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DECREASING WALL SHEAR STRESS IN HYDROMIXTURE FLOW AFTER DEFLOCCULANT APPLICATION

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Abstract: The aim of the paper is to present the influence of selected deflocculants on decreasing the hydromixture viscosity and as a consequence decreasing the wall shear stresses in a flowing medium. Adding deflocculants to improve the conditions encountered in a pipeline during the hydromixture flow is called chemical processing. The experimental studies presented in the article were performed for a hydromixture with a mass concentration of 20% and 43% consisting mostly of solids with the averaged diameter equal to 45.5 µm. The measurements were performed for varied doses of deflocculants in three proportions in a wide range of shear rates. The results of experiments have confirmed that the influence of the deflocculant on the wall shear stress is complex as there is an opposing phenomenon strongly depending on the doses of deflocculant samples. The results of the experiments are discussed and major conclusions are drawn.

Keywords: slurry flow, wall shear stress, deflocculation

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1. Introduction

The solid-liquid flow is widely employed in the industry and occurs in the nature, and it can be found in transport by pumps in various pipelines. Determining the most efficient and economical way for pumping any solids in a carrier liquid requires careful consideration and analysis of numerous factors, some of which can have significant impact on the performance and costs. These include the particle diameter, solid concentration, particle density, deposition velocity, and properly matched characteristics of the pipeline and the pump [1].

It is the mechanical and chemical methods that should be considered to improve the hydromixture properties during the flow in a pipeline. Mechanical methods are focused on especially designed grooves or mechanically deformed pipes. Chemical methods are using deflocculants mainly in order to decrease the hydromixture viscosity and, as a consequence, decrease the shear stress. The presence of solid particles in a carrier liquid could increase or attenuate the turbulence and depends on the solid sizes, flow conditions and carrier liquid properties [2–7]. It is very important to adapt the quantity and quality of the deflocculants to the physical and chemical properties of the hydromixture. The main task of added substances is to stabilize the hydromixture and improve its ability to disperse solids in order to increase its fluency. This will cause a reduction in the viscosity and shear stress in the hydromixture. In the analyzed example, the values of the viscosity and the shear stress increase as the result of saturation by dust particles derived from raw material processing.

The paper concerns a simulation of decreasing the wall shear stress in a hydromixture after applying deflocculants with a defined composition. The addition of deflocculants was aimed to increase the concentration of solids in the hydromixture and make the transportation process economically efficient. The proposed solution has an effect on increasing the flow rate without increasing the energy consumption of the pumps or the pumping system.

2. Hydromixture flow in pipeline installation

There are several ways in which a hydromixture consisting of fine solid particles and water that serves as a carrier liquid of the solid phase can flow in a pipeline. The main influence on the behavior of such a hydromixture during transportation is the interaction between the particles, the particle diameter, the critical velocity of the hydromixture at which the bottom sediment forms, and the solid particle settling rate. According to Figure 1, four different flow regimes can be distinguished [8]:

- a homogeneous or pseudo-homogeneous flow, characterized by a homogeneous distribution of solid particles in a flow cross section;
- a heterogeneous flow in which all particles remain in suspension or a heterogeneous flow with the bottom sediment moving by leaps;
- a flow with the moving bottom sediment (sliding bed);
- a flow with the stationary bottom sediment (fixed bed).

The velocity distribution in a horizontal pipeline of the transported hydromixture in the cross-section; the average volume concentration of the solid phase in the flow cross-section and transport concentration of the solid phase in the unit of the cross-section regarding the mentioned flow types are presented in Figure 1.

The distribution of the local concentration in the pipe cross-section has a great effect on both the flow and the pressure drop and it is important for understanding the mechanism of the heterogeneous mixture flow. Friction losses in the pipeline flow of heterogeneous solid particle-water mixtures are strongly dependent on the flow pattern [9].

For a hydromixture consisting of a liquid and a fine dispersed solid phase with a moderate ratio of the particle density to the liquid phase density and at corresponding high flow rates, the flow is usually assumed to be homogeneous [7, 10]. Therefore, homogeneous and pseudo-homogeneous flows are the subject of analysis in this work.

