

## Rheological analysis of an effect of different deflocculants on the fly-ash slurry

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**Abstract.** During the combustion of coal in the combined heat and power plant (CHP), a very large amount of combustion waste, called further as a fly-ash, is produced. It is typical that fly-ash appears during the combustion process of the fine coal and is transported by a pipeline with support of water as a carrier liquid to a pond storage site, where it is disposed. The pond is localized usually a few kilometers from the CHP, which makes it possible that decrease of friction in such a pipeline can result in energy savings of electricity needed for the pump and water needed as a carrier liquid. In the study an efficient method using a few deflocculants for reducing shear stress, and as a consequence viscosity, is demonstrated. The objective of the paper is to improve the efficiency of the hydrotransport of the fly-ash slurry by adding own designed additives. During the experiments a solids concentration by weight was determined from procured raw material in order to compute the real value occurring in industrial conditions. In addition, the analysis of the particle size distribution was conducted. The Anton Paar MCR 302 electronic rheometer was used to measure the dependence of shear stress and viscosity vs shear rate in the fly-ash existing in the CHP. Another part of the analysis was focused on the additives (deflocculants), to examine their influence on the reduction of the shear stress. The paper proves positive deflocculants impact on the rheological properties of the fly-ash slurry. The results of measurements are presented as figures and conclusions.

### 1. Introduction

Poland is the sixth energy producer in the European Union. In order to obtain energy, more than 75 million tons of coal and over 64 million tons of lignite (brown coal) were used in 2012. The energy balance of both of these resources makes up almost 90% of the all fuel consumed energy. The combined heat and power plants (CHP) used over 40 million tons of coal in 2012 [1]. During the combustion of coal in the CHP, a very large amount of combustion waste, called further as a fly-ash, is produced.

The CHP Kielce (Elektrociepłownia Kielce) in Poland production potential of thermal energy is provided by boilers as follows:

- water-coal boiler WP-140 with a thermal power of 140 MW,
- five water-coal boilers WR-25 with a thermal power of 29 MW each.

Total installed thermal performance in CHP Kielce is 286 MW. However, since 2008 the CHP has been operating a new power unit with a power of 10.5 MW, which uses as fuel wood chips and coal.

