing thermal conductivtiy in SiO_2@TiO_2 nanofluid can be described as follows: The nanoparticles, which has large surface area for energy exchange, acts as energy absorber and storage which are transported by diffusion or forced convection (flow). Therefore, a maximum thermal transport will be achieved when sufficient amount of SiO_2@TiO_2 particles, whose thermal conductivity and heat capacity is higher than the base fluid, is reached. Nonetheless, the there is saturated concentration of nanoparticles in nanofluid which behaves like turning point (global maximum), in which higher concentration of nanoparticles will result in the worse particle diffusion and possible agglomeration/aggregation and hence, reduces the overal thermal conductance of the nanoparticle/fluid system.

Heat Transfer Analysis. The heat transfer performance of SiO_2@TiO_2 nanofluids can be indirectly assessed by dynamic of temperature changes in the hot (T_h) and cold (T_c) stream upon varying the nanofluid concentration, *i.e.* mass fraction of SiO_2@TiO_2 to water/ethylene glycol, from 0 – 0.025% as shown in Fig. 4. The results show that outflow of T_h and T_c is decreasing and increasing, respectively, with increasing concentration of SiO_2@TiO_2 nanofluids. This further indicates that the higher the concentration of nanofluids, the higher the heat is transferred. In addition, this seemingly increasing heat transfer upon increasing nanofluid concentration up to 0025% is in a good agreement with the thermal properties of investigated nanofluids as discussed earlier. It should be noted that the thermal conductivity of SiO_2@TiO_2 increases up to 0.040% mass fraction.

The SiO_2@TiO_2 nanoparticles also affects the density of nanofluid determining the Reynold number (Re). Higher Re implies a dominant inertial force which speeds up the movement of molecules accelerating the rate of heat transfer. In addition, thermal conductivity depends on the mass fraction of the nanofluid, the size and morphology of the particles, and the base fluid characteristics. The addition of SiO_2@TiO_2 nanoparticles results in an increase in the work surface of the heat transfer area. Nonetheless, agglomeration of nanoparticles should be avoided in practical application [23-25], since this can change the thermal characteristics of the nanoparticles themselves, which affects the heat transfer process.

The external forced convection in this study is supported by blowers with an average speed of 6.8 $m \cdot s^{-1}$ and a temperature of 30°C. Addition of $SiO_2@TiO_2$ mass fraction to the base fluid can result in an increase in the value of the convection coefficient of nanofluid (Fig. 5). Furthermore, the change in fraction affects the convection coefficient of the air since there is a change in temperature indicating an increasing contact surface area during the heat transfer process. The addition of $SiO_2@TiO_2$ nanoparticles at a concentration of 0.025% increase the heat transfer coefficient by 9.15%. The convection coefficient increases with increasing mass fraction of nanoparticles is also reported by other study [6]. The earlier study indicates that the convection coefficient is improved by 6.6% at a TiO_2 mass fraction of 0.3%.

Referring to the calculation of thermal conductivity and convection coefficient in the earlier discussion, the total heat transfer coefficient value is evaluated, and the results are described as follows: The total heat transfer coefficient does not significantly increase, that is ca. 0.03-0.07% for each increment of mass fraction. This result is also in line with other study [8], that the total heat transfer coefficients in the fractions of 0.3%, 0.8%, and 1.5% (at a certain Re) only slightly increases. The overall heat transfer evaluation is based on the Newton equation. As the heat exchanger used in this study using cross-flow configuration, the log man temperature difference (ΔT_{LMTD}) is used to calculate the heat transfer rate (Fig. 6).

At the same flow rate, *i.e.* 8 litre per min (LPM), increasing the concentration of $SiO_2@TiO_2$ nanoparticles up to 0.025% results in an increase of heat transfer rate up to 18.11% (from 2168 $W \cdot m^{-2}$ to 2344 $W \cdot m^{-2}$). This result is found higher than the heat transfer rate of water based nanofluid containing TiO_2 nanoparticles: At a concentration of 0.25%, the heat transfer rate is only enhanced by 11% [25]. Other study reported that at the flowrate of 1.8 LPM the TiO^2-based nanofluids are able to produce a heat transfer rate of around 5000 $W \cdot m^{-2}$ and increased to 8000 $W \cdot m^{-2}$ when the flowrate is doubled. This implies that the heat transfer rate of the investigated low concentration $SiO_2@TiO_2$ nanofluids can be improved by increasing the flowrate of nanofluids in the heat exchanger.

In general, according to the energy conservation law, the effectiveness of heat transfer using different $SiO_2@TiO_2$ concentration is linearly enhanced when the mass fraction of nanoparticles to base fluid is increased (Fig. 6). It is shown that the effectiveness of heat transfer increases by 1.6 - 2% for increasisng mass fraction by 0.005%. Overall, there is an increase in the effectiveness of heat transfer by 21%, *i.e.* from 0.203 to 0.246, when the concentration of 0% is added to 0.025%. The results at hand indicate that the investigated system, *i.e.* EG:water based nanofluid containing $SiO_2@TiO_2$ nanopartices, is better than other study using EG:water (3:2) based nanofluid containing 0.02% TiO_2 which is only able to increase the effectiveness of heat transfer by 13% [19].

Conclusion. It has been successfully prepared and evaluated EG:water based nanofluids containing SiO_2@TiO_2 core-shell nanoparticles for application of finned tube cross-flow heat exchanger. Increasing mass fraction of SiO_2@TiO_2 nanoparticles to EG:water base fluid can improve the thermophysical characteristics and thermal characteristics of nanofluid. The saturation concentration of SiO_2@TiO_2 nanoparticles in nanofluid is 0.04%. From the mass fraction of 0% to 0.025%, the total heat transfer coefficient increases from 22.77 $W \cdot m^{-2} \cdot K^{-1}$ to 22.89 $W \cdot m^{-2} \cdot K^{-1}$ resulting in the enhancing heat transfer rate in the exchanger from 2168 $W \cdot m^{-2}$ to 2344 $W \cdot m^{-2}$. Furthermore, the effectiveness of heat transfer also increases from 0.203 to 0.246.

Notations. D_h, hydraulic diameter, m; h, convective heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$; k, conductive heat transfer coefficient, $W \cdot m^{-1} \cdot K^{-1}$; Nu, Nusselt number; Pr, Prandtl number; Q, heat rate, W; Re, Reynold number; U, overall heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$; T, temperature, K; V, flow rate, m/s; ΔT_{LMTD},log mean temperature different, K; ε, heat transfer effectiveness; φ, mass fraction SiO_2@TiO_2 to water/EG; Indices: h, hot nanofluids; c, cold nanofluids; nf, nanofluid; bf, base fluid; in, inlet; out, outlet.

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Figure Caption:

Figure 1. (*top*) The heat exchanger apparatus and (*bottom)* the schematic its component.

