XX Polish Fluid Mechanics Conference,
Gliwice, 17-20 September 2012

INVESTIGATIONS ON HEAT AND MOMENTUM TRANSFER IN NANOFLUID

Grzegorz DZIDO, Michał DRZAZGA, Marcin LEMANOWICZ, Andrzej GIERCZYCKI
Department of Chemical and Process Engineering, Silesian University of Technology, Gliwice, Poland
E-mail: gdzido@polsl.pl, michal.drzazga@polsl.pl, marcin.lemanowicz@polsl.pl, andrzej.gierczycki@polsl.pl

Abstract

This paper presents results of investigations on the application of the CuO-water nanofluids for intensification of convective heat transfer. Performance of nanofluids of 2.2 and 4.0 vol. %. CuO contents were examined with respect to heat transfer coefficient and pressure loss for transient and turbulent flow in tube. It was found negligible impact of examined nanofluid on heat transfer improvement. Moreover, measured pressure loss significantly exceed one determined for host liquid. The observations show that application of nanofluid for heat transfer intensification with relatively high solid load in examined flow range is rather controversial.

Key words: nanofluids, fluid mechanics, heat transfer

INTRODUCTION

A concept of nanofluid was introduced by Choi, et al. (1995) and refers to the suspension of nanoparticles in the host liquid e.g. water, ethylene glycol, oil etc. A development of nanotechnology made possible the preparation of highly stable suspensions of solids characterized by low size, typically below 100 nm and relatively high heat conductivity coefficient, Karthikeyan, et al. (2008). This makes nanofluid desirable medium for intensification of heat transfer. As solid phase mainly metals, nonmetals or their oxides are used, Wang, et al. (2007). Due to very high unit surface area the former may undergo fast oxidation, so application of oxides seems to be more convenient, save and economical in industrial applications. A lot of researches on preparation, characterization and thermal performance of nanofluid can be found in open literature Li et. al (2009). Most reported data refers to convective heat transfer in laminar or turbulent flow of Al_2O_3, Meiboldi et al. (2010), TiO_2, Duangthongsuk et al. (2010) or CNT (*carbon nanotubes*), Ding et al. (2006). There is a relatively small number of papers dealing with the problem of thermal performance of CuO based nanofluids, Hojjat et al. (2011), Kulkarini et al. (2009). This paper presents results on heat transfer and pressure loss in aforementioned nanofluid in transient and turbulent flow regime.

EXPERIMENTAL

Preparation and tests of nanofluids

For experimental purpose nanofluid CuO-water with 2.2 and 4.0 vol. % load of solid was prepared by two-step method. A prescribed amount of CuO 30-50 nm nanoparticles (NPs) was mixed with 0.15 wt. % water solution of triammonium citratrate (CTA) and then stirred vigorously with high-shear stress homogenizer Micra D 9 for 1 hr at rotating speed 15 000 1/min. Then suspension was processed with ultrasonic horn Sonics VCX 750 for 5 hr at 60%

amplitude. Application of CTA as stabilizer lowers pH of CuO-water system to the optimal range 5-6 where zeta potential exceeds 30 mV that provide good stability of suspension Pantzali et. al. (2009). Such obtained nanofluid was stable for at least one day without sedimentation. Heat transfer coefficient of thermostated sample was measured by means of commercial instrument Decagon KD2 equipped with 6 cm probe KS-1. This instrument employs THW (*Transient Heat Wire*) method and provide accuracy +/-5%. Dynamic coefficient of viscosity was determined by Brookfield LV II Pro viscometer at mean measurement temperature. Density of nanofluids was determined with pycnometer method. Heat capacity was calculated according to (1):

$$c_{nf} = \frac{\phi \rho_{CuO} c_{CuO} + (1-\phi)\, \rho_w c_w}{\rho_{np}} \qquad \text{[J/kgK]} \qquad (1)$$

where:
φ-volumetric fraction of CuO,
$c_{(w)CuO}$ – heat capacity of (water) and CuO – 535.6 J/kgK,
$\rho_{(w)CuO}$ – bulk density of (water) and CuO – 6300 kg/m^3.

Properties of examined nanofluids were gathered in the Tabl. 1.