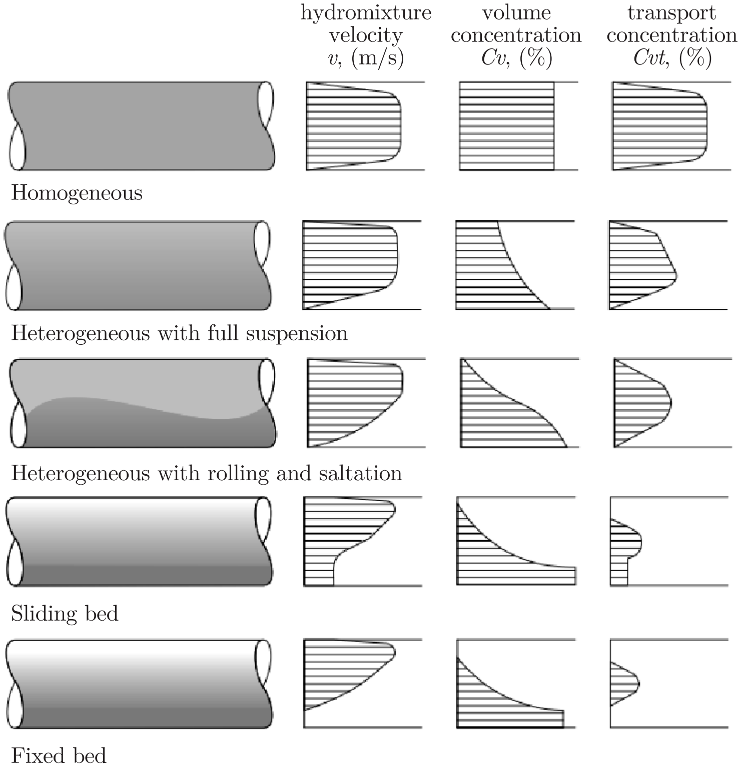

Figure 1. Hydromixture flow types – horizontal pipeline [8]

3. Raw hydromixture

The tested hydromixture was originally procured from the lime production process. Such a hydromixture appears as a result of rinsing stones and consists of a finely granular solid phase and water that serves as a carrier liquid. In the final stage of the production process, the hydromixture is subjected to the sedimentary reservoir located at a considerable distance from the plant. Its rheological properties hinder its further free transport via the pipeline.

To describe the physical properties of a raw hydromixture, a granulometric analysis was carried out on a Mastersizer 3000 particle size analyzer. Measurements in the range from 0.01 to 3500 µm were taken to determine the grain composition. The measured particle sizes were in the range from 0.5 to 163.5 µm and the averaged particle diameter was equal to 45.5 µm. The percentage content of the grain sizes with a different particle diameter in the tested hydromixture is presented in Table 1.

Table 1. Percentage content of grain fraction in hydromixture

Fraction	Clay	Dust	Sand
Grain diameter (µm)	<2	2–50	>50
Percentage content	6.5%	82.4%	11.1%

Three fraction types were separated as a result of the analysis: clay, dust and sand. The highest percentage in a hydromixture were the dust fraction particles (82.4%) with the diameter in the range of 2–50 microns. The clay fraction with the average grain diameter of less than 2 microns was 6.5%, while the phase of sand with the grain diameter greater than 50 microns was 11.1% for all particles.

Chemically, the tested hydromixture consisted mostly of calcium oxide (CaO – 73.6%) and silicon oxide (SiO_2 – 13%). Other chemicals included in hydromixture were: MgO – 0.6%, Fe_2O_3 – 0.3%, Al_2O_3 – 1.1% and SO_3 – 0.3%. The unidentified substances accounted for about 11.1% of all (Figure 2).