Figure 2. (a) Scanning electron micrograph and (b) XRD pattern of SiO_2@TiO_2. Inset of (b) indicates FTIR spectra of SiO_2@TiO_2

Figure 3. Thermal conductivity of SiO_2@TiO_2 nanofluids determined from transient hot wire measurements.

Figure 4. Inlet and outlet temperature of (a) hot and (b) cold stream of nanofluids in heat exchanger apparatus.

Figure 5. The estimated convection coefficient of air (h_a) and SiO_2@TiO_2 nanofluids (h_{nf}).

Figure 6. The overal heat transfer coefficient (U), heat rate (W), and heat transfer effectiveness (ε) in heat exchanger using different concentration of SiO_2@TiO_2 nanofluids.

Figures:

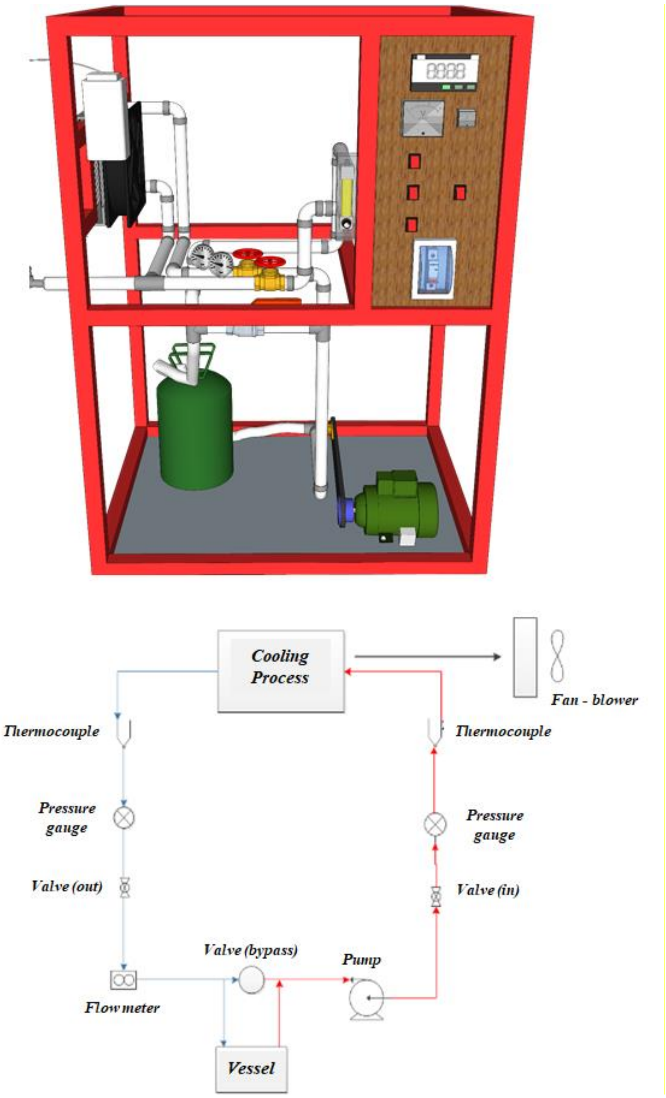
Cooling
Process
Fan - blower
Thermocouple
Thermocouple
Pressure
gauge
Pressure
gauge
Valve (out)
Valve (in)
Valve (bypass)
Pump
Flow meter
Vessel

Figure 1.

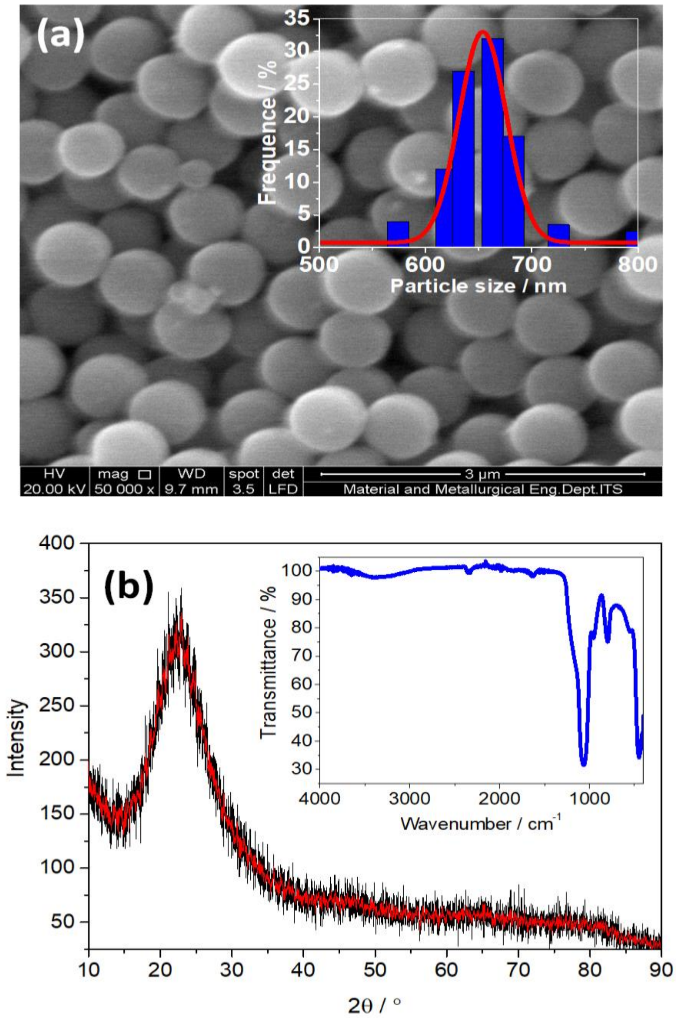

Figure 2.

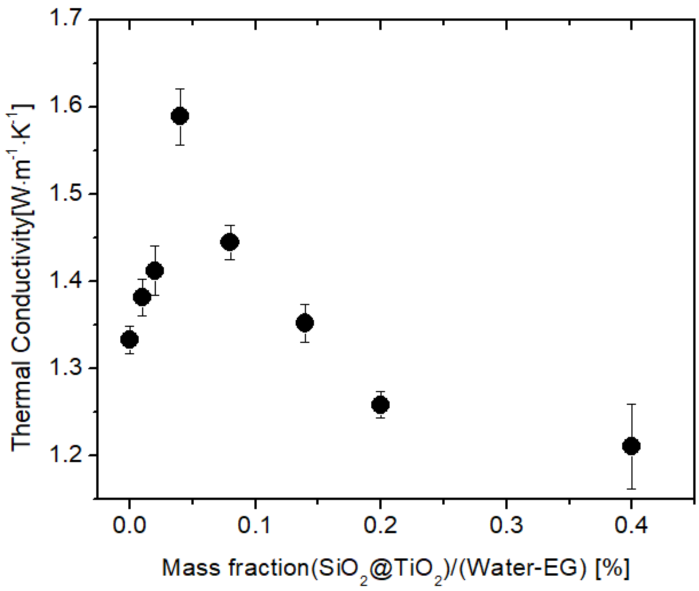

Figure 3.