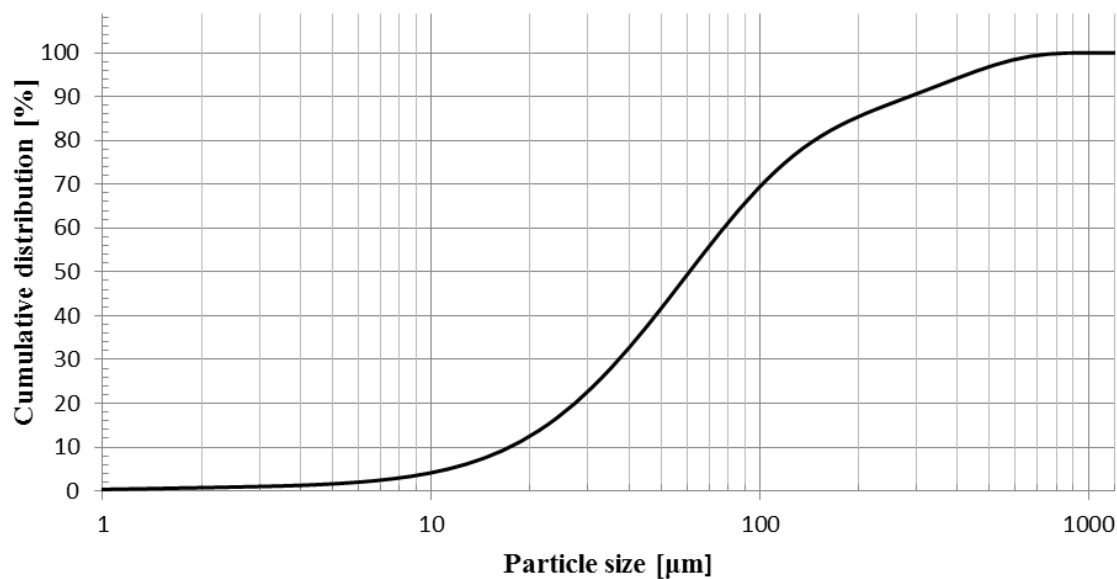


The boiler WP-140 works with an electrostatic precipitator - device that reduces dust emission with the efficiency of 99.5%. In addition, the boiler collaborates with the installation for reducing emission of nitrogen oxides by 40%. The fly-ash that appears during the combustion process of fine coal in WP-140 boiler is transported by a pipeline with support of the water as a carrier liquid to a pond storage site, localised far from the plant, where it is disposed. The pipeline has a length of 1.5 km and a diameter of 250 mm. As the carrier liquid, technological waste water is used, which comes from an industrial and rain sewage treatment plant. The far location of the pond causes a huge consumption of the energy to transport such large quantities of waste. It is seen that in 2011 the amount of 680 Mg of ash was deposited at the storage site, while in 2012 even 1680 Mg. The decreasing of friction in such pipeline can result in energy savings of electricity needed for the pump and water needed as a carrier liquid.

The main objective of the research is to examine the influence of chosen deflocculants for reduction of the shear stress in fly-ash slurry in one of the CHP. The deflocculants are the chemical additives which cause increased liquidity. In the study, own designed additives, as deflocculants, were used.

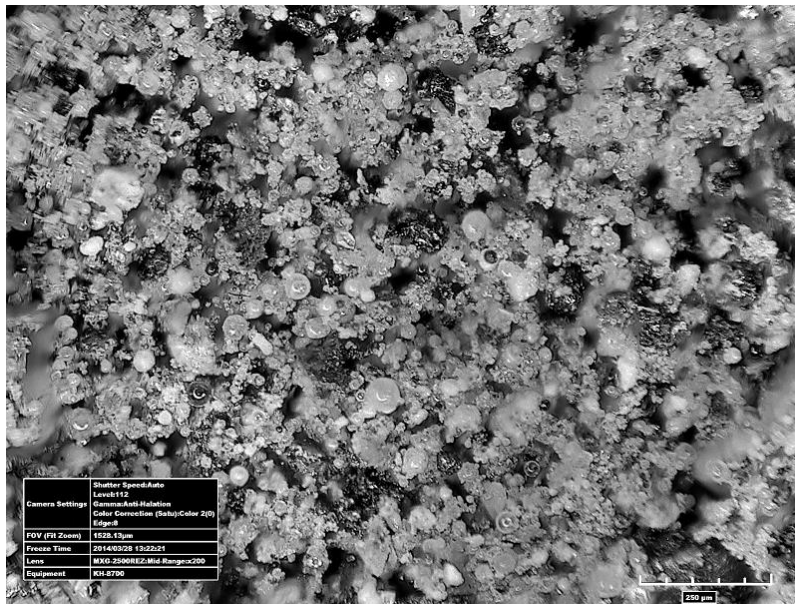
## 2. Raw material

The fine-ash sample was taken in CHP Kielce from the pipeline at the downtime period. Unfortunately such samples possess rust with a large diameter. This required screening of the material to avoid damage of the measuring equipment, so the tested raw material was dried and sieved to avoid big pieces of the rust. The sieve diameter was 1 mm. Determined density of the fly-ash particles was equal to  $2350.3 \text{ kg}\cdot\text{m}^{-3}$ . The size distribution of the ash particles was measured using the Malvern Mastersizer 3000 laser diffraction particle size analyser. The weighted-average particle diameter of the sample was determined to be  $60.98 \text{ }\mu\text{m}$ . The particle size distribution is shown in figure 1.



**Figure 1.** Particle size distribution.

In addition, the fly-ash grains were measured in microscope. Figure 2 shows the fly-ash in 200x magnification.



