Original Research

Rheological Measurements of Disintegrated Activated Sludge

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Abstract

Our paper deals with the description of the rheological properties of activated sewage sludge before and after disintegration. There is an assumption that disintegrated activated sewage sludge is able to change rheological properties. These changes probably cause the modification of the structure of activated sewage sludge after disintegration. The reason is that during disintegration, cell walls of organisms (from which the activated sewage sludge is composed) are disturbed. Currently there are not published many papers that deal with rheological properties of disintegrated activated sewage sludge. There is therefore no opportunity to confront our assumption with papers of other authors. The sample of activated sewage sludge was collected from aeration tank of the wastewater treatment plant for 10,000 population equivalent (PE). In our work the following rheological properties were described: temperature dependence on viscosity and the shear stress dependence on shear rate. On the basis of measured data Arrhenius mathematical model has been applied. By using this mathematical model the activation energy has been obtained.

Keywords: activated sewage sludge, rheology, viscosity, mechanical disintegration, Arrhenius model

Introduction

Rheological measurements of substances are very important and find applications in many fields of human activity. Determination of rheological behavior of substances is particularly important for designing equipment for transport, pumping, and storage of substances. A survey of rheological behavior also plays an important role in food rheology, where rheology among other things relates to quality control and sensory properties [1]. Other applications of rheology include, for example, the polymer industry [2], the building industry [3], metallurgy [4], geology, and mining industry [5]. An equally important application is using rheology in waste management. These include wastewater treatment and sewage sludge utilization. Determination of rheological parameters of sewage sludge is the base for its characterization. Information about rheological properties is very important for processes, which relate to the utilization of sewage sludge. These are especially transport, dewatering, drying, and landfilling of sewage sludge [6].

Rheological properties of various kinds of sewage sludge can be very different. These properties are different in various steps of wastewater treatment [7, 8]. It is known that suspensions of biological sewage sludge are non-Newtonian fluids [9]. However, from the rheological point of view very thin layers behave as Newtonian fluid. When the suspension is concentrated the sludge starts to behave as

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non-Newtonian fluid [6]. The dependence of total solid soluble (TSS) on rheological properties of the activated sewage sludge has been described by other authors [9-12].

In the present process, the disintegration of activated sewage sludge comes to the foreground of interest. There are many methods of disintegration of activated sewage sludge. The basic methods include disintegration by using ultrasonic [13-15] and mechanical disintegration [16]. Disintegration causes disruption of cell walls of organisms in the activated sewage sludge. Liquids, which are contained in the sewage sludge, are released to sewage sludge suspension. After disintegration an increase of specific surfaces of particles of sewage sludge were found. This process enables better accessibility of organic materials for organisms. Organisms can decompose this material, for example during the process of anaerobic fermentation or aerobic stabilization. The result of disintegration processes is better dewatering of sewage sludge [13]. Disintegration of sewage sludge can be one way to improve operation costs of sewage sludge utilization at a wastewater treatment plant.

Material and Methods

Activated Sewage Sludge

Samples of materials were collected from an aeration tank at the wastewater treatment plant of 10,000 PE. The collection of samples was performed according to standard ISO 10381-6: Soil quality – Sampling – Part 6. On collection day samples were transported to the laboratory. Before and after disintegration solid content in activated sewage sludge was determined at 105ºC in the electric muffle furnace LHM 07/12. The weighing of samples was executed with use of a Radwag AS 220/X analytical scale with an accuracy of 0.0001 g. Disintegration of samples has been performed in the special developed experimental device using a water blast. This device is composed from two identical conical vessels; in one of these vessels a sludge pump has been placed. The pressure hose is connected with the pump and hose leads to the second conical vessel. At the end of the inner part of pressure hose is a disintegration device composed of two counter-rotating steel discs with small holes that are placed in motion with the use of kinetic energy of flowing sewage sludge. Between steel discs arise a sudden local increase of pressure in the small time period. After disintegration a sample of disintegrated activated sewage sludge was homogenized and the measurement of rheological properties was performed.

Measurement of Rheological Behavior

There are several methods designed to measure of rheological behavior of substances with different types of measuring geometry such as concentric cylinders, cone, and plate or parallel plates [17]. An extensive overview about measurement techniques for rheological testing is given in [18]. Rheological measurement of substances for this paper was performed using an Anton Paar MCR 102 rheometer (Austria) with measuring geometry cone-plate. The diameter of cone was 50 mm and angle 1º. Three curves were evaluated: dependence of dynamic viscosity η [Pa·s] on temperature, fluidity φ [$Pa^{-1}\cdot s^{-1}$], and dependence of shear stress τ [Pa] on a shear rate $\dot{\gamma}$ [s^{-1}].

Dynamic viscosity is given by equation:

$$\eta = \frac{\tau}{\dot{\gamma}} \quad [\mathrm{Pa\cdot s}] \qquad (1)$$

..where:
τ – shear stress [Pa]
$\dot{\gamma}$ – shear rate [s^{-1}]

The reciprocal of a dynamic viscosity is fluidity and it is given by equation:

$$\varphi = \frac{1}{\eta} \quad [\mathrm{Pa^{-1}\cdot s^{-1}}] \qquad (2)$$

The dynamic viscosity with fluidity has been measured in a range of 5-40ºC and with the constant shear rate 50 s^{-1}. The measurement of shear stress dependence on shear rate was performed in the range 0 s^{-1}-100 s^{-1}.