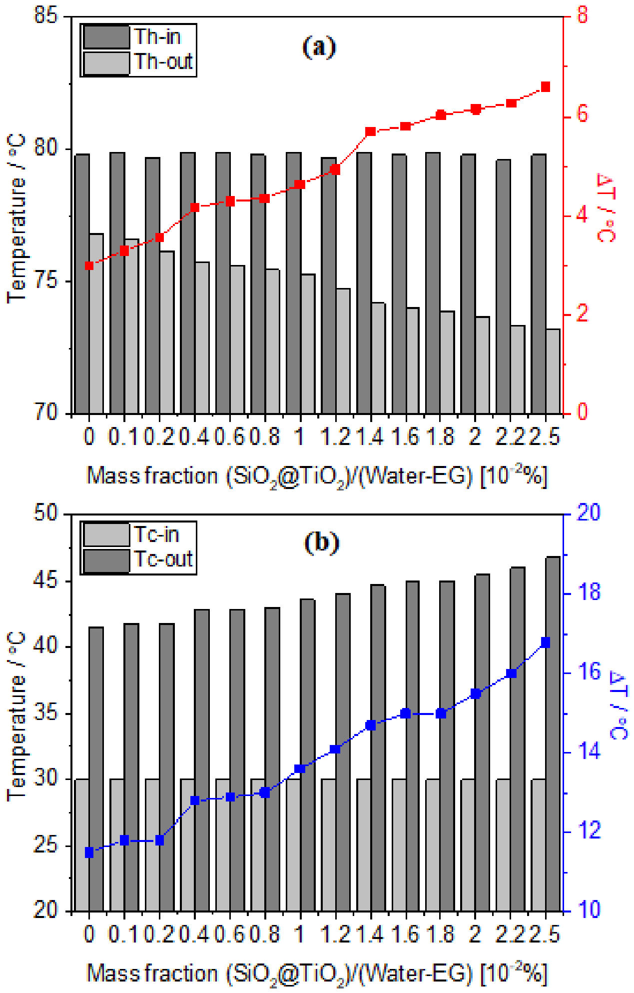

Figure 4.

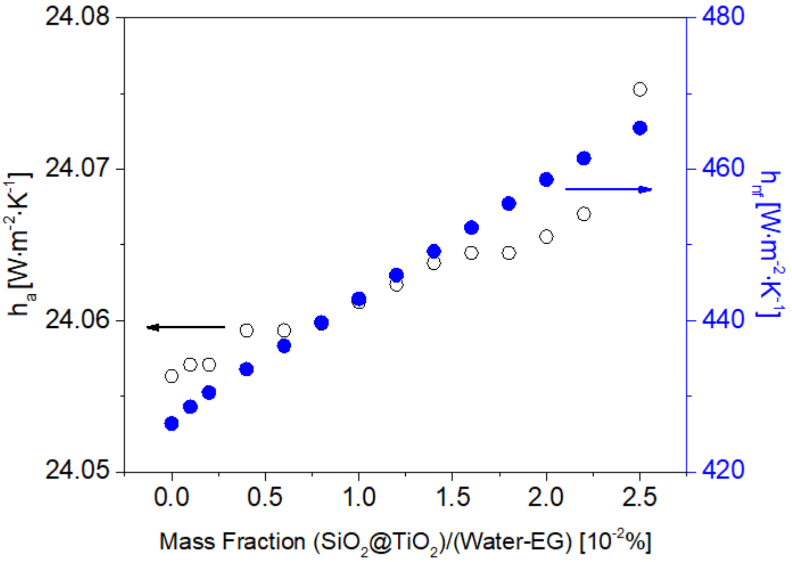

Figure 5.

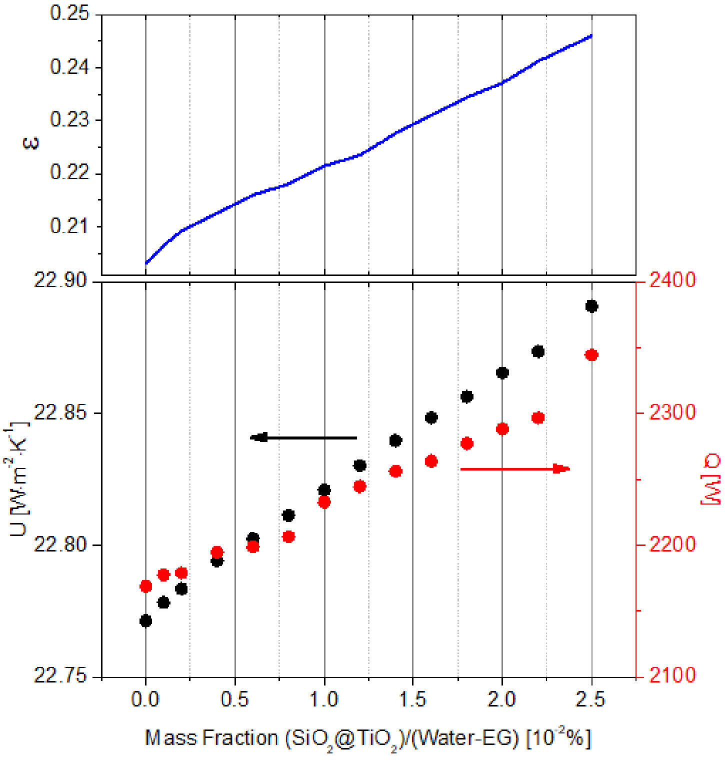

Figure 6.

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LAMPIRAN C

Letter of Acceptance dari Editor Journal of Engineering Physics and Thermophysics

I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

Jepter <jepter@itmo.by> 12 September 2019 16.16
Balas Ke: jepter@itmo.by
Kepada: I Made Arsana <madearsana@unesa.ac.id>

Dear Dr. Arsana,

Please find the attached Letter of Acceptance. As to your question regarding the queue, we are not able now to give a definite answer, it depends on many factors.

Best regards,

Editors

НАЦИОНАЛЬНАЯ АКАДЕМИЯ НАУК БЕЛАРУСИ

ИНСТИТУТ ТЕПЛО- и МАССООБМЕНА им. А. В. ЛЫКОВА

ИНЖЕНЕРНО-ФИЗИЧЕСКИЙ ЖУРНАЛ

220072, г. Минск, ул. П. Бровки, 15. Телефоны: (017) 284-21-31, (017) 284-23-31, факс: (017) 232-25-13. Email: jepter@itmo.by. URL: "http//www.itmo.by/jepter.html". Сервер новостей: newssero@itmo.by (группа sci.ifzh-jepter.news). Индекс 74920 по каталогам РО "Белпочта", агентства "Роспечать", "Издания стран СНГ" национальных агентств.

September 12, 2019

Dear Dr. Arsana,

This is to acknowledge that the paper "Enhanced Heat Transfer Effectiveness Using Low Concentration SiO_2@TiO_2 Core-Shell Nanofluid in Water/Ethylene Glycol Mixture" (reg. number 163-2019) by I. M. Arsana , L. C. Muhimmah, G. Nugroho, and R. A. Wahyuono has been accepted for publication in the Journal of Engineering Physics and Thermophysics.