**Figure 2.** The fly-ash grains in 200x magnification.

### 3. Experimental procedure

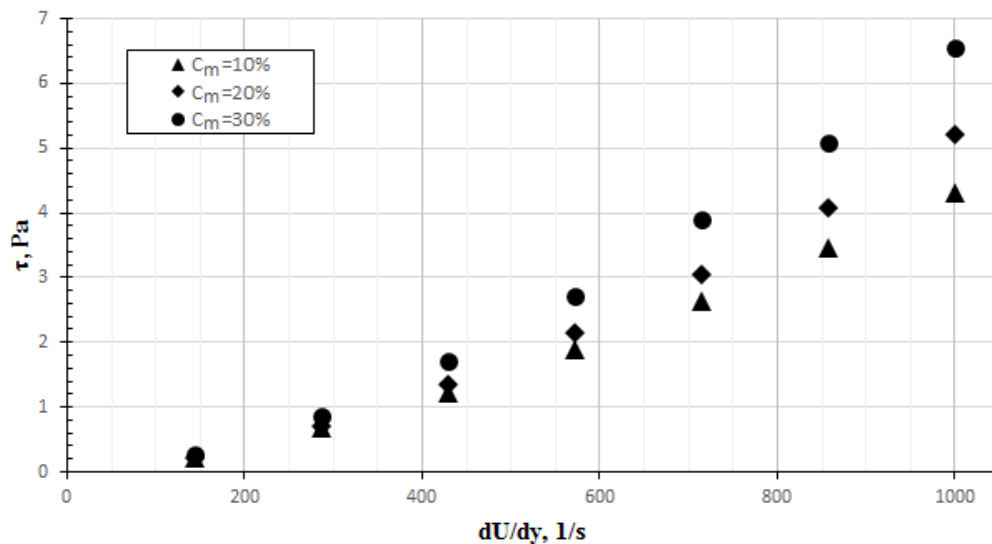
In the preparation of fly-ash slurry sample of a known solid content, dry fly-ash and tap water were mixed to obtain the desired solid concentration. The sample preparation procedure was similar to Naik, Mishra and Rao Karanam methodology [2]. Solids concentration was calculated as a ratio of mass of solid particles to total mass of slurry, which is the sum of solid particles and liquid phase. For the tests, 500 ml of the fly-ash slurry was prepared by mixing an appropriate amount of the fly-ash and tap water in the beaker. The fly-ash was weighted by the laboratory balance with a resolution of  $10^{-3}$  g. The slurry was mixed about 2 minutes and then the beaker was covered by the PP film to prevent evaporation of water from the slurry. The sample was allowed to wet for at least one hour before the measuring tests to ensure release of entrapped air. Before tests, the slurries were always stirred to ensure homogeneity of the sample slurry. In the case when a deflocculant was added, a dose of the additive was added in the slurry before the 2 minute mixing procedure. The deflocculant dose was appointed as a 0.2% of the dry fly-ash (mass of solid particles).

Determination of rheological properties was performed using the Anton Paar MCR 302 electronic rheometer. The shear stress and viscosity at specific shear rates were measured. To provide accurate results, CC27 measuring system with coaxial cylindrical geometry was used for the study. The gap between cylinders was equal to 1.1 mm. All experiments were performed at temperature of 20 °C. The measuring system required about 18 ml of a sample, which was taken from the previously prepared 500 ml sample.

First, the fly-ash slurry rheological properties were measured at different solids concentration,  $C_m=10\%$ , 20%, 30% by weight to determine the reference values of the sample. Afterwards, the slurry with the 10%, 20% and 30% solids concentration with the different deflocculants were tested. Considering the nature of the slurry our measurements were analysed at the shear rates from  $144\text{ s}^{-1}$  to  $1000\text{ s}^{-1}$ . To avoid sedimentation process, which naturally exists in such type of slurry with fine solid particles, each slurry sample in the measuring cup was pre-sheared for 30 seconds at the  $1000\text{ s}^{-1}$  shear rate prior to the measurements. Afterwards, the measurement started from the highest setpoint value and stepped down linearly one by one until the shear rate reached the minimum setpoint value, which was  $144\text{ s}^{-1}$ . The results of measured shear stress ( $\tau$ ) and viscosity ( $\eta$ ) were recorded at each share rate ( $dU/dy$ ).