Table 1. Properties of investigated nanofluids

CuO load [vol.%]	heat capacity [J/kg·K]	density [kg/m^3]	viscosity [Pa·s]	heat conductivity coeff. [W/m·K]
2.2	3856	1074	0.00165	0.620
4.0	3415	1214	0.00219	0.682

Experimental set-up

An experimental determination of overall heat transfer coefficient and pressure drop were determined in experimental loop presented in the Fig. 1. Nanofluid from container (1) was delivered by pump (2) through cooling system (3, 4) to the shell-tube heat exchanger (6). The shell of the last was heated by water from thermostat (5) at known constant flow rate G_s and measured inlet and outlet temperature. Then through second cooling system (7) nanofluid was delivered to the container. Inlet and outlet temperatures were measured by means of four K-type thermocouples, calibrated with accuracy +/-0.1K connected to the A/D Advantech converter. Flow rate of nanofluid G_{nf} was determined by measurement of time needed to fill 1 dm^3 vessel. Pressure loss in 6 mm I.D. tube was measured with pressure transducer Peltron NPDX at the distance 1.080 m with accuracy +/- 0.25%. Readings were conducted after time ca. 45 min. which was necessary to approach steady state condition for heat transfer. Experiments were conducted in the range of Reynolds number 4 000-12 000.

Data reduction

Global heat transfer coefficient for examined nanofluids was determined on the base of fundamental heat transfer equation (2):

$$U = \frac{Q}{F \Delta t_m}, \qquad \text{[W/m}^2\text{K]} \qquad (2)$$

where:
F – heat transfer surface of tube with external/internal diameter 8/6 mm,
Δt_m – LMTD of measured inlet and outlet temperatures, [K]

Q – arithmetic mean of heat determined for shell Q_s and tube Q_{np} sections (3, 4):

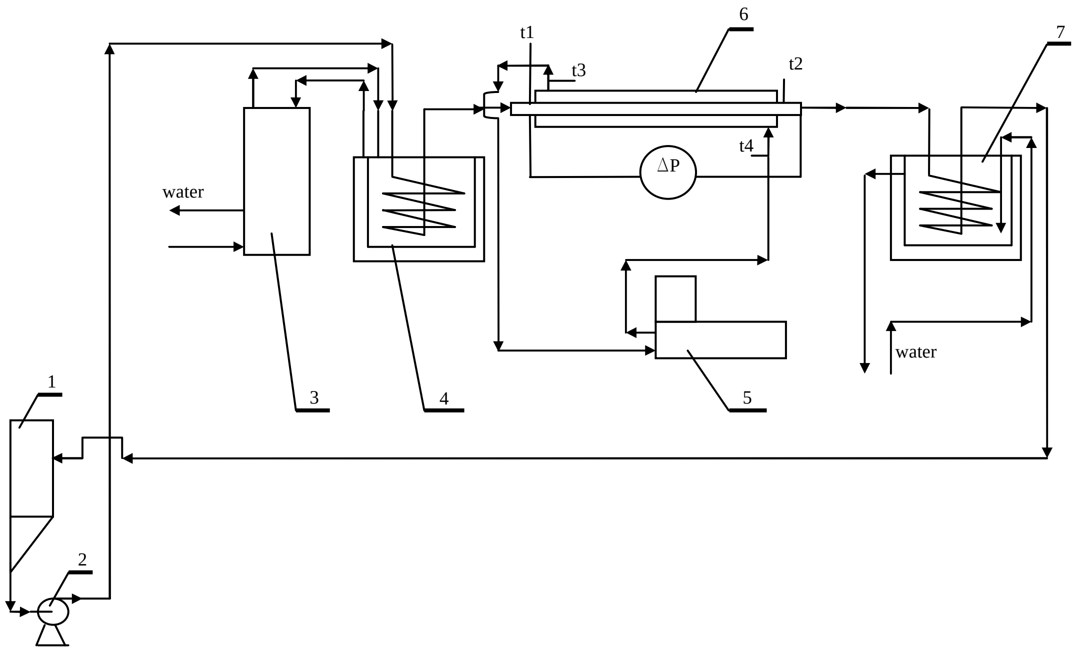

Fig. 1 Experimental set-up. 1 – nanofluid container, 2 – pump, 3 – chiller, 4 – secondary cooler, 5 – thermostat, 6 – shell-tube heat exchanger, 7 – primary cooler, t_1, t_2, t_3, t_4 – K-type thermocouples, ΔP – pressure transducer

$$Q_s = G_s \bar{c}_w \left(t_4 - t_3\right), \quad \text{[W]} \qquad (3)$$

$$Q_{nf} = G_{nf} \bar{c}_{nf} \left(t_1 - t_2\right). \quad \text{[W]} \qquad (4)$$

