INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr 11/2011, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 109–117
Komisja Technicznej Infrastruktury Wsi
Commission of Technical Rural Infrastructure, Polish Academy of Sciences, Cracow Branch

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PRELIMINARY RESEARCH ON THE EFFECT OF LIME ADDITION ON THE RHEOLOGY OF SLUDGE

Summary

Samples of excess sludge from wastewater treatment plants were investigated in order to determine the dependence of rheological parameters of sewage sludge on lime addition. Hydration of the sludge is one of its main features which determine sludge management and waste disposal cost. The rheological behavior of sludge is a key characteristic, since it determines the treatment processes. This research has evaluated the use of rheological properties for characterization and control of sludge and lime mixture flow behaviour. A laboratory investigation was conducted using rotating coaxial cylinder and several different gravimetric concentrations of the investigated sludge. In order to describe the rheological characteristics, the 3-parameter Herschel–Bulkley model was applied. Rheological characterization is of great importance in sludge management, both in terms of biomass dewatering and stabilizing properties, and in terms of design parameters for sludge handling operations.

Key words: sludge treatment, lime, rheology, flow curve, rheological model, rheological parameters

INTRODUCTION

Wastewater treatment is inseparably connected with sludge production. The sewage treatment product is a highly hydrated sludge. Purified municipal waste is composed in 1–2 % of such a sludge. However, despite its little content in sewage, it contains half of the pollutants load; therefore its utilization is a major workability problem in wastewater treatment plants (WWTPs). Its chemical and physical constitution depends on the sort and amount of contaminants put into the sewage and the purification processes applied. The constitution depends on the method of sludge stabilization and also on its disposal and utilization. Hence, sludge chemical constitution depends on the sort and amount of impurities being removed and determines the treatment process as well as its stability [Dentel, 1997, Forster, 2002, Kempiński et al., 2005, Moeller et al., 1997, Nagaoka et al., 1996, Sanin, 2002]. Sludge is quite a difficult material to characterize in a quantitative manner. According to the basics, it is a two-phase mixture. Therefore, the intermolecular attraction and repulsion of dispersed particles, as well as chemical bonds, influence its properties. The presence of these forces determines the constitution, shape and structure of the sludge [Sozański, 1988, Tixier et al., 2003, Tal-Figiel et al., 2002].

The rheology describes the deformation of a body under the influence of stress. The shear rate of Newtonian fluids is linearly related to the shear stress. The sludge, however, is a non-Newtonian fluid because the relationship between the shear rate and shear stress is non-linear, and a sludge apparent viscosity changes with the shear rate (flow velocity). Therefore the rheological measurements should be considered in hydraulic calculations to estimate head loss and optimization of technological processes. The non-Newtonian characteristics of the sludge have been extensively investigated under steady flow conditions. According to some authors [Battistoni, 1997, Dentel, 1997, Lotitoet al., 1997, Moeller et al, 1997, Sozanski, 1988,Tixier et al., 2003], sludge is characterized using different rheological models. Moreover, some authors, like Honey et al [2000], have indicated that sludge is time-dependent (thixotropic) – shear stress reduces with duration of shear, what complicates its detailed characterization. The presence of hysteresis in flow curves is most frequently explained by disintegration of internal structure of the liquid suspension as a result of shear stress operation [Aranowski et al., 2010].