Managing Editor

Larissa Shemet

LAMPIRAN D

Consent to Publish ke Journal of Engineering Physics and Thermophysics

I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

Jepter <jepter@itmo.by> 4 Januari 2021 18.45
Kepada: I Made Arsana <madearsana@unesa.ac.id>

Dear Dr. I Made Arsana,

In the near future we'll begin to prepare your paper "ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION SiO_2@TiO_2 CORE-SHELL NANOFLUID IN WATER/ETHYLENE GLYCOL MIXTURE" (reg. number 163-2019)

for publication in the Journal of Engineering Physics and Thermophysics. As prescribed by the Springer Publishers, please sign the attached Consent to Publish, then date, scan the Consent and send the scanned PDF file to our address.

We'll connect with you if we have some questions during editing.

With best regards,
Editors

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I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

I Made Arsana <madearsana@unesa.ac.id> 9 Januari 2021 10.42
Kepada: Jepter <jepter@itmo.by>

Dear Editors,

The first time I thank you for my paper will be published in the near future. I hereby attach the Consent.

Best Regards,

(Dr. I Made Arsana)
Department of Mechanical Engineering, Universitas Negeri Surabaya, East Java, Indonesia 60231
Phone: +6281230004262
+6282245760098

[Kutipan teks disembunyikan]

Consent-I MADE ARSANA.pdf
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Title in English: **Journal of Engineering Physics and Thermophysics**

Title of article: **ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION $SiO_2@TiO_2$ CORE-SHELL NANOFLUID IN WATER/ETHYLENE GLYCOL MIXTURE**

NAMES OF ALL CONTRIBUTING AUTHORS: I. M. ARSANA, L. C. MUHIMMAH, G. NUGROHO, R. A. WAHYUONO

Corresponding author's signature:

Corresponding author's name: I.M. ARSANA

Date: 09 JANUARY 2021

LAMPIRAN E-1
(Hasil Review Kedua disampaikan Oleh Editor)

UNESA Mail

I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

Jepter <jepter@itmo.by> 20 Januari 2021 pukul 17.40
Kepada: I Made Arsana <madearsana@unesa.ac.id>

Dear Dr. I Made Arsana,

Now I, as an Editor of the Journal of Engineering Physics and Thermophysics, prepare your paper “ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION SiO_2–TiO_2 CORE–SHELL NANOFLUID IN WATER/ETHYLENE GLYCOL MIXTURE” for publication. In this connection, I would like to ask you to answer a few my attached questions.

Best regards,

Editor

From: I Made Arsana [mailto:madearsana@unesa.ac.id]
Sent: Saturday, January 09, 2021 5:42 AM
To: Jepter
Subject: Re: Manuscript Submission (163-2019)

Dear Editors,

[Kutipan teks disembunyikan]
[Kutipan teks disembunyikan]

About Paper 163-19.pdf
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Dear Dr. I Made Arsana,

Now I, as an Editor of the Journal of Engineering Physics and Thermophysics, prepare your paper “ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION SiO_2–TiO_2 CORE–SHELL NANOFLUID IN WATER/ETHYLENE GLYCOL MIXTURE” for publication. In this connection, I would like to ask you to answer a few my questions:

1. You twice use in the first paragraph in **Materials and Method** the phrase “The particles ~~where~~ were extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and redispersed in 25 mL ethanol by ultrasonication for 30 min. ” Does this mean that such a process was carried out twice?
2. Please, explain what are:

   Pr_s in Eq. (4), k_w in Eq. (6), k_f in Eq. (7), h_i and h_0 in Eq. (8), and A in Eq. (9). These quantities are absent in **Notation**.
3. In what units is the intensity given in Fig. 2b?

You should not send a new variant of the paper, only send your answers. Thank you in advance.

Best regards,
Valeria Leitsina, Editor

LAMPIRAN E-2

(Jawaban atas Komentar Reviewer kepada Editor)

UNESA Mail

I Made Arsana <madearsana@unesa.ac.id>

RE: Manuscript Submission (163-2019)

I Made Arsana <madearsana@unesa.ac.id> 23 Januari 2021 pukul 05.14
Kepada: Jepter <jepter@itmo.by>

Dear Dr. Valeria Leitsinia,

Editor of The Journal of Engineering Physics and Thermophysics,

In response to your questions for our manuscript, please find the following answers addressing your queries:

1. No. We apologize in advance and please omit/remove the sentence "The particles were extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and re-dispersed in 25 mL ethanol by ultrasonication for 30 min" which comes first in the paragraph (page 2, line 27 – 29).

2. Pr_s in Eq. (4) is the static Prandtl number calculated for the average of the inlet and outlet temperatures.

k_w in Eq. (6) is conductive heat transfer coefficient of nanofluids ($W \cdot m^{-1} \cdot K^{-1}$)

k_f in Eq. (7) is conductive heat transfer coefficient of air ($W \cdot m^{-1} \cdot K^{-1}$)

h_i and h_0 in Eq. (8) are convective heat transfer coefficient of nanofluids and convection coefficient of air ($W \cdot m^{-2} \cdot K^{-1}$), respectively.

A in Eq. (9) is total heat transfer area in normal direction (m^2)

3. The unit of intensity in figure 2b is "counts" (number of X-ray photon diffraction)

Many thanks in advance for the suggestion to correct mistakes in our manuscript.

Best regards,

I Made Arsana

[Kutipan teks disembunyikan]

Letter for Editor .pdf
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LAMPIRAN F

Naskah Versi *Galley Proof*

(Perubahan mengakomodasi revisi di-highlight warna kuning)

DOI 10.1007/s10891-021-02312-x
Journal of Engineering Physics and Thermophysics, Vol. 94, No. 2, March, 2021

NANOSTRUCTURES

ENHANCED HEAT TRANSFER EFFECTIVENESS USING LOW CONCENTRATION SiO_2–TiO_2 CORE–SHELL NANOFLUID IN A WATER/ETHYLENE GLYCOL MIXTURE

I. M. Arsana,[a] L. C. Muhimmah,[b] G. Nugroho,[b] and R. A. Wahyuono[b]

UDC 536+544

This paper assesses the heat transfer performance of nanofluids containing a core–shell structure of SiO_2–TiO_2 nanoparticles of low concentration in a mixture of water and ethylene glycol (EG) in a commercially available heat exchanger. For heat transfer analysis, 0–0.025% of SiO_2–TiO_2 nanoparticles were employed in a finned-tube cross-flow heat exchanger (automobile radiator kit). The obtained results indicate that SiO_2–TiO_2 particles have an amorphous structure and make it possible to increase the thermal conductivity as the nanoparticle fraction increases up to 0.04%. The nanofluid characteristics (Reynolds, Nusselt, and Prandtl numbers) increase, leading to an increase in the convection coefficient. As the thermal conductivity and the convection coefficient increase, the total heat transfer improves. Finally, the heat transfer effectiveness increases linearly by 21% with 0.025% mass fraction of SiO_2–TiO_2 in a water/EG-based fluid.