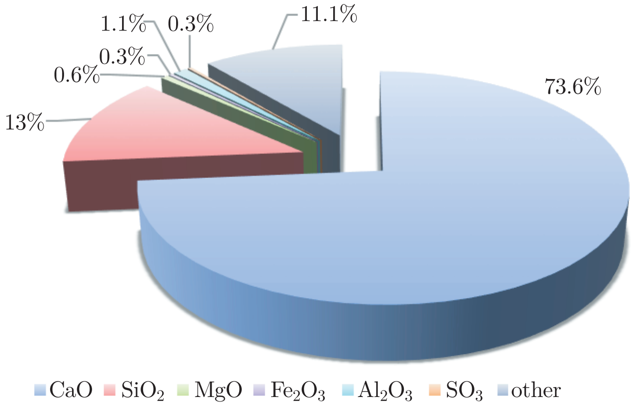

Figure 2. Chemical composition of raw hydromixture

The hydromixture samples used in experiments were in two mass concentrations equal to 20% and 43%. The mass concentration determines the percentage content of solids in the total weight of the hydromixture.

4. Deflocculants used in the experiment

The main objective of the work was to increase the concentration of solids in the hydromixture during the transportation process. Additives called deflocculants were applied to the hydromixture to reduce the wall shear stress occurring in the flow.

The experimental studies of the influence of two arbitrarily selected deflocculants were carried out. Substances used in experiments were sodium water glass and calcareous groats. These two substances were mixed together in three proportions and added to the hydromixture in five doses, according to the dry mass included in the hydromixture.

The substance, known as calcareous groats, is a side product of the lime production process which has not found industrial application so far. Calcareous groats are formed as a remnant of lime slaking after the process of hydration, where the lime and water are mixed together in a suitable mixing chamber. Heavier particles of the lime that have not been slaked and unburned lime stones sink at the bottom of the chamber and are periodically removed outside by the trigger aperture. After a two-stage separation process, the hydrated lime is sold as a finished product, while the remains of the separation are called calcareous groats [3].

Figure 3 presents an image of the surface of calcareous groats made by a scanning electron microscope. The micro-scale features shown in the picture were made with 1100 magnifications after application of the 10 kV electron-accelerating voltage.

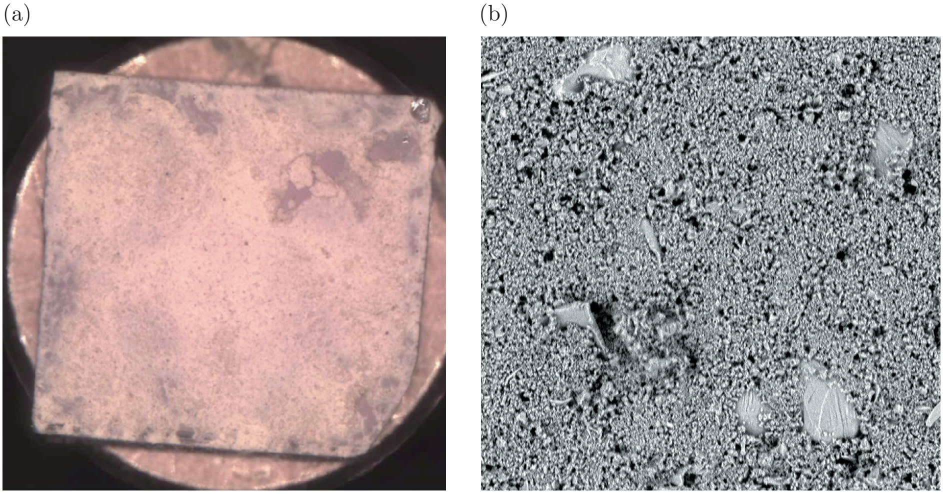

Figure 3. Image of the surface of calcareous groats zoomed by 1100 using the Phenom Pro X Scanning Electron Microscope

Figure 4 presents the results of the measurements of a chemical microanalysis of calcareous groats made by Energy Dispersive X-Ray Spectroscopy in conjunction with Scanning Electron Microscopy. The analyzed substance is formed by mineral particles with the grain diameter smaller than 1.8 mm and the average particle diameter equaling 240 microns. Chemically, calcareous groats mostly consist of calcium oxide.

The second substance used in the experiment is sodium water glass, known also as liquid glass (Na_2SiO_3). It is an aqueous solution of sodium silicate resembling the characteristics of a colloid or a polymer. Its main task as a deflocculant is to push away the suspended particles contained in the hydromixture and increase its fluency. The sodium water glass has the appearance of a colorless thick liquid with high viscosity. Its average density is equal to 2.61 g/cm^3. The solubility of sodium water glass in water is at the level of 22.2 g/100 ml (25°C).