Sludge is often highly viscous, exhibits high shear stress especially when it is highly concentrated [Malczewska, 2008, Sanin, 2002]. Decreasing water content and thus increasing sludge concentration has lately been introduced in order to limit the overall unit cost in slurry pipeline technology. The rheological investigation is particularly useful for assessment of sludge structure changes during treatment [Abu-Orf et al., 1997, 2003, Ayol et al., 2005, Bache et al., 2000, Battistoni, 1997, Bień et al., 2001, Forster, 2002, Heywood, 2008, Kopp et al., 2000, Lotito et al., 1997, Mikkelsen, 2001, Moeller, 1997, Slatter, 1997], especially in case of sludge thickening, which causes difficulties in pump operation and hydraulic transport [Forster, 2002, Honey, 2000, Heywood, 2008, Spinosa et al., 2003, Wolny et al., 2008]. The tendency of increasing slurry content was investigated by Heywood and Slatter [Heywood, 2008, Slatter, 1997]. The sludge rheology has recently been found used as a tool for assessment and control of chemical conditioning process [Bień et al., 2001, Wolny et al., 2008]. The quantity of polymer required for impurities removal is minimized with effective mixing and flocculation. A number of papers have been devoted to exploring the correlation between rheological characteristics of sludge and sewage sludge conditioning [Ayol et al., 2005, Bache et al., 2000, Bień et al., 2001, Wolny et al., 2008]. Selection of lowest acceptable chemical dose using rheological parameters as a control tool has been proposed [Bień et al., 2001, Wolny et al, 2008]. This can lead to potential savings from reduced chemical consumption, according to the industry demands.

Sludge can be stabilized with several different methods including: sedimentation, mesophilic or thermophilic anaerobic digestion or composting, storing as well as combinations of these methods. The technical capability to use lime in order to destroy pathogens is based on the generation of thermal conversion in hydration of calcium oxide with water enclosed in the sludge. Lime compounds are used in many countries for disinfecting sludge, and were proven efficient in removing *E. Coli* and *Salmonella Spp*. Hydrated lime suspensions are used as an addition to sludge to achieve compliance with valid regulations regarding agricultural utilization, which is the most restrictive among the methods used. The use of lime for dewatering in sewage sludge treatment in order to produce a sludge cake is a typical practice, although lime pre-treatment is also used. The use of lime to stabilize sludge has been well documented and reported [ASTM D 1990, BLA 2007, EPA 2007, Nagaoka, 1996].

Particle size distribution is influenced by the treatment process. Thermal alkaline hydrolysis generally reduces the particle size. Both sewage sludge and liquid lime are non-Newtonian fluids. Lime is a typical shear thinning fluid [BLA 2007]. Sewage sludge is known as pseudoplastic fluid. However, solids concentration has the most significant impact on sludge behaviour. Therefore sludge samples, depending on their concentration, can behave like non-Newtonian or Newtonian fluid. The variability of viscosity is the result of structure changes proceeding in the sludge during the flow [Kempiński et al., 2005, Malczewska, 2008, 2009].

This paper presents preliminary research concerning the impact of addition of lime compounds to the sludge on changes in the flow properties of lime and sewage sludge mixture. Adding soluble lime compounds to sewage sludge can result in substantial increase in dry solids content. Rheological investigation can contribute to dewatering optimization.

Rheological characterization is of crucial importance in sludge management, both in terms of biomass dewatering and stabilization properties, and in terms of design parameters for sludge handling operations [Laera et al, 2007].

MATERIALS AND METHODS

Sludge samples were taken from municipal WWTPs after sewage digestion but before mechanical dehydration. Adding lime compounds to the sludge prior to disinfection increases both pH of the mixture and sludge concentration, which has a significant effect on yield stress. The yield stress increases with solids concentration, therefore it contributes to technological problems in pumping and transport.

The mixing methods can fall in one of two categories. One of them is dosing into stirred tanks and another is injecting into pipes [BLA 2007]. Adequate mixing of lime-sludge mixture must be attained. The analyzed samples were chemically stabilized after preliminary dehydratation. The mixing method was to dose CaO into stirred tanks.

Rheological measurements were carried out after sampling. The measurements were carried out using a VT550 viscometer (manufactured by Haake) with rotating coaxial cylinder. The temperature was stabilized with a thermostat. The viscometer enabled to measure the flow curves for a wide range of deformation velocity and shear stress. The coaxial cylinders were of various diameters. The measurement system MV1 P with measuring gap width 0.96 mm was used. The rheological tests were carried out at the shear rate from 300 to 0 s^{-1} and from 0 to 300 s^{-1}. The investigation has been performed according to the method described in paper [Kempiński et al., 2005]. The data were interpreted using Herschel–Bulkley's model.

RESULTS AND DISCUSSION

Sludge can be utilized agriculturally provided it is stabilized and disinfected. Adding lime compounds is a typical wastewater disposal practice. Lime addition influences flow behaviour, therefore it has an impact on sludge rheological behaviour (Fig. 1).