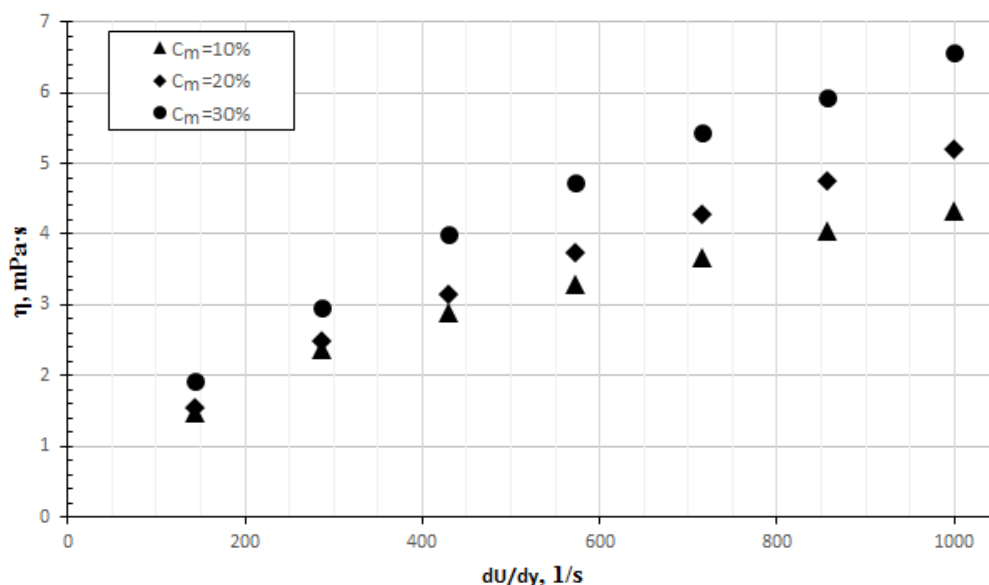
#### 4. Experimental results and discussion

For each concentration of solid particles the variation of the shear stress with the shear rate was measured. Figure 3 shows the flow curves for the  $C_m=(10-30)\%$ .



**Figure 3.** Dependence of the shear rate on shear stress at different solids concentration for fly-ash slurry.

The flow curves presented in figure 3 are dilatants (shear thickening). It was observed that the shear stress increased with the increase of shear rate non-linearly. It can be also seen that the shear stress increased with the increase of solids concentration. The difference is more visible at higher shear rates values. Below  $300 \text{ s}^{-1}$  of shear rate the shear stress is less than 1 Pa. The phase separation process in the experiments at high shear rate values, similar to the limestone slurry measurements, was not noticed [3].