For known U value, heat transfer coefficient of nanofluid h_{nf} was calculated (5):

$$h_{nf} = \frac{1}{\frac{1}{U}\frac{F_s}{F_m} - \frac{s}{\lambda_{Cu}}\frac{F_s}{F_m} - \frac{1}{h_s}\frac{F_s}{F_t}}, \quad \text{[W/m}^2\text{K]} \qquad (5)$$

where:
F_s, F_t, F_m,– surface of shell, tube section and mean respectively [m^2],
λ_{cu} – heat transfer coefficient of copper (400 W/mK),
s – width of tube wall (1 mm).

Heat transfer coefficient in shell section was calculated similar to Yang, et. al. (2005), eqn. (6):

$$Nu = 0.020\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33}\left(\frac{d_1}{d_2}\right)^{0.53}, \quad \text{[-]} \qquad (6)$$

where: d_1, d_2 are outer (20 mm) and inner (8 mm) diameters of annuli.

Results

Firstly, an accuracy of method of determination h_{nf} was examined. Fig. 2 presents the comparison of experimental data for water with data calculated according to Gnielinski's (2009) eqn. (7):

$$Nu = \frac{\left(\frac{\lambda}{8}\right)(\mathrm{Re}-1000)\,\mathrm{Pr}}{1+12.7\left(\frac{\lambda}{8}\right)^{0.5}\left(\mathrm{Pr}^{2/3}-1\right)}\left(1+\left(\frac{d}{l}\right)^{2/3}\right), \qquad [-] \qquad (7)$$

where: Darcy friction coefficient λ was calculated according to (8):

$$\lambda = \frac{1}{\left(1.8\log(\mathrm{Re})-1.5\right)^2}\,. \qquad [-] \qquad (8)$$

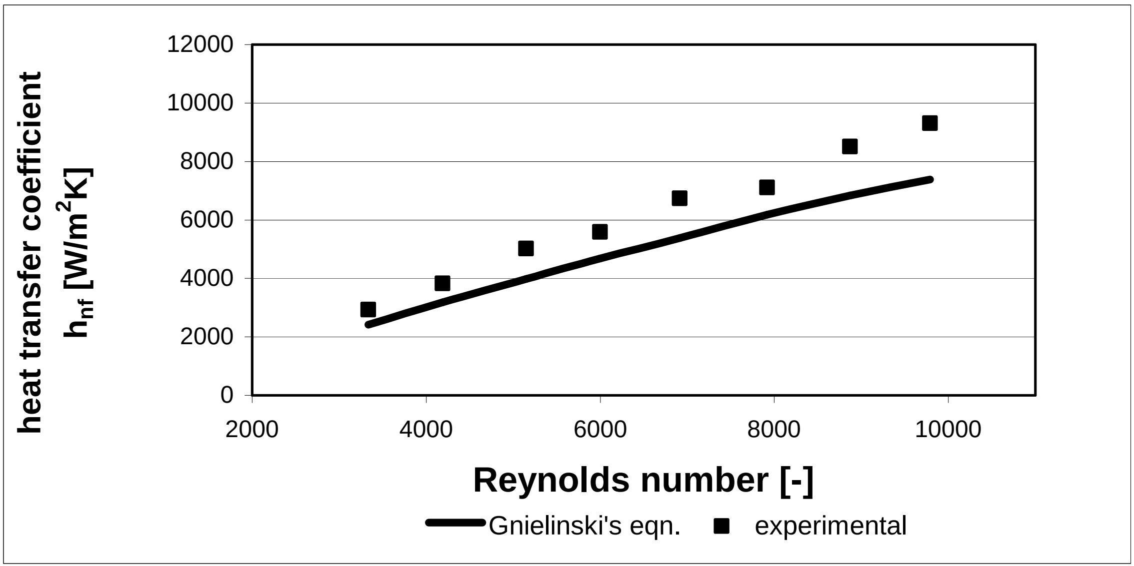

Fig. 2 Comparison of experimental heat transfer coefficient for water with theoretical one calculated with eqn.(7)

Experimentally determined values of heat transfer coefficient are slightly larger than theoretical ones. Maximal discrepancy did not exceed 25%. Fig. 3 presents values of heat transfer coefficient for water and examined nanofluids vs. Reynolds number. The last ones are almost the same as for water or slightly lower. Expected heat enhancement in this case is rather controversial but in agreement with findings of other works, Pantzali et al. (2009). This is especially visible in case of turbulent flow regime where heat transfer coefficient is function of nanofluid properties as heat conductivity, viscosity and density. A presence of NPs influences values of the last and resultant trend of changes may lead in general to moderate heat properties improvement, even heat conductivity of nanofluids is larger than one for host liquid.