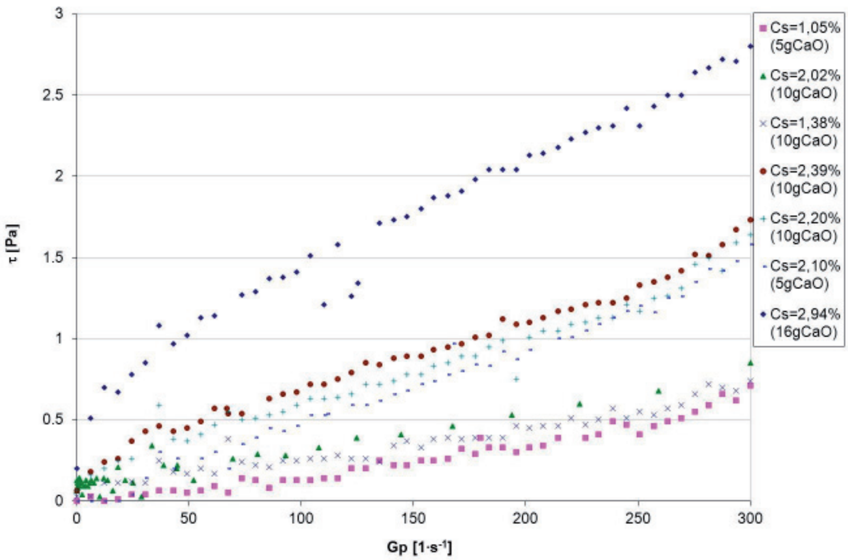

Figure 1. Relationship $\tau = f(Gp)$ for various gravimetric concentrations (Cs) and added CaO

Lime dose in treated sludge exhibits a higher shear requirement than untreated sludge. The apparent viscosity of the sludge increases with increasing solids concentration [BLA 2007]. The increase of stress depends on solids concentration and lime addition. A comprehensive assessment of lime compounds and its influence on sludge can be found in [BLA 2007].

Results indicated that the yield stress was present in a range of analysed gravimetric concentrations. The yield stress is described as a stress to be exceeded to form a fluid flow. It has a substantial influence on the resistance and thus on maintenance costs. Sludge samples exhibited yield stress that exhibited a power dependence on concentration. The apparent viscosity rapidly decreases with increasing shear rate.

This research also showed that the sludge exhibited pseudoplastic behaviour, which supports the research [Forster, 2002, Sanin, 2002, Slatter, 1997]. Figure 1 presents a typical sludge pseudoflow curve.

Selection of the rheological model was performed based on determined true flow curves, according to the method described in the papers [Kempiński et al., 2005, Malczewska, 2008, 2009]. In order to describe rheological characteristics, the 3-parameter Herschel–Bulkley model was applied as follows:

$$\begin{aligned} \tau &= \tau_0 + kG^n && \text{for } \tau > \tau_0 \\ G &= 0 && \text{for } \tau \le \tau_0 \end{aligned}$$

where:

- τ – shear stress,
- τ_0 – yield stress,
- k – rigidity coefficient,
- n – structural number,
- G – shear rate.

The relationships between the rheological parameters τ_o, *k*, *n* and gravimetric concentration *Cs* were established, and are as follows: the yield stress and rigidity coefficient of Herschel–Bulkley's model increase, while the structural number demonstrates decreasing tendency with rising gravimetric concentration (Figs. 2, 3, 4).

The critical concentration $C_{s,gr}$ delimitating Newtonian and non–Newtonian behavior of the sludge was determined from an approximation of the dependence $\tau_0(C_s)$, for $\tau_o = 0$ and $n(C_s)$ for n = 1. The sludge with gravimetric concentration $C_s < C_{s,gr}$ behaves like a Newtonian fluid, whereas with the concentration of solid constituent $C_s > C_{s,gr}$ appears to be a non–Newtonian fluid. After exceeding critical concentration $C_{s,gr1}$ (for $n = 1$) the sludge behaves like the Ostwald de Waele substance, while for concentration higher than $C_{s,gr2}$ (for $\tau_o = 0$) it behaves like the Herschel–Bulkley substance.