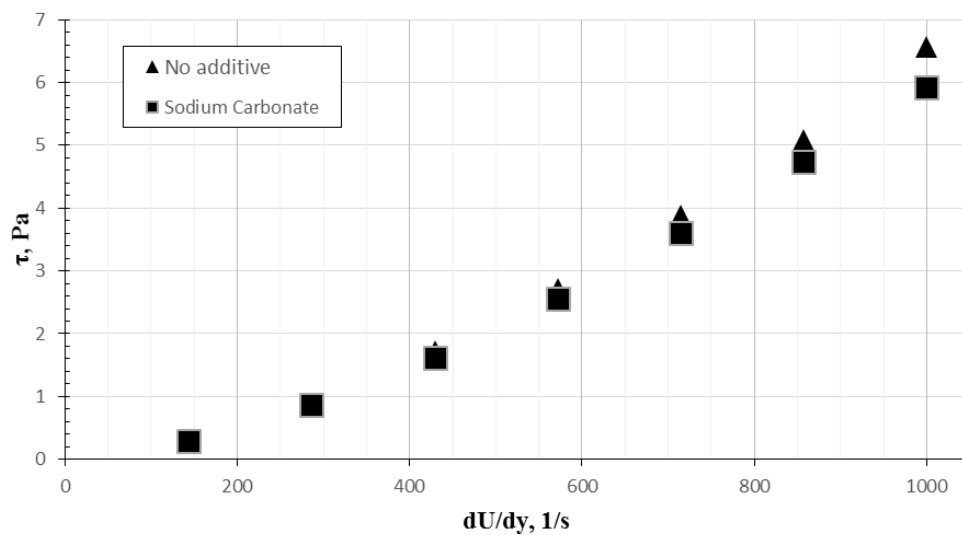


**Figure 4.** Dependence of the shear rate on viscosity at different solids concentration for fly-ash slurry.

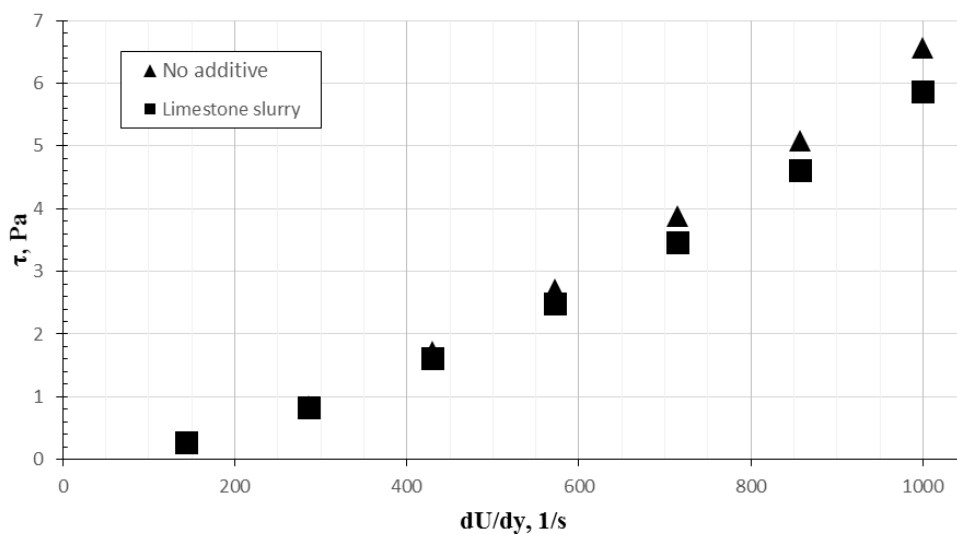
The viscosity curves at different solids concentration are shown in figure 4. The shear thickening occurrence was confirmed. The viscosity is increasing with the increase of shear rate but the rate of these changes is decreasing with the shear rate increase. It was also observed during the measurements that viscosity increased with the increase of solids concentration.

The shear stress and viscosity values, presented in the paper, are significantly smaller than in the fly-ash slurry measurements done by Naik et al. [4]. They found the shear thinning and the viscosity nature of both fly-ash slurries samples is different. Occurrence of such differences proves that coal dust can have different rheological properties that depend on production facility or quality of the dust precipitator performance as well.