Keywords: *nanofluid, SiO_2–TiO_2, EG/water mixture, automobile radiator, heat transfer.*

Introduction. The operation of heat exchangers in industry is often characterized by the thermal properties of a used working fluid, such as water, ethylene glycol, or oil, that are worse than optimal ones, which leads to the lower heat transfer effectiveness [1, 2]. An increase in the overall heat exchanger performance can be achieved by improving the thermal properties of working fluids, for example, by the introduction of micrometer- or nanometer-sized particles into the working fluid [3, 4]. However, a blockage of the heat transfer process can occur in heat exchanger tubes with the use of the working fluids with large particles and high particle concentrations [5, 6]. Therefore, the use of nanoparticles dispersed in a base fluid (i.e., of nanofluids) is considered an alternative solution that not only increases the thermal conductivity of the working fluid, but also increases the long-term stability and mantains a low pressure drop [7]. The utilization of nanofluids results in the enhancement of the heat transfer effectiveness in a laminar flow, as an increasing concentration of nanoparticles increases the Reynolds number [3–7]. This suggests that the nanofluid convection coefficient increases.

A number of recent studies were carried out to investigate the improved heat transfer mechanism in nanofluids with the use of various metal oxide semiconductor nanomaterials, for example, TiO_2, Al_2O_3, CuO, and SiO_2 [3–12]. Among these nanomaterials, TiO_2 is one of the widely explored ones for increasing the heat transfer effectiveness due to its excellent chemical and thermophysical stability [6–11]. TiO_2 nanoparticles dispersed in various base fluids are widely used in heat exchangers of various forms. In addition, TiO_2 nanoparticles are cost-effective and commercially available. An increase in the TiO_2 concentration up to 0.25% is followed by an increase in the value of the Nusselt number without increase in the pressure drop [12]. Beside the n-type semiconductor TiO_2, other metal oxides, such as SiO_2, with greater electrical insulating properties in an oil emulsion-based nanofluids also exhibit the promising heat transfer effectiveness [13–19]. It is found that an increasing concentration of SiO_2 leads to the enhanced thermal conductivity without a noticeable change in the viscosity [14]. With a concentration of only 0.5–3% SiO_2, the increase in the heat transfer effectiveness is as great as 43.75%.

[a]Department of Mechanical Engineering, Universitas Negeri Surabaya, Jl. Ketintang 60231, Surabaya, Indonesia; email: madearsana@unesa.ac.id; [b]Department of Engineering Physics, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember (ITS), Jl. Arief Rahman Hakim 60111, Surabaya, Indonesia. Published in Inzhenerno-Fizicheskii Zhurnal, Vol. 94, No. 2, pp. 439–446, March–April, 2021. Original article submitted January 21, 2020.

In this study, we propose the utilization of SiO_2 and TiO_2 nanoparticles in the form of the SiO_2–TiO_2 core–shell structure for nanofluids. Particularly, we evaluate the effect of low concentrations of SiO_2–TiO_2 nanoparticles in a water/ethylene glycol-based nanofluid on the heat transfer effectiveness in a cross-flow heat exchanger consisting of finned tubes.

Materials and Method. Spherical SiO_2 particles were prepared using a slightly modified Stöber method in batching sol precipitation. Tetraethylorthosilicate (TEOS) in an amount of 2.725 mL was added dropwise under stirring at room temperature into a mixture of 180 mL ethanol, 30 mL saturated ammonia solution, and 9 mL MilliQ water. This addition of TEOS was repeated four times every 12 h. After additional stirring for 6 h, 200 μL (aminopropyl)trimethoxysilane (APTMS) was added. The solution was heated to reflux and kept stirring for 4 h. Then 100 mg of SiO_2 nanoparticles were dispersed in 100 mL ethanol by ultrasonication for 30 min. The nanoparticle solution was heated to reflux, and then a solution of 200 μL tetraisopropoxide (TTIP) in 20 mL ethanol was added under stirring to the reaction solution with a dropping funnel. The mixture was kept under reflux for 2.5 h. The particles were extracted from the reaction solution by centrifugation (3000 rpm, 6 min) and redispersed in 25 mL water by ultrasonication for 30 min, and 100 mg of SiO_2 nanoparticles were dispersed in 100 mL ethanol by ultrasonication for 30 min. The micromorphology of SiO_2–TiO_2 core–shell particles was analyzed by a scanning electron microscope (SEM) FEI Inspect-S50 operating at an accelerating voltage of 20 kV. The crystal structure of nanoparticles was determined by powder X-ray diffraction (XRD) with a PANalytical X-pert MPD diffractometer. This diffractometer was operated at a voltage of 40 kV and a current of 20 mA with the use of CuK_α radiation (λ = 0.15406 nm). The thermal conductivity of nanofluids was assessed by using the transient hot-wire technique.

The effectiveness of heat transfer was assessed in the experimental heat transfer system, i.e., in an automobile radiator training kit, including a closed loop of hot and cold flows (Fig. 1). As a heat exchanger, a finned-tube cross-flow heat exchanger (Suzuki) was used. Particles of SiO_2–TiO_2 in a mixture of water/EG (1:1) nanofluid was employed as a hot fluid in the system. The SiO_2–TiO_2 concentration varied in the mass fraction range 0–0.025% in water/EG-based fluids. The system included calibrated thermocouples, flowmeter, and pressure gauges. The schematic diagram of the automobile radiator training kit is shown in Fig. 1. The heat exchanger performance at different concentrations of SiO_2–TiO_2 was evaluated by the heat tranfer effectiveness. The heat transfer parameters of nanofluids were determined by joint experimental and theoretical approaches, and only the conductivity was determined directly from the transient hot-wire measurements. Other parameters are determined as follows [1, 2, 17–19]:

density of nanofluids

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{nf} \;; \qquad (1)$$

viscosity of nanofluids (Einstein equation)

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{bf} \;; \qquad (2)$$

Reynolds number

$$\mathrm{Re} = \frac{\rho V D_h}{\mu} \;; \qquad (3)$$

Nusselt number of an external flow

$$\mathrm{Nu} = 0.683\ \mathrm{Re}^{0.38}\ \mathrm{Pr}^{0.37}\ (\mathrm{Pr}/\mathrm{Pr_s})^{0.25}$$

where Pr_s is the static Prandtl number calculated for the average of the inlet and outlet temperatures;

Nusselt number of an internal flow

$$\mathrm{Nu} = 0.0265\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.36}; \qquad (5)$$

convective heat transfer coefficient of nanofluids

$$h_{nf} = 0.295\ \frac{k_{nf}}{D_h}\ \mathrm{Re}^{0.64}\ \mathrm{Pr}^{0.32}\ \frac{\pi}{2}\;; \qquad (6)$$