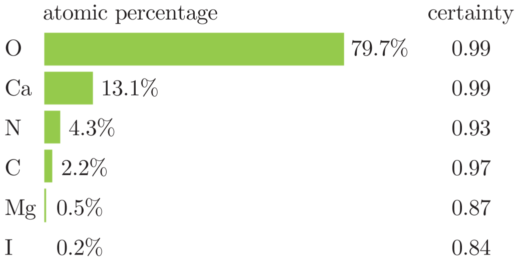

Figure 4. Chemical composition of calcareous groats made by Energy Dispersive X-Ray Spectroscopy

5. Experimental studies

The published research results were prepared in the Laboratory of Rheology at the Kielce University of Technology. The device used in the experiments was an Anton Paar MCR 302 rotational viscometer. The measurements were taken in systems of coaxial cylinders with the measuring gap equal to 1.1 mm for samples of the 18 ml volume at the temperature of 20°C. The experimental studies included investigations of the influence of varied doses of deflocculants on the rheological properties of the hydromixture.

A mixture of two deflocculants was applied in doses of 0.1%, 0.2%, 0.3%, 0.4% and 0.5%, according to the dry mass of the hydromixture in three different proportions. Studies were carried out for a hydromixture with two mass concentrations: 20% and 43% after 10 seconds of mixing with $\frac{\partial U}{\partial y} = 200$ (1/s). Measurements of shear stresses versus shear rates were performed in the range from 1 to 1000 (1/s).

6. Results of measurements

The paper presents the results of measurements of two deflocculants: sodium water glass denoted as d_1 and calcareous groats denoted as d_2 and their influence on the wall shear stress in the tested hydromixture. The measurements confirmed that the hydromixture was a non-Newtonian fluid and could be described by the Bingham model.

The figures show the dependence of the wall shear stress in the hydromixture with the mass concentration of 20% (Figure 5) and 43% (Figure 7) after application of different samples of deflocculants. The added doses were in the range from 0.1% to 0.5% for three values of shear rates, equal to (200; 600; 1000) (1/s) after 10 seconds of mixing at $\frac{\partial U}{\partial y} = 200$ (1/s).

On the basis of the experiments, we can conclude that considering the samples of deflocculants added to the hydromixture with the mass concentration of 20%, made in three proportions, it is clear that the deflocculant sample with the proportion of $\left(\frac{1}{3}d_1 + \frac{2}{3}d_2\right)$ gives the lowest wall shear stress if the deflocculant doses are in the range from 0.1% to about 0.3%. The same effect can be observed for all the chosen shear rates. However, in the range of deflocculant doses from

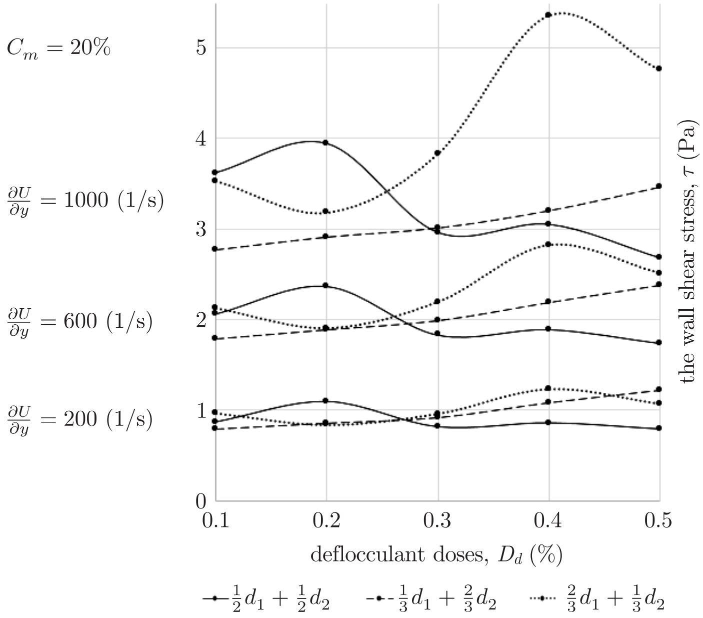

Figure 5. Dependence of the wall shear stress values for chosen shear rates after application of different samples of deflocculants in a hydromixture with 20% mass concentrations

0.3% to 0.5%, the lowest wall shear stress values were obtained for the sample of $\left(\frac{1}{2}d_1+\frac{1}{2}d_2\right)$ for all values of the chosen shear rates.