Various mathematical models are used for description of rheological properties of substances, where viscosity is the basic input parameter. These mathematical models include, e.g. Arrhenius, Gaussian, exponential, etc. [17]. The Arrhenius mathematical model is commonly used, and given by equation:

$$\eta = \eta_0 \cdot e^{-\frac{E_A}{RT}} \quad [\mathrm{Pa\cdot s}] \qquad (3)$$

…where:
η_0 – constant, initial value of dynamic viscosity [Pa·s]
E_A – activation energy [J]
R – universal gas constant [$J\cdot K^{-1}\cdot mol^{-1}$]
T – thermodynamic temperature [K]

This model has been used for an evaluation of dependence of the dynamic viscosity η on temperature and for an evaluation of activation energy E_A. All measurements have been performed in three repetitions. Subsequently arithmetic mean has been evaluated from measured data. The data has been tested by Grubbs test for remoteness values.

Results and Discussion

Solid content in samples of untreated sewage sludge and disintegrated activated sewage sludge has been 3.8 $g\cdot l^{-1}$. Dynamic viscosity of disintegrated and untreated activated sludge is shown on Fig. 1. From where it is obvious that viscosity of disintegrated sludge ranges from 5.67 mPa·s at 5ºC to value 3.37 mPa·s at 40ºC. A value of dynamic viscosity of untreated activated sludge (before disintegration) ranges from 8.86 mPa·s at 5ºC to 5.42 mPa·s at 40ºC. According to Guibaud [7], dynamic viscosity has been approximately 8 mPa·s at shear rate 50 s^{-1}, temperature of 20ºC and TSS 3.6 $g\cdot l^{-1}$. In the case of the experimental measurement value of dynamic viscosity, it has been 6.13 mPa·s at the same boundary condition. Similar values were obtained in other papers [12]. When content of TSS in the activated sewage sludge increased, dynamic viscosity increased, too [9-11].

It is evident from Fig. 1 that disintegration of activated sewage sludge changes viscosity dependence on temperature. The dynamic viscosity has been 4.41 mPa·s at 20ºC and shear rate 50 s^{-1}. Values of the dynamic viscosity decreased about 18% compared to untreated activated sewage sludge. But there are not many papers that can be compared with experimental measurement. The exception includes the work of Ruiz-Hernando [19]. However, in that paper rheological measurement of secondary sludge was performed and subsequently compared with values of rheological measurements of disintegrated sludge using ultrasonic waves at various specific energy values. The decrease of dynamic viscosity there was 38% to 82%.

Fluidity of disintegrated and untreated activated sewage sludge is shown in the Fig. 2, from which it is evident that according to assumption, the disintegrated activated sewage sludge reaches a higher value of fluidity than untreated activated sewage sludge.

Both dependences (i. e. temperature dependence on the viscosity of disintegrated and untreated activated sewage sludge) have been subjected to further mathematical analysis. Arrhenius' mathematical model has been used for this analysis. This model is shown in equation (3). The logarithm of this equation is:

$$\ln \eta = \ln \eta_0 + \frac{E_A}{R \cdot T} \tag{4}$$

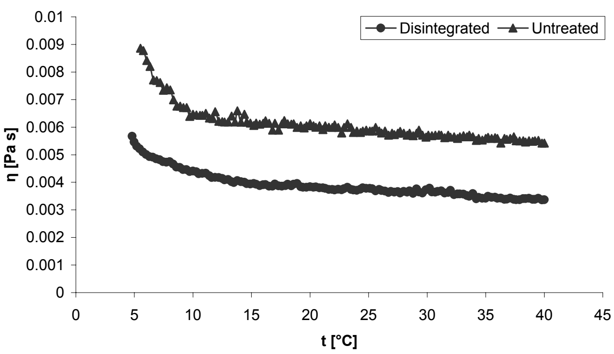

Fig. 1. Temperature dependence on viscosity of disintegrated and untreated sludge.

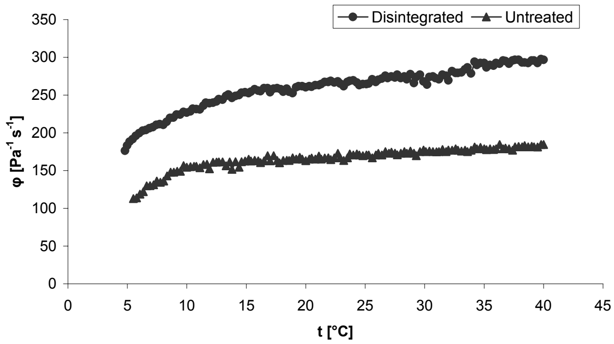

Fig. 2. Fluidity of disintegrated and untreated sludge.

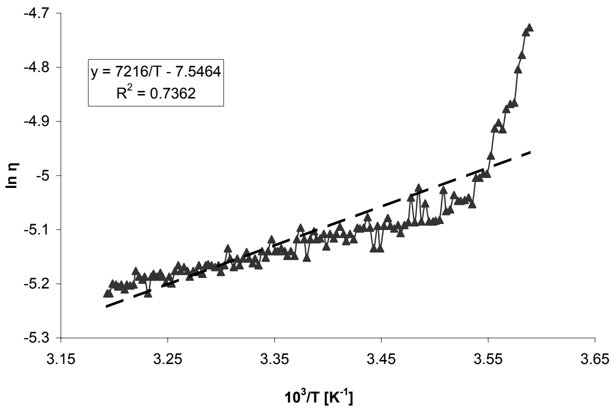

Fig. 3. Evaluation of Arrhenius model of an untreated sludge.