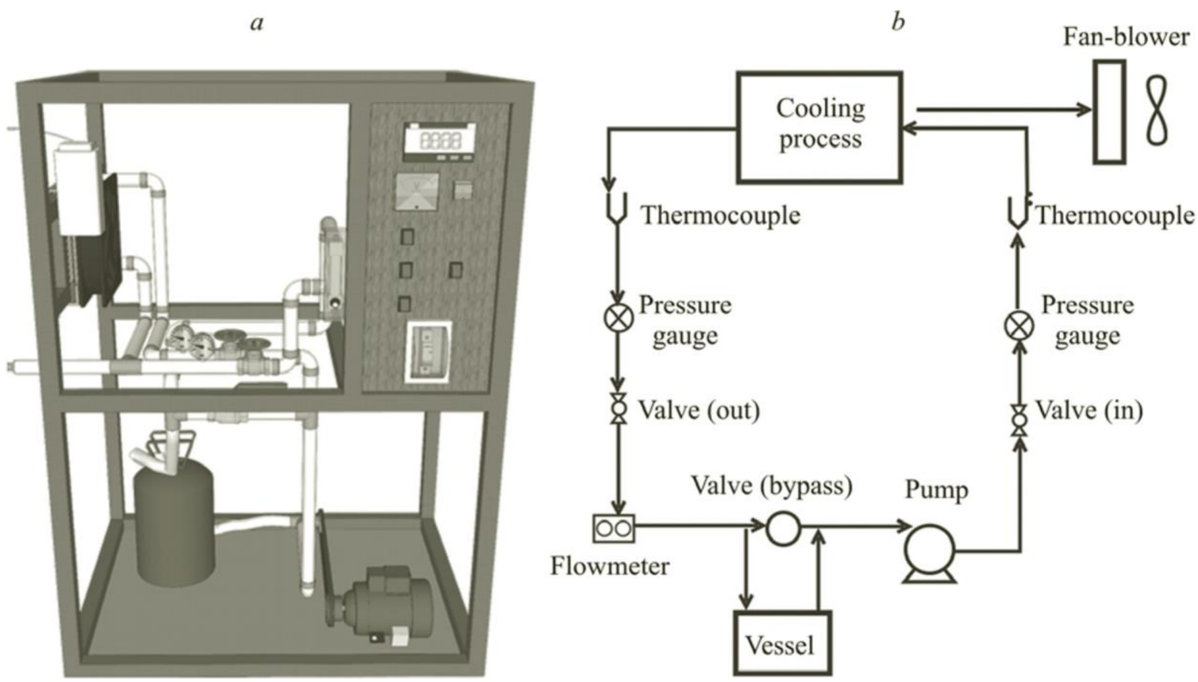

Fig. 1. Heat exchanger apparatus (a) and its schematic (b).

convective heat transfer coefficient of air

$$h_a = \frac{\mathrm{Nu}\, k_a}{D_h}. \tag{7}$$

Once all the above parameters were determined, the overall heat transfer coefficient U was estimated. For a single-tube heat exchanger, U is determined as follows:

$$U = \frac{1}{\frac{1}{h_{nf}} + \frac{\Delta x}{k_w} + \frac{1}{h_a}}, \tag{8}$$

where Δx is the tube wall thickness. Finally, the heat transfer rate which involves convection and conduction was evaluated:

$$Q = U A \Delta T_{LMTD}, \tag{9}$$

where

$$\Delta T_{LMTD} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln \frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}}. \tag{10}$$

Physical Properties of SiO_2–TiO_2 Core–Shell Particles. The morphology of SiO_2–TiO_2 core–shell particles is displayed in Fig. 2a. The average size of the particles is 640 nm, and the particle size distribution indicates that they can be considered monodisperse. To understand the structure of SiO_2–TiO_2 core–shell particles, XRD patterns of these particles and TiO_2 particles after calcination at 500°C for 3 h were recorded (in Fig. 2b the intensity is given in counts, i.e., in the numbers of X-ray diffraction photons). All the SiO_2–TiO_2 core–shell particles started to show clear anatase peaks corresponding to the (101), (004), and (200) planes at 2θ = 25.3, 37.8, and 48.1°, respectively. With increase in the number of coating steps, the full width at half maximum (FWHM) of the anatase peaks decreased, suggesting that crystallite sizes increase. Nonetheless, a higher X-ray diffraction background indicates that the nanoparticles are amorphous. Inset in Fig. 2b shows the FTIR (Fourier

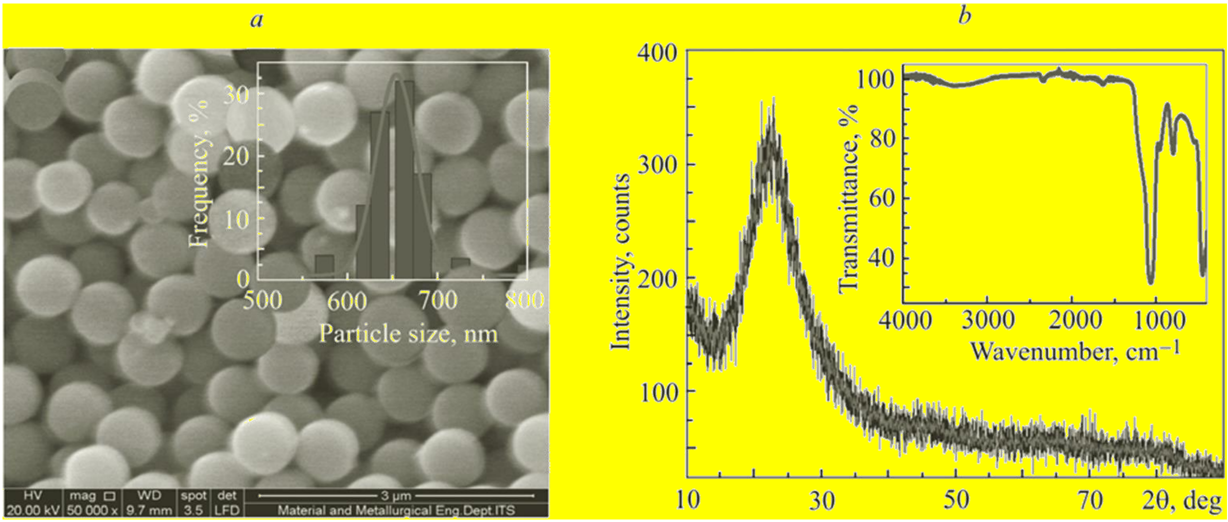

Fig. 2. Scanning electron micrograph of SiO_2–TiO_2 nanoparticles (a), their XRD pattern (b), and the upper inset with their FTIR spectrum.