In present paper pressure loss in the flow through a straight tube was investigated. Fig. 4 presents pressure loss measured for water against theoretical calculated as for hydraulically smooth tube according to classical equations (9, 10):

$$\Delta P = \lambda \frac{l}{d}\frac{u^2}{2}\rho \qquad [\mathrm{Pa}] \qquad (9)$$

$$\lambda = \frac{0.316}{\mathrm{Re}^{0.25}} \qquad [-] \qquad (10)$$

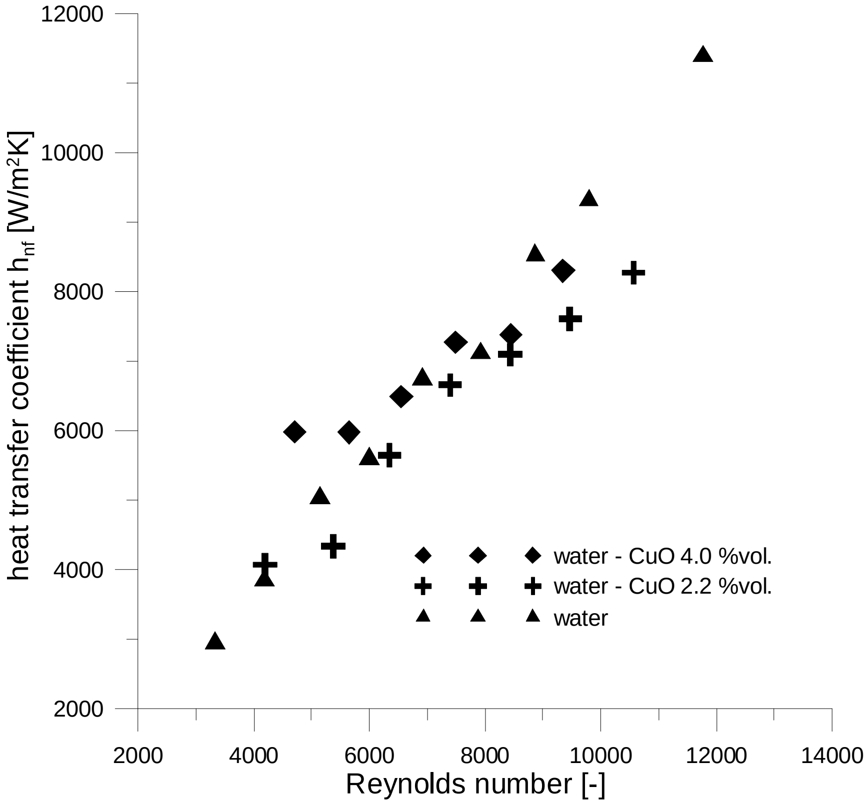

Fig. 3 Heat transfer coefficient for nanofluids and water

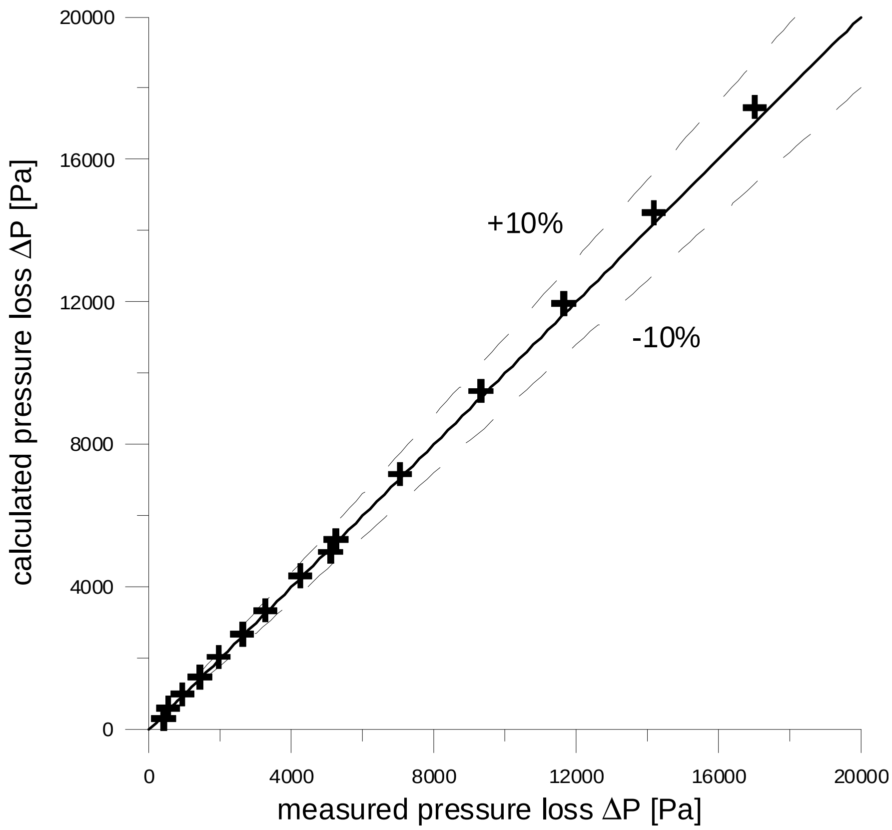

Fig. 4 Comparison of experimental and theoretical pressure drop for flow of water