Figure 6 presents the dependence of the wall shear stress versus the shear rate for a hydromixture of 20% of mass concentration after addition of deflocculants in the proportions of $\left(\frac{1}{2}d_1+\frac{1}{2}d_2\right)$, $\left(\frac{1}{3}d_1+\frac{2}{3}d_2\right)$ and $\left(\frac{2}{3}d_1+\frac{1}{3}d_2\right)$.

As we can see in Figure 6 (a), the addition of deflocculants in the proportion of $\left(\frac{1}{2}d_1+\frac{1}{2}d_2\right)$ and at a dose from 0.1% to 0.2% in relation to the dry mass included in the hydromixture does not improve its fluency but even worsens it. It is only higher doses of deflocculants that cause a reduction of the wall shear stress in a wide range of the shear rates. After application of 0.5% of deflocculants, we can observe the largest decrease in the shear stress. Application deflocculants in the other two proportions does not improve the rheological properties of the hydromixture in such a significant way.

The influence of chosen deflocculants on the shear stress is complex and strongly depends on the solid mass concentration of the hydromixture. The presented results of experiments for a hydromixture with 43% of the solid mass concentration show that the lowest wall shear stress refers to the addition of $\left(\frac{2}{3}d_1+\frac{1}{3}d_2\right)$ for doses of 0.1% to 0.4% and $\left(\frac{1}{2}d_1+\frac{1}{2}d_2\right)$ for deflocculants doses of 0.5% (Figure 7).

In both cases ($C_m = 20\%$ and 43%) the lowest value of the wall shear stress was obtained for the deflocculant sample equal to $\left(\frac{1}{2}d_1+\frac{1}{2}d_2\right)$ and for the dose of up to 0.5%.