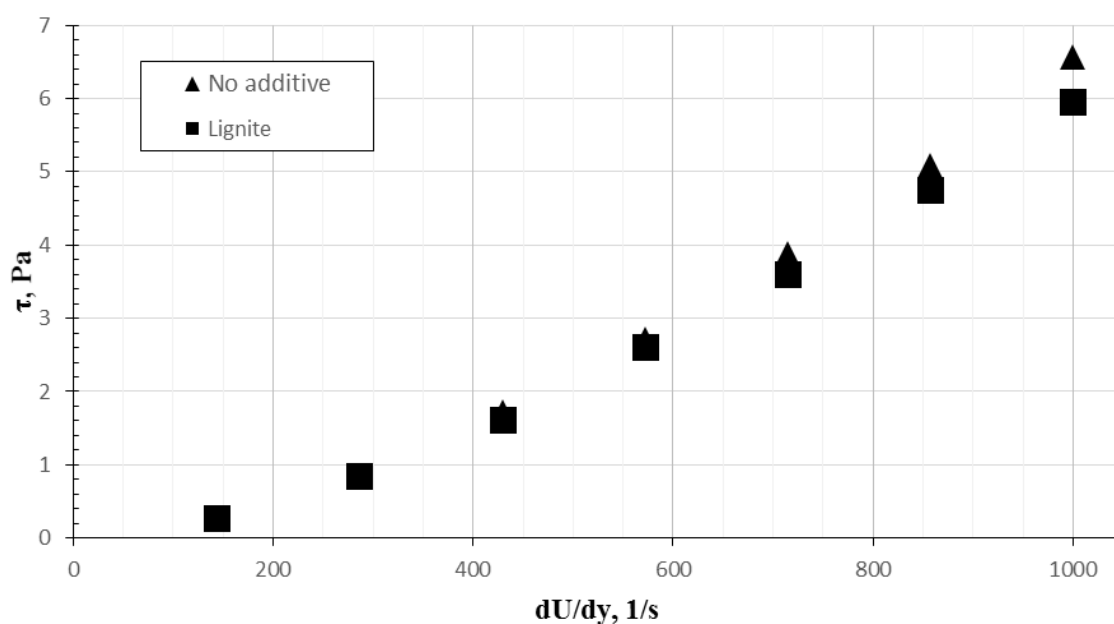
Chemical additives (deflocculants) were added to the fly-ash slurry to increase its liquidity. Deflocculants were dosed in portion of 0.2% of the solid mass of the fly-ash slurry. Sodium carbonate, limestone slurry (70% wt.), lignite and sodium salicylate were selected as a potential effective deflocculants. The results of measurements of the shear rate versus the shear stress for fly ash slurry, with and without aforementioned additives, are presented in figures 5-8.



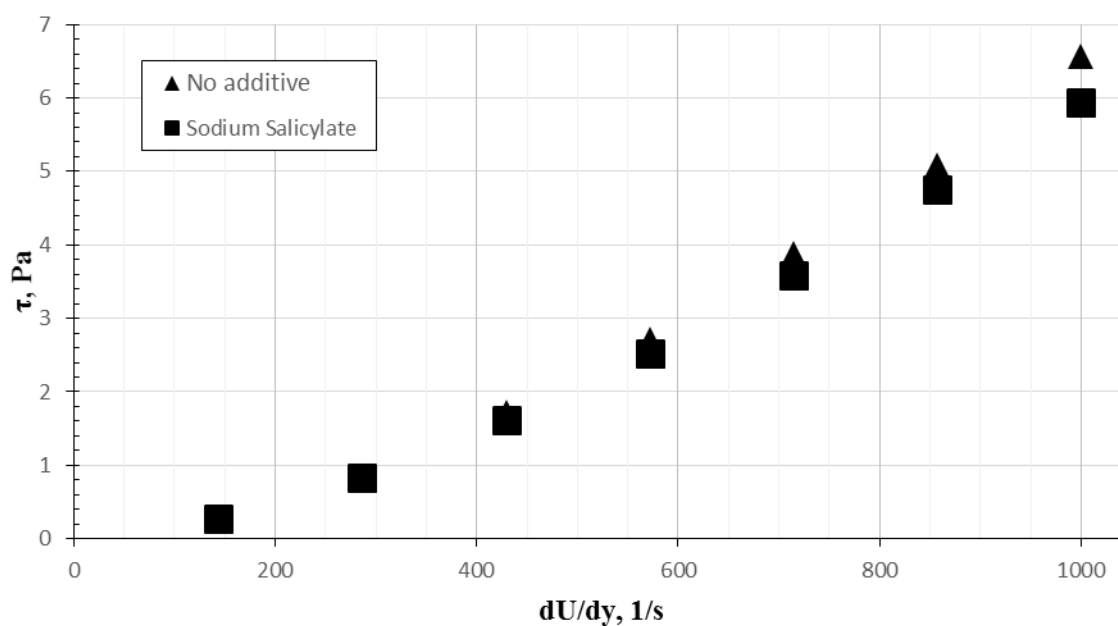
**Figure 5.** Flow curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of sodium carbonate.