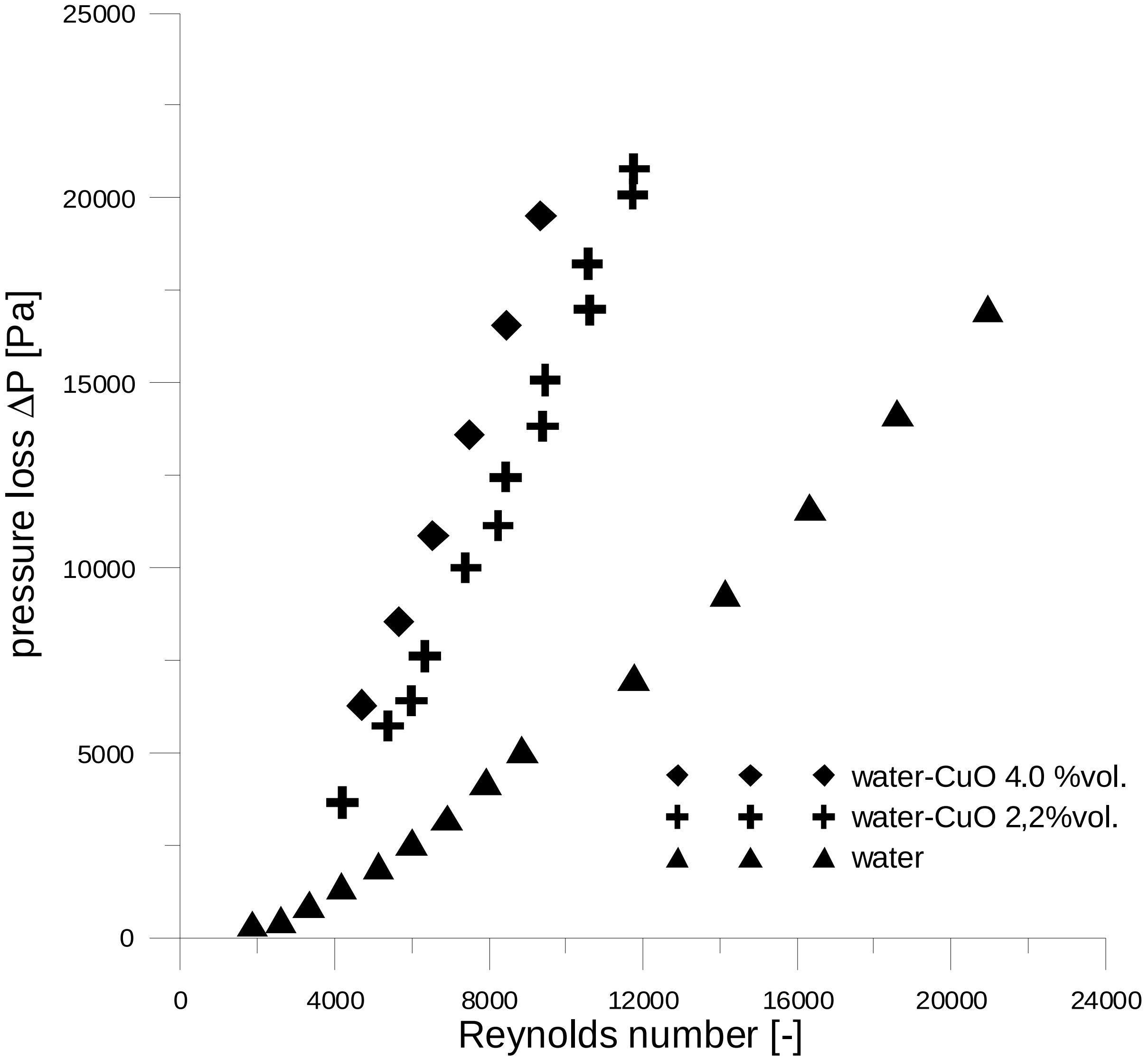

Fig. 5 Pressure loss in nanofluids and water

It can be seen very good agreement between theoretical and experimental results. Maximal difference did not exceed +/-10%. Fig. 5 presents experimental pressure drop measured for water and examined nanofluids. Pressure loss for nanofluids at the same Reynolds number is significantly larger than one for water in the same flow regime. In case of examined nanofluids run of $\Delta P=f(Re)$ is almost linear what is characteristic for laminar flow. Similar results were reported for higher NPs concentration, Vajjha et al. (2011). It is also in agreement with findings of Ko et al. (2007) who postulated that laminar flow regime of CNT based nanofluids was extended to higher Re number than pure host liquid water. A comparison of experimental pressure loss of nanofluids with predicted by eqn. 9, 10 shows differences that are 18-42% of experimental value (Fig. 6, 7) and