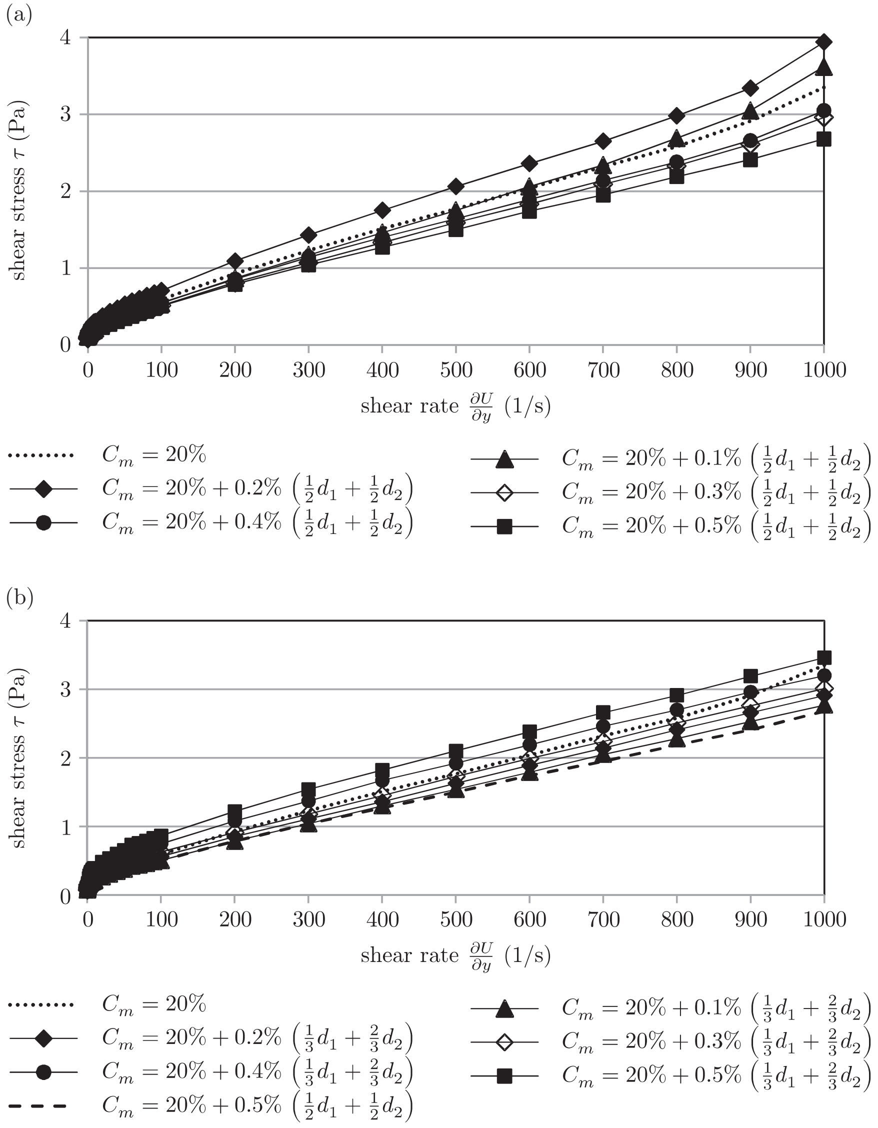

Figure 6. Flow curves of hydromixture with $C_m = 20\%$ after addition of 0.1–0.5% of deflocculants in proportion of: (a) $\frac{1}{2}d_1 + \frac{1}{2}d_2$, (b) $\frac{1}{3}d_1 + \frac{2}{3}d_2$

The results of measurements for higher mass concentration of the hydromixture ($C_m = 43\%$) point out to a clear decrease in the shear stress for all doses of deflocculants in the full range of shear rates. The best influence on the decrease in the shear stress can be noticed for the dose of 0.5% of sodium water glass and calcareous groats in relation to the dry mass of the hydromixture in the proportion of $\left(\frac{1}{2}d_1 + \frac{1}{2}d_2\right)$. Figure 8 presents data demonstrating shear stress values in a hydromixture after application of deflocculants in the proportions of $\left(\frac{1}{3}d_1 + \frac{2}{3}d_2\right)$ and $\left(\frac{2}{3}d_1 + \frac{1}{3}d_2\right)$.

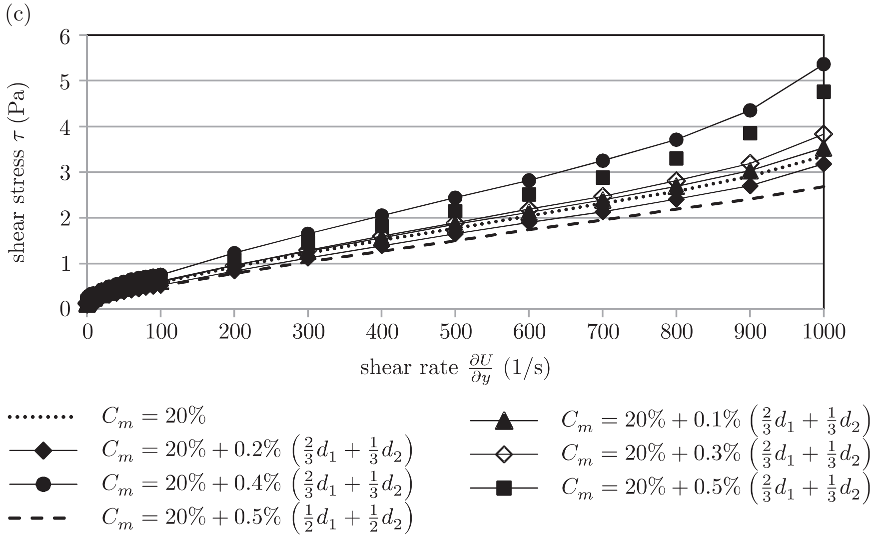

Figure 6 – continued. Flow curves of hydromixture with $C_m = 20\%$ after addition of 0.1–0.5% of deflocculants in proportion of: (c) $\frac{2}{3}d_1 + \frac{1}{3}d_2$