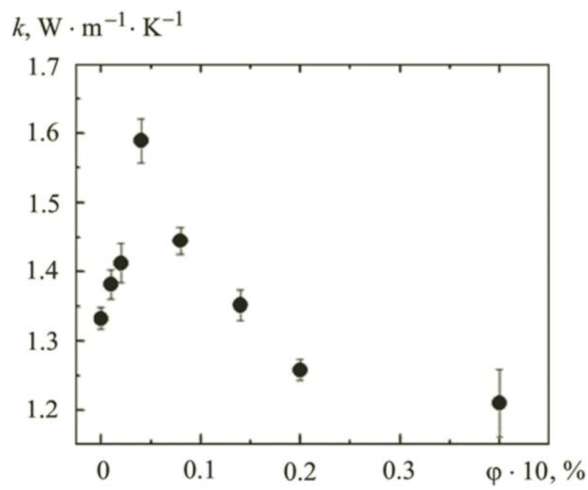

Fig. 3. Thermal conductivity of SiO_2–TiO_2 nanofluids determined by the transient hot-wire measurements vs. the nanoparticle concentration.

transform infrared spectroscopy) patterns of SiO_2–TiO_2 core–shell particles. The absorption band at 460 cm^{-1} relates to Si–O–Si bending modes which appear in the same range of Ti–O–Ti band (400–600 cm^{-1}) for SiO_2–TiO_2 core–shell particles [20, 21]. The absorption peak at 940 cm^{-1} is observed in the SiO_2–TiO_2 core–shell particles spectrum, which is indicative of the characteristic vibrations of Ti–O–Si.

Thermal Properties of SiO_2–TiO_2 Nanofluids. To aid the heat transfer analysis, the thermal conductivity of the prepared SiO_2–TiO_2 core–shell nanofluids is assessed by the transient hot-wire measurements. The measurement results are summarized in Fig. 3. It is seen that the thermal conductivity of a water/EG mixture increases by 19.7% with increase in the mass fraction of SiO_2–TiO_2 core–shell nanoparticles up to 0.04%. However, further the thermal conductivity decreases with increase in the nanoparticle fraction. The increasing and decreasing thermal conductivtiy in a SiO_2–TiO_2 nanofluid can be explained as follows. The nanoparticles with a large surface area for energy exchange act as energy absorbers and storages and are transported by diffusion or forced convection (i.e., by flows). Therefore, the maximum thermal transport will be achieved when sufficient amount of such particles, whose thermal conductivity and heat capacity are higher than

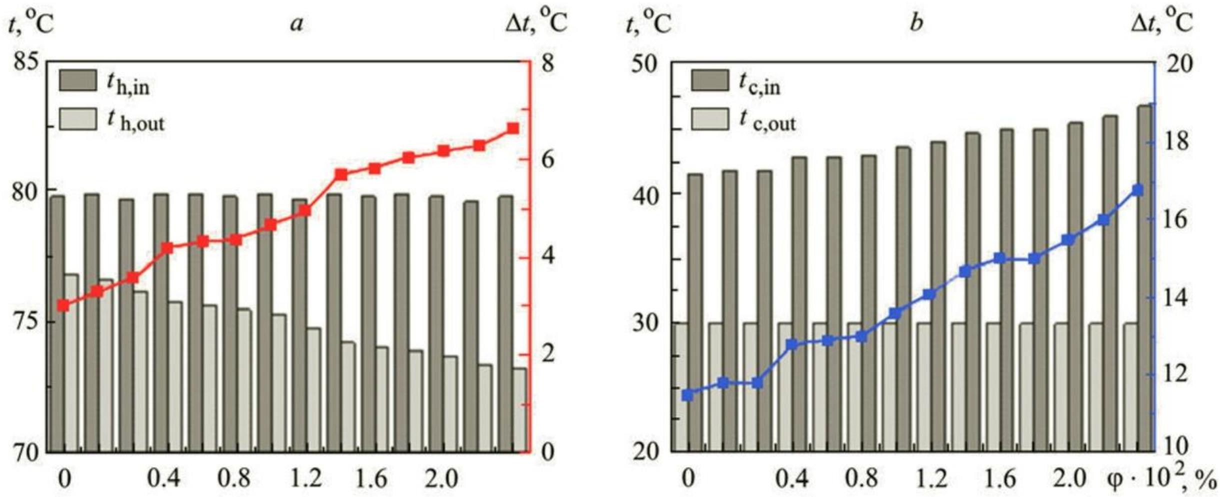

Fig. 4. Inlet and outlet temperatures of hot (a) and cold (b) nanofluid flows in the heat exchanger apparatus vs. the nanoparticle concentration.

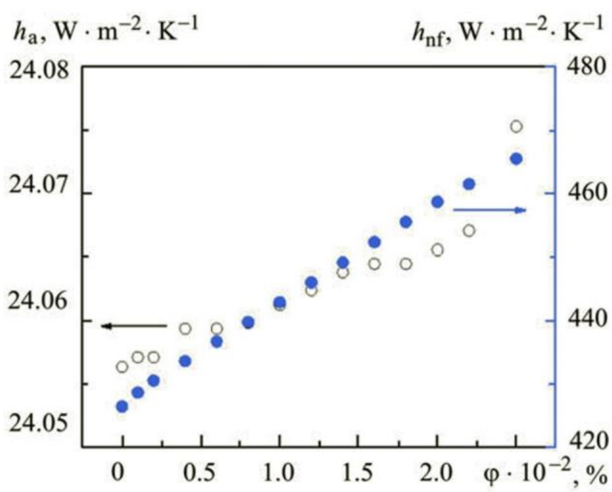

Fig. 5. Convection coefficient of air and SiO_2–TiO_2 nanofluids vs. the nanoparticle concentration.

those of the base fluid, is reached. Nonetheless, there is the saturated nanoparticle concentration which is a turning point (the global maximum), so that a higher nanoparticle concentration results in worse particle diffusion and possible agglomeration/aggregation, and thus the overal thermal conductance of the nanoparticles–fluid system reduces.

Heat Transfer Analysis. The heat transfer performance of SiO_2–TiO_2 nanofluids can be indirectly assessed by dynamics of the temperature changes T_h and T_c in the hot and cold flows with the nanofluid concentration, i.e., the mass fraction of SiO_2–TiO_2 in a water/ethylene glycol mixture, from 0 to 0.025% (see Fig. 4). The results show that the outlet temperature T_h and T_c decreases and increases, respectively, with increasing concentration of SiO_2–TiO_2. This indicates that the greater is the nanoparticle concentration, the higher is the heat transferred. In addition, this seemingly increasing heat transfer with increasing nanoparticle concentration up to 0.025% is in a good agreement with the thermal properties of the investigated nanofluids discussed earlier. It should be noted that the thermal conductivity of SiO_2–TiO_2 increases with increase in the mass fraction up to 0.04%.