increase with load CuO NPs. Aforementioned discrepancies are significantly larger than inaccuracy of measurement system (Fig. 5). This may be attributed to suppression of turbulence by NPs and changes in rheological properties of nanofluid. Detailed explanation of this effect needs further work.

Conclusions

Present work deals with investigations on the application of CuO-water nanofluids for intensification of convective heat transfer. Performance of nanofluids of 2.2 and 4.0 vol. %.

CuO contents were examined with respect to heat transfer coefficient and pressure loss for transient and turbulent flow in the tube. The main results can be summarized as follows:
- an addition on NPs to the host liquid increases heat conductivity, viscosity and density of resultant nanofluid,

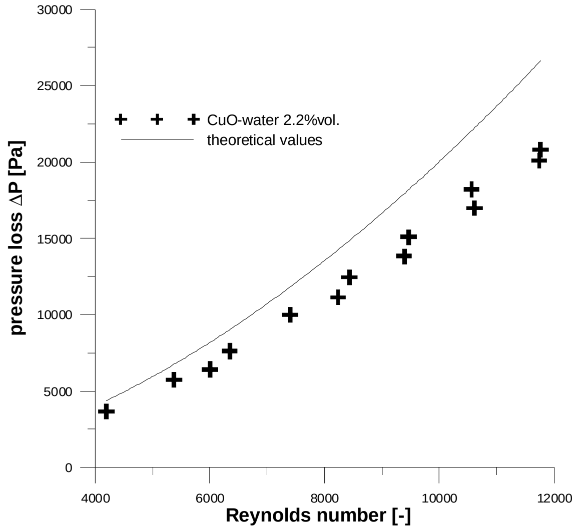

Fig. 6 Comparison of experimental and theoretical pressure loss calculated according to eqn. (9), (10); CuO NPs content 2.2% vol.