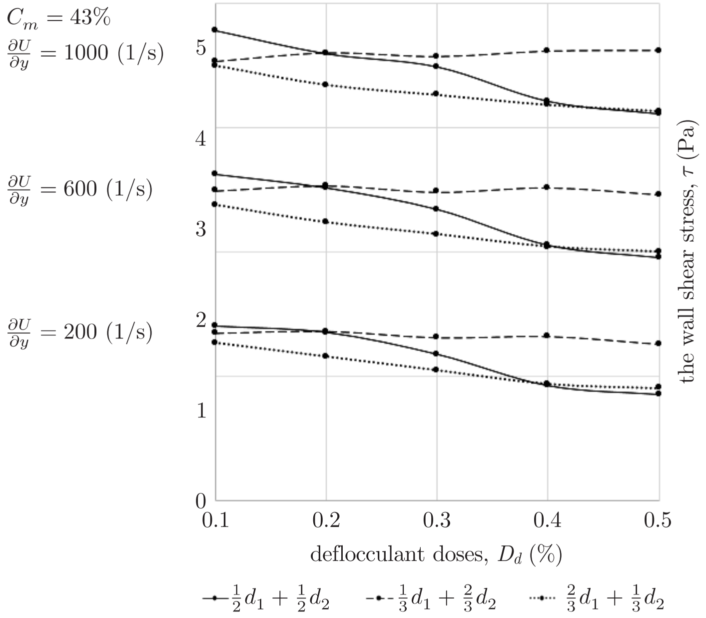

Figure 7. Dependence of the wall shear stress values for chosen shear rates after application of different samples of deflocculants in hydromixture with 43% of mass concentrations

7. Conclusions

The presented results of experiments have confirmed that the influence of deflocculants on the wall shear stress depends on the proportion of deflocculant samples and the mass concentration of the hydromixture. The received data shows