The presence of SiO_2–TiO_2 nanoparticles also affects the nanofluid density determining the Reynold number Re. A higher value of Re implies a dominant inertial force which speeds up the molecule movement, increasing the heat transfer rate. In addition, the thermal conductivity depends on the mass fraction of nanoparticles, particle size and morphology, and on

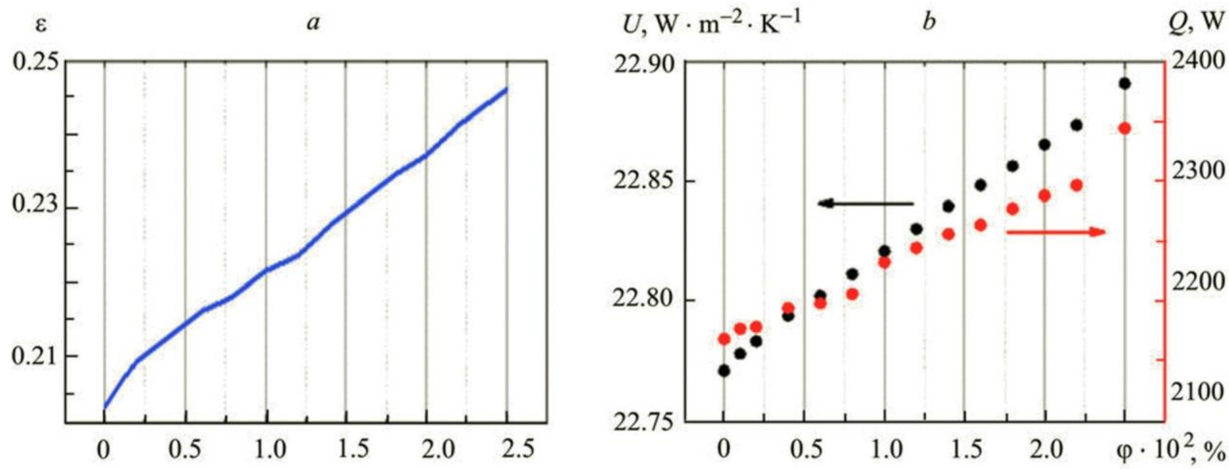

Fig. 6. Heat transfer effectiveness (a), overall heat transfer coefficient, and the heat transfer rate of SiO_2–TiO_2 nanofluids in the heat exchanger (b) vs. the nanoparticle concentration.

the base fluid characteristics. The addition of SiO_2–TiO_2 nanoparticles results in an increase in the working area of the heat transfer surface. Nonetheless, agglomeration of nanoparticles should be avoided in practical applications [22–24], since this can change the thermal characteristics of the nanoparticles themselves, which affects the heat transfer process.

External forced convection in this study was supported by blowers with an average speed of 6.8 $m \cdot s^{-1}$ and a temperature of 30°C. The addition of SiO_2–TiO_2 nanoparticles to the base fluid can result in an increase in the value of the nanofluid convection coefficient (Fig. 5). Furthermore, a change in the nanoparticle fraction affects the air convection coefficient, since a temperature change takes place, suggesting that the contact surface area during the heat transfer process increases. The addition of SiO_2–TiO_2 nanoparticles at a concentration of 0.025% increases the heat transfer coefficient by 9.15%. An increase in the convection coefficient with the nanoparticle mass fraction was also reported in [6]. It was shown that the convection coefficient increased by 6.6% at a TiO_2 mass fraction of 0.3%.

The calculations showed that the total heat transfer coefficient does not increase significantly (the increase is 0.03–0.07%) with increase in the nanoparticle mass fraction. This result is in line with the results of [8], where the total heat transfer coefficient for the fractions 0.3, 0.8, and 1.5% (at a certain Re) was shown to increase only slightly. The overall heat transfer evaluation is based on the Newton equation. For the studied heat exchanger with cross-flow configuration, the logarithmic mean temperature difference ΔT_{LMTD} is used to calculate the heat transfer rate, and the calculation results are given in Fig. 6.

At the same flow rate, namely, 8 L/min, the increase in the concentration of SiO_2–TiO_2 nanoparticles up to 0.025% results in the increase of the heat transfer rate up to 18.11% (from 2168 to 2344 $W \cdot m^{-2}$). This value is found to be higher than that for a water-based nanofluid containing TiO_2 nanoparticles, where the heat transfer rate is enhanced by only 11% [24]. It was reported that at the flow rate 1.8 L/min, TiO_2-based nanofluids are able to produce a heat transfer rate of around 5000 $W \cdot m^{-2}$ which increased to 8000 $W \cdot m^{-2}$ when the flow rate was doubled. This implies that the heat transfer rate of the investigated low-concentration SiO_2–TiO_2 nanofluids can be increased by increasing the nanofluid flow rate in the heat exchanger.

In general, according to the energy conservation law, the effectiveness of heat transfer with the use of nanofluids with different SiO_2–TiO_2 particle concentrations is enhanced linearly with the mass fraction of nanoparticles (see Fig. 6). It is shown that the effectiveness of heat transfer increases by 1.6–2% with increase in the mass fraction by 0.005%. Overall, there is the increase in the heat transfer effectiveness by 21%, namely, from 0.203 to 0.246, when the concentration rises up to 0.025%. The results at hand indicate that the investigated system, i.e., water/EG-based nanofluid containing SiO_2–TiO_2 nanoparticles, is preferred than water/EG (2:3)-based nanofluid containing 0.02% TiO_2 which is able to increase the effectiveness of heat transfer only by 13% [19].

Conclusions. Water/EG-based nanofluids containing SiO_2–TiO_2 core–shell nanoparticles have been successfully prepared and evaluated for the application in finned tube cross-flow heat exchangers. It was shown that an increase in the mass fraction of SiO_2–TiO_2 nanoparticles in an water/EG-based fluid can improve the thermophysical characteristics of the nanofluids. The saturation concentration of SiO_2–TiO_2 nanoparticles in the nanofluid is 0.04%. With increase in the nanoparticle mass fraction from zero to 0.025%, the total heat transfer coefficient increases from 22.77 to 22.89 $W\cdot m^{-2}\cdot K^{-1}$, resulting in the increase in the heat transfer rate in the exchanger from 2168 to 2344 $W\cdot m^{-2}$. Furthermore, the effectiveness of heat transfer also increases from 0.203 to 0.246.

NOTATION

A, total heat transfer surface area, m^2; D_h, hydraulic diameter, m; h, convective heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; k, thermal conductivity, $W\cdot m^{-1}\cdot K^{-1}$; Nu, Nusselt number; Pr, Prandtl number; Q, heat rate, W; Re, Reynolds number; T, temperature, K; t, temperature, °C; U, overall heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; V, flow rate, m/s; ΔT_{LMTD}, logarithmic mean temperature difference, K; ε, heat transfer effectiveness; θ, angle between a reflected beam and a crystallographic plane, deg; μ, viscosity, $kg\cdot m^{-1}\cdot s^{-1}$; ρ, density, $kg\cdot m^{-3}$; φ, mass fraction of SiO_2–TiO_2 in water/EG. Indices: a, air; bf, base fluid; c, cold nanofluids; h, hot nanofluids; in, inlet; nf, nanofluid; out, outlet; w, wall material.

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