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Drag reduction in the flow of CuO based nanofluid

Introduction

Energy saving methods in industrial cooling and heating systems are important issues nowadays. Application of solutions that will minimize energy required for pumping and enhance thermal properties of working fluid would allow one to save electrical energy needed to work of installations and reduce their operational costs. One of the possible enhancement methods is the application of nanofluids with drag reducing additives.

Long-chain polymers belong to the first group of these substances. Toms [1977] was the first who found that a small amount of polymer added to a base fluid decreased its friction factor. A second group of such additives are surfactants [Gu et al., 2010; Kamel and Shah, 2013]. White [1967] and Savins [1967] investigated soap solutions and observed that they also exhibit drag reducing properties. Nowadays, cationic surfactants are the most widely applied group of drag reducing additives. Surfactant additives are applied mainly in closed loop systems in order to save pumping power. They were used e.g. in heating [Myska and Mik, 2003; Jiao et al., 2008; Li et al., 2012] and air-conditioning systems [Li et al., 2012; Saeki, 2011]. Application of surfactant additives reduced consumption of electricity by pumps up to 28% acc. to Jiao et al. [2008] and even up to 65% acc. to Li et al. [2012]. The aim of this work was to check the possibility of using drag reducing (DR) additives in case of nanofluids.

Experimental

In the experiments two drag reducing additives: cationic surfactant CTAC (cetyltrimethylammonium chloride) (Alfa Aesar, Germany) and NaSal (sodium salicylate) (Alfa Aesar, Germany) were used. The base fluids were reverse osmosis water and CuO based nanofluid. CTAC and NaSal were used in 1:2 molar ratio. Nanofluid was obtained by dispersing 1% vol. 30÷50 nm copper(II) oxide (Nanostructured & Amorphous Materials Inc., USA) nanoparticles in water. CTAC/NaSal solution displayed very good stabilizing properties [Drzazga et al., 2013], so there was no need to add other stabilizing agents. A schematic drawing of experimental setup is shown in Fig. 1.

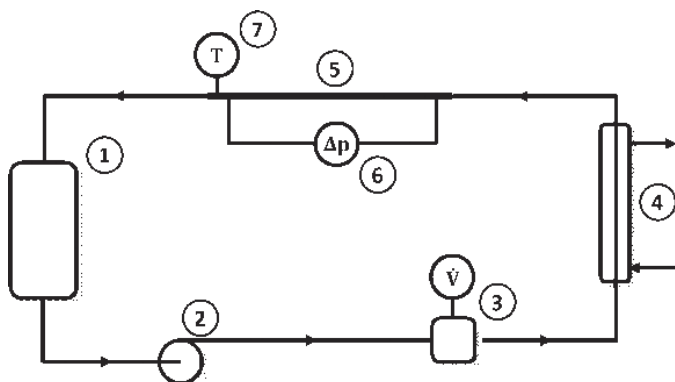


Fig. 1. Scheme of experimental setup for pressure drop measurements: 1 – storage tank, 2 – centrifugal pump, 3 – electromagnetic flowmeter (Codea Flowmex (Codea s.r.o., Czech Republic), 4 – cooler, 5 – replaceable measuring smooth copper pipes with diameters 4, 8 and 12 mm, 6 – differential pressure transducers: NPXD 1, NPXD 0,2 (both Peltron Poland) and APR-200 ALW (Aplisens, Poland), 7 – J-type thermo-couple

In the first step nanopowder was added to base fluid, i.e. the mixture of CTAC/NaSal. Next, the suspension was mixed for an hour by Mic-

cra-D9 homogenizer (ART Prozess & Labortechnik GmbH & Co. KG, Germany). Then, in order to break up agglomerates and obtain stable nanofluid, suspension was recirculated and sonicated with the ultrasonic processor Sonics VCX 750 for 4 hours. Dynamic viscosity of tested solutions was determined at 25°C by DV-II+ Pro viscometer (Brookfield, USA). Density was measured at 25°C using 50 ml pycnometer and laboratory scale with 0.002 g precision. Pressure drop was measured at 25°C. Experiments were performed for three pipes of different inner diameters, i.e. 4, 8 and 12 mm. Uncertainties of the results are determined from accuracies of measuring devices. For differential pressure transducers it was ±0.25% and for flow meter ±1%. Additionally, pressure resistance was measured for CTAC/NaSal solutions in reverse osmosis water.

Results and Discussion

Values of Reynolds number referred to base fluid were calculated using the well-known equation:

$$Re = wd\rho_{bf}\eta_{bf}^{-1} \quad (1)$$

where:

- w – average fluid flow rate, [m/s];
- d – pipe inner diameter, [m];
- ρ_{bf} – base fluid density;
- η_{bf} – dynamic viscosity of base fluid.

Due to a very small concentration of drag reducing additives their influence on density is negligible. Due to simplification and comparison purposes viscosity of water was used in calculations neglecting the fact that obtained solution revealed shear-thinning non-Newtonian behaviour. Friction factor was calculated for experimentally determined pressure drop using Darcy-Weissbach equation:

$$\lambda = \Delta p \frac{2d}{\rho_{bf}lw^2} \quad (2)$$

where:

- Δp – pressure losses in pipe measurement section, [Pa];
 - l – length of pipe measurement section, [m];
- the rest of symbols as previously.