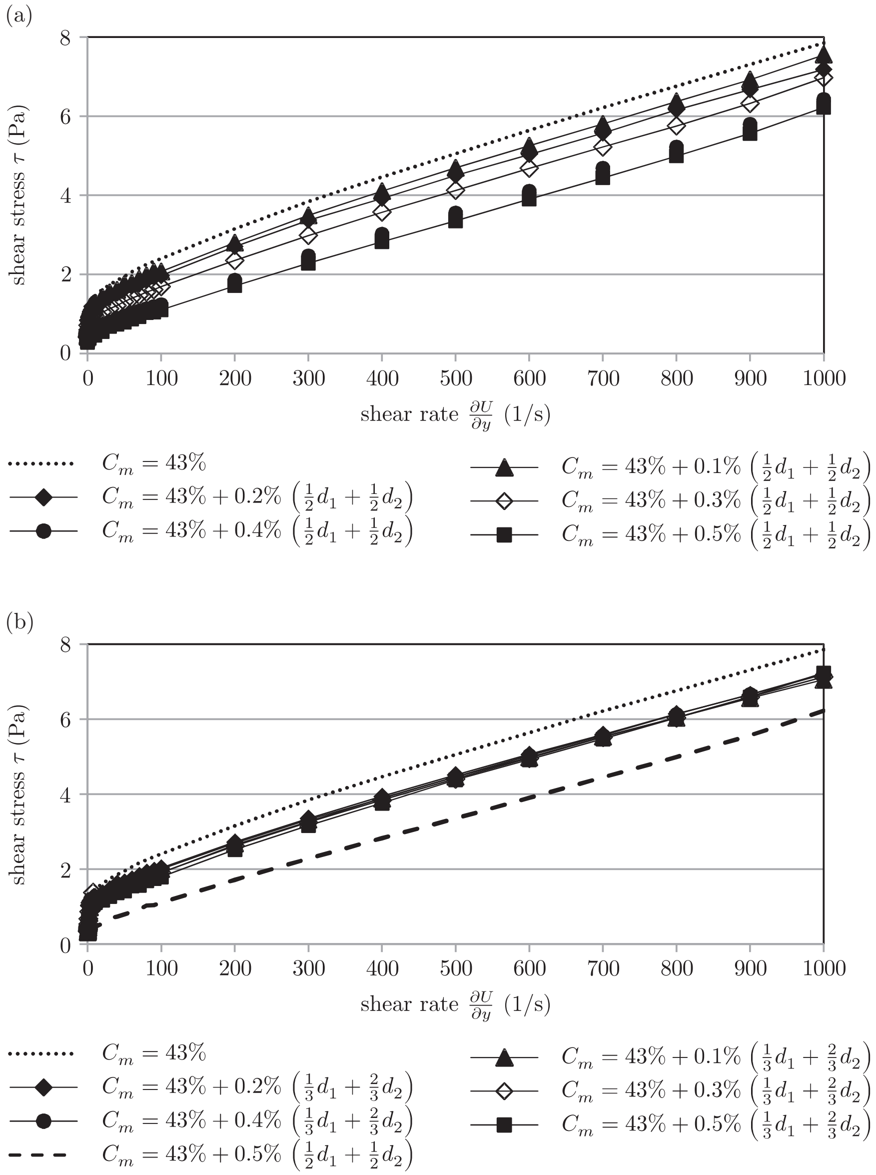

Figure 8. Flow curve of hydromixture with $C_m = 43\%$ after addition of 0.1–0.5% of deflocculants in proportion of: (a) $\frac{1}{2}d_1 + \frac{1}{2}d_2$

an observable decrease in viscosity and the wall shear stress in a full range of shear rates after application of 0.5% of deflocculants to the hydromixture in the proportions of $\left(\frac{1}{2}d_1 + \frac{1}{2}d_2\right)$ by mass. This phenomenon is the same for both mass concentrations: 20% and 43%.

The tested hydromixture is shear-thinning and its pseudo-plasticity increases with increasing the concentration of solids. The addition of a deflocculant

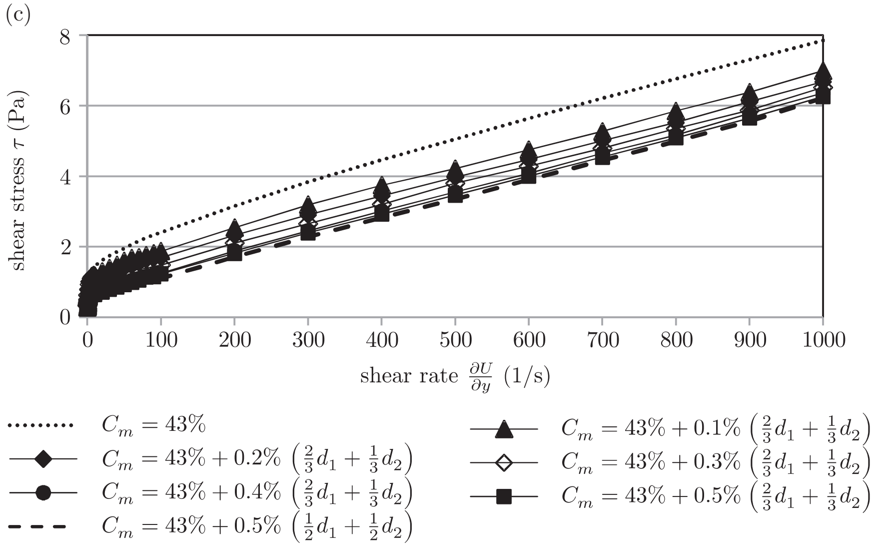

Figure 8 – continued. Flow curve of hydromixture with $C_m = 43\%$ after addition of 0.1–0.5% of deflocculants in proportion of: (c) $\frac{2}{3}d_1 + \frac{1}{3}d_2$

in a suitable composition improves its flow ability by decreasing its viscosity and improves the energy efficiency of the hydromixture transport.

The presented solution causes a reduction in the wall shear stress in a hydromixture flow of about 20%. Therefore, it is possible to decrease the energy consumption for further transportation of the hydromixture and decrease the volume of water that serves as the carrier liquid of the solid phase.

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