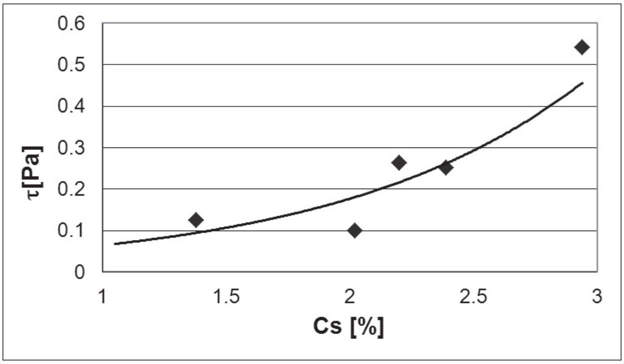

Figure 2. Dependence of yield stress τ_o for Herschel–Bulkley's model on gravimetric concentration

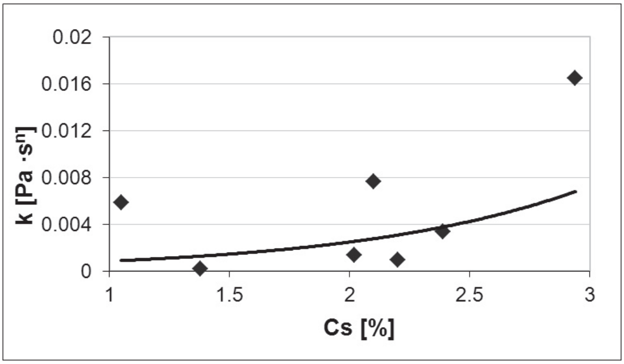

Figure 3. Dependence of rigidity coefficient *k* for Herschel–Bulkley's model on gravimetric concentration

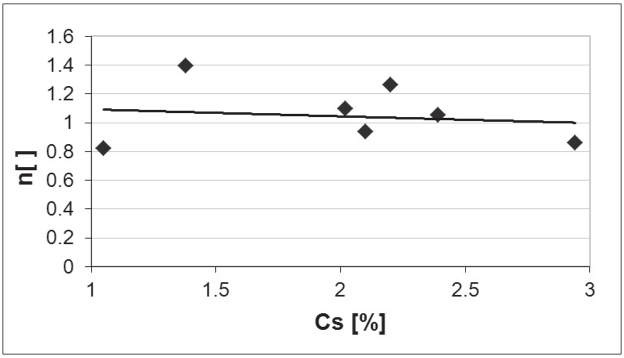

Figure 4. Dependence of structural number *n* for Herschel–Bulkley's model on gravimetric concentration

The effect of variations of physico-chemical parameters such as pH (involving surface charge change), size, surface roughness and gravimetric concentration on the evolution of viscosity (rheological parameters) has been studied. Preliminary research confirmed the variation of sludge apparent viscosity with shear rate. As the shear rate increases the shear stress increases accordingly. Addition of lime causes the shear to increase depending on concentration of the mixture.

CONCLUSIONS

The use of wastewater treatment to remove pathogens from wastewater has raised the issue of treating the generated sludge to allow its reuse or disposal. Lime compounds dosing and effective method of mixing it with sludge can be helpful in achieving parameters suitable for agricultural utilization of the sludge.

The properties of flow and mixing during hydration have an important impact on optimization of the lime-treatment process. Sewage sludge behaves like a non-Newtonian fluid. In this study the investigated samples behaved as a pseudoplastic fluid, however the rheological behaviour of the sludge depends on critical concentration $C_{s,\ gr.}$

The results show that the values of yield stress for sludge treated with CaO are higher than the values of yield stress obtained for non-treated sludge. The initial yield stress for the sludge increased and the characteristic shape of the rheogram curve changed with CaO dosage.

The research evaluates the ability of the rheological parameters to assess the dehydration of a sludge. This study needs to be carried out to evaluate the use of viscosity measurement as a method of optimizing the dewatering process.

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