Drag reducing coefficient in [%] for CTAC/NaSal solution in water and nanofluid with the addition of CTAC/NaSal mixture of different concentrations was determined using the following formula [Broniarz-Press et al., 2007]:

$$DR = \frac{\lambda_{bf} - \lambda_{DR}}{\lambda_{bf}} \cdot 100 \quad (3)$$

where:

- λ_{bf} – friction factor for base fluid,
- λ_{DR} – friction factor for fluid containing DR additives.

Exemplary results showing an influence of Reynolds number on DR coefficient during flow of CuO based nanofluid with CTAC/NaSal additives of three concentrations in the pipe of 4 mm in diameter are given in Fig. 2. It can be seen that the DR phenomenon occurs in the transitional and incipient turbulence ranges. The Reynolds number value for which DR starts to increase lies below ca. $Re = 7000$, however the maximum values of DR tends to shift to greater Re for a higher DR additive concentration.

There is now a general consensus that structures responsible for drag reduction phenomenon in surfactant solutions are micelles [Li et al.,

2012]. When the surfactant concentration is high enough the micelles start to form. It is the reason why no drag reduction is observed for low additives concentrations. With increasing concentration micellar structures become more organized, stronger and therefore they are more resistant to high shear stress.

Pipe diameter has also an influence on drag reduction. This phenomenon is called diameter effect [Gasljevic *et al.*, 1999] and means that friction factor of suspensions containing drag reducing agents is not only a function of Re , but also a pipe diameter. The larger the diameter the lower the maximum drag reducing coefficient. In our experiments it was 55÷70% for 4 mm pipe (Fig. 2), 40÷50% for 8 mm pipe and cá. 20% for 12 mm pipe. However such significant difference in maximum drag reducing coefficient between different diameters was not observed by other researchers [Usui *et al.*, 1998; Aguilar *et al.*, 2001]. Savins [1964] suggested that flow in pipes of smaller diameter shows larger drag reduction ability due to the fact that drag reducing agents act mainly within the boundary layer (the larger the diameter the lesser is the share of boundary layer in the overall cross-section area).

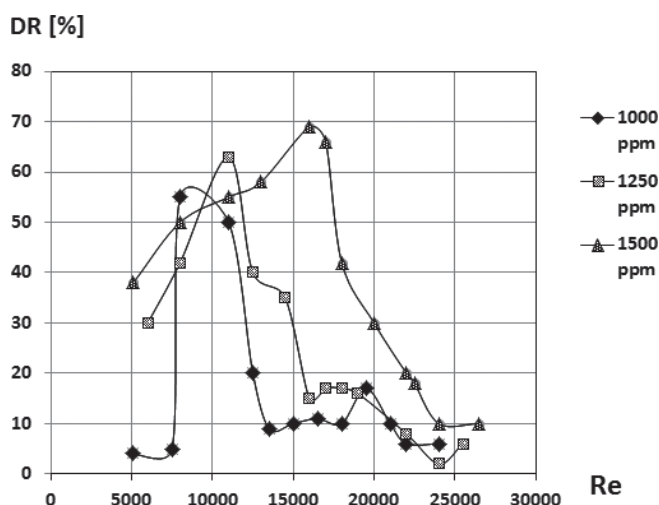


Fig. 2. Influence of Reynolds number and CTAC/NaSal concentration on drag reduction for CuO based nanofluid in the pipe of 4 mm in diameter

It is also worth to notice that DR effect is greater in case of water in comparison to nanofluid and additionally the range of the Re number in which drag reduction phenomenon occurs is narrower than in case of aqueous solutions. These observations may be explained by the fact that both CTAC and NaSal acts also as stabilizers. Part of surfactant molecules is adsorbed on the nanoparticles surface stabilizing the CuO dispersion. These molecules cannot take part in formation of micelles, which are responsible for drag reducing effect. Due to this fact, despite the same concentration of drag reducing agents, lesser amount of surfactant is engaged in drag reducing. Micellar structures are weaker and the range of DR effect is narrower.

Conclusions and Summing-up

Experimental investigations on DR phenomenon of aqueous solution of CTAC/NaSal and CuO based nanofluid with the addition of CTAC/NaSal mixture in straight pipes of three different diameters (4, 8 and 12 mm) were performed. The influence of CTAC/NaSal mixture concentration on DR was examined. Comparison of DR in water and nanofluid was carried out. The main conclusions are as follows:

- Aqueous solutions of CTAC/NaSal mixture and CuO based nanofluid with CTAC/NaSal additives possess DR ability, however, the effect is smaller in case of nanofluid. It can be explained by adsorption of surfactant molecules on the surface of CuO particles. Therefore, smaller number of surfactant molecules is engaged in formation of micelles which are responsible for DR effect.
- The higher the CTAC/NaSal mixture concentration in water or nanofluid the higher the maximum value of DR and broader the Re number range in which DR occurs. This is because the micellar structures are stronger and more resistant to stresses connected with fluid flow for the higher concentrations of CTAC/NaSal.
- Maximum value of DR coefficient decreases with increasing pipe diameter. The DR agents act mainly within the boundary layer. For larger pipe diameters the share of boundary layer is smaller than in case of smaller diameter.
- The Re number range in which drag reduction occurs is narrower in nanofluid than in water solution. It is caused by adsorption of surfactant molecules on nanoparticles.

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