**Figure 6.** Flow curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of limestone slurry.



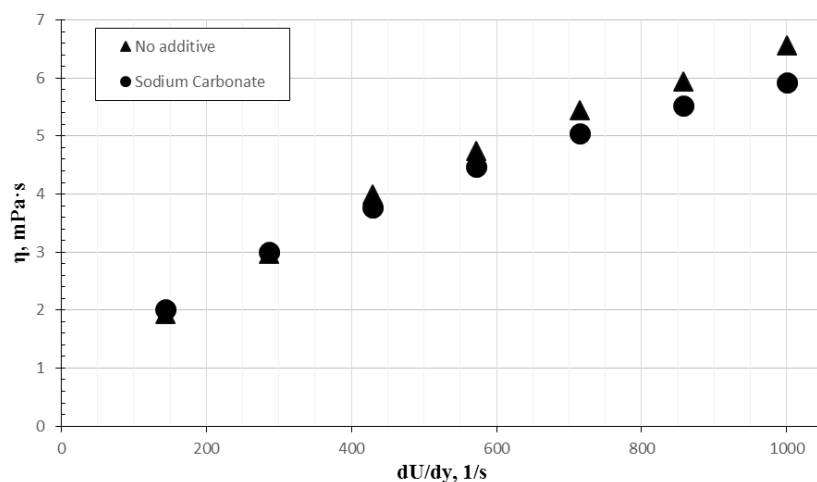
**Figure 7.** Flow curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of lignite.



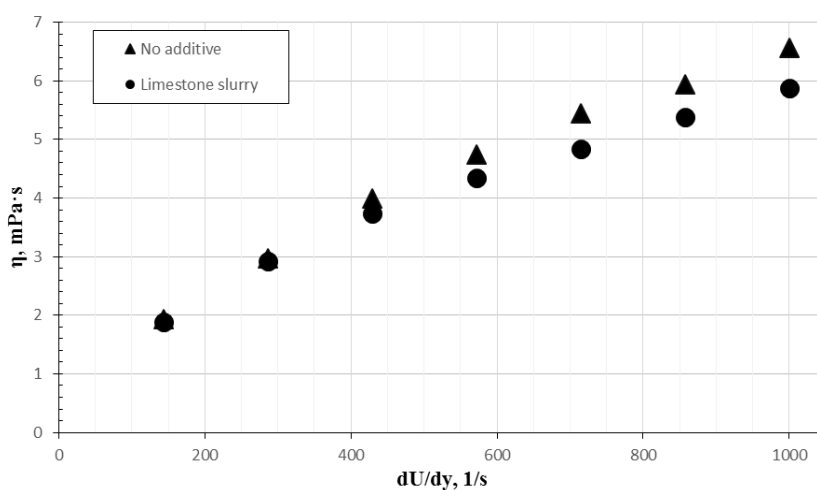
**Figure 8.** Flow curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of sodium salicylate.

The addition of selected deflocculants demonstrates small influence on reduction of the shear stress. The decrease in the shear stress ranged from 9% to 11% for the highest shear rate values. For the lower shear rate values gain from adding deflocculant is not clearly visible.