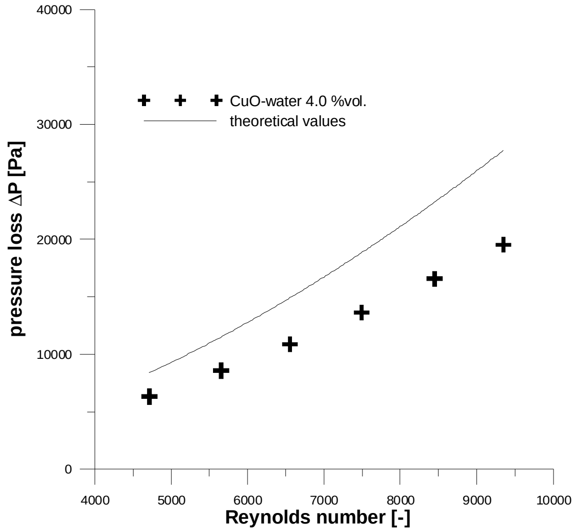

Fig. 7 Comparison of experimental and theoretical pressure loss calculated according to eqn. (9), (10); CuO NPs content 4.0% vol.

- for investigated range of Reynolds number it was found negligible impact of NPs presence on heat transfer improvement which is the evidence of multicomponent and complex influence of physical properties,
- experimental heat transfer coefficients of nanofluids were the same or slightly lower than ones determined for host liquid,
- pronounced pressure loss penalty was found in case of both nanofluids.

ACKNOWLEDGEMENTS

This research was supported by the State Committee for Scientific Research (Poland) under grant number N N209 76 4040.

REFERENCES

Pantzali M.N, Mouza A.A, Paras S.V. (2009): *Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE),* Chem. Eng. Sci., Vol. 64, pp. 3290-3300.

Choi U.S. (1995): *Enhancing thermal conductivity of fluids with nanoparticles*, ASME FED, Vol. 231, pp. 99–103.

Ding Y, Alias H, Wen D, Williams R.A. (2006): *Heat transfer of aqueous suspensions of carbon nanotubes.* Int. J. Heat Mass Trans. Vol. 49, pp. 240–250.

Duangthongsuk W, Wongwises S. (2010): *An experimental study on the heat transfer performance and pressure drop of TiO2 - water nanofluids flowing under a turbulent flow regime*. Int. J. Heat Mass Trans. Vol. 53, pp. 334–344.

Fotukian S.M, Esfahany M,N. (2010): *Experimental study of turbulent convective heat transfer and pressure drop of dilute CuO-water nanofluid inside a circular tube*. Int. Comm. Heat Mass Trans. Vol. 37, pp. 214–219.

Gnielinski V. (2009): Heat *transfer coefficients for turbulent flow in concentric annular ducts,* Heat Trans. Eng. Vol. 30(6), 431-436.

Hojjat M, Etemad S. Gh, Bagheri R, Thibault J. (2011): *Convective heat transfer of non-Newtonian nanofluids through a uniformly heated circular tube*. Int. J. Thermal Sci. Vol. 50, pp. 525-531.

Karthikeyan N.R, Philip J, Raj B. (2008): *Effect of clustering on the thermal conductivity of nanofluids,* Mat. Chem. Phys. Vol. 109, pp. 50–55.

Ko G.H, Heo K, Lee K, Kim D.S, Kim Ch, Sohn Y, Choi M. (2007): *An experimental study on the pressure drop of nanofluids containing carbon nanotubes in a horizontal tube*, Int. J. Heat Mass Trans. Vol. 50, pp. 4749–4753.

Kulkarni D.P, Das D.K, Vajjha R.S. (2009): *Application of nanofluids in heating buildings and reducing pollution.* Appl. Energy, Vol. 86, pp. 2566–2573.

Li Y, Zhou J, Tung S, Schneider E, Xi S. (2009): *A review on development of nanofluid preparation and characterization*, Powder Technol. Vol. 196, pp. 89–101.

Meibodi M.E, Vafaie-Sefti M, Rashidi A.M, Amrollahi A, Tabasi M, Kalal H.S. (2010): An estimation for velocity and temperature profiles of nanofluids in fully developed turbulent flow conditions. Int. Comm. Heat Mass Trans. Vol. 37, pp. 895–900.

Vajjha R.S, Das D.K, Kulkarni D.P. (2010): *Development of new correlations for convective heat transfer and friction factor in turbulent regime for nanofluids*, Int. J. Heat and Mass Trans. Vol. 53, pp. 4607–4618.

Wang X.Q, Mujumdar A.S. (2007): *Heat transfer characteristics of nanofluids: a review*, Int. J. Thermal Sci. Vol. 46, pp. 1–19.

Yang Y, Zhang Z.G, Grulke E.A, Anderson W.B, Wu G. (2005): *Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow*, Int. J. Heat Mass Trans. Vol. 48, pp. 1107–1116.