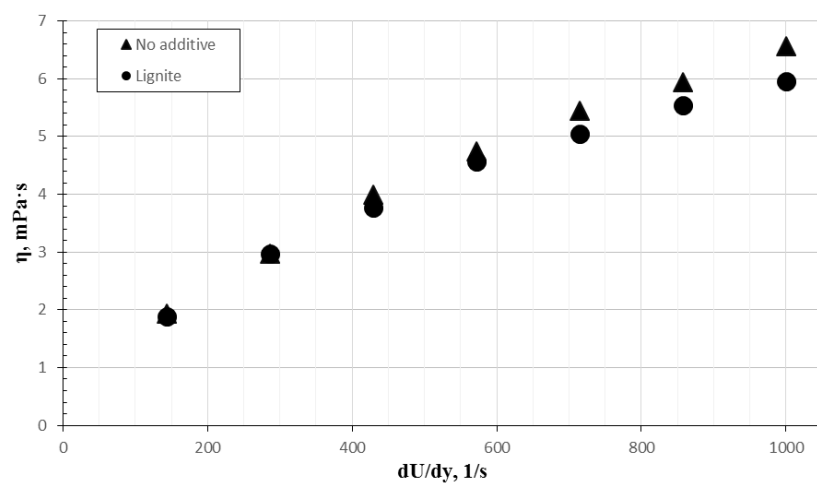
The influence of additives on viscosity is better visible, compared to the shear stress. For this reason calculations of viscosity with and without chemical additives are presented in figures 9-12.



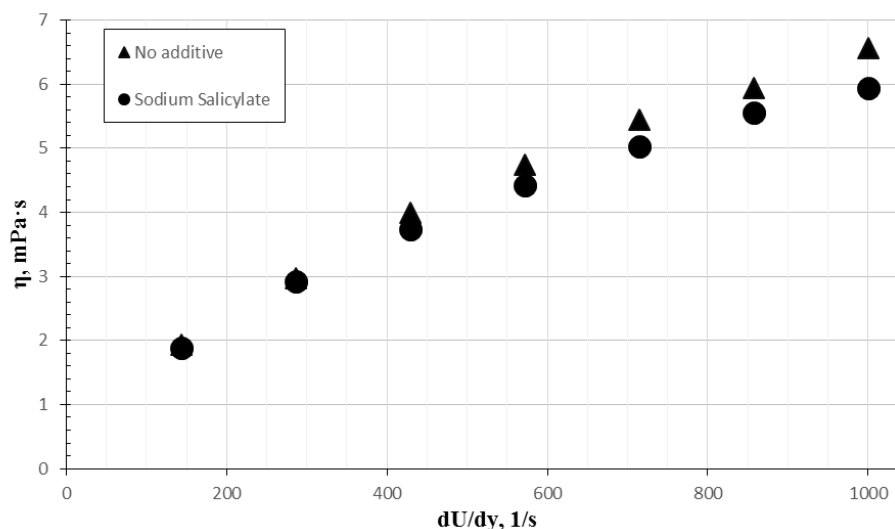
**Figure 9.** Viscosity curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of sodium carbonate.



**Figure 10.** Viscosity curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of limestone slurry.



**Figure 11.** Viscosity curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of lignite.



**Figure 12.** Viscosity curves of the fly-ash slurry for  $C_m=30\%$  and with 0.2% additive of sodium salicylate.

The results confirmed a weak influence of selected additives on the rheological properties on the fly-ash slurry. This is in contrast with measurements for sand slurries. Appearance of shear thickening causes those chemical additives, which successfully decrease the shear stress in sand slurries, not to work well in the fly ash slurry.

## 5. Conclusions

The effect of deflocculants additives on the rheological behaviour of the fly-ash slurry was examined experimentally. Experiments were performed at the shear rates possible to appear in the industrial conditions. Tested additives gave a small but positive influence on decreasing the shear stress and the viscosity. The addition of one component provides too weak benefits to allow their implementation in the industry. The more effective way to increase liquidity seems to be the application of cationic surfactant and counter-ion which has been proposed by Naik et al. [4] and would be the next step in further research.

Measurements of fly ash slurries are extremely difficult as they require a special treatment before measurements. For this reason many researchers prefer a tube viscometer for determining rheology of such slurries [5], [6].

## 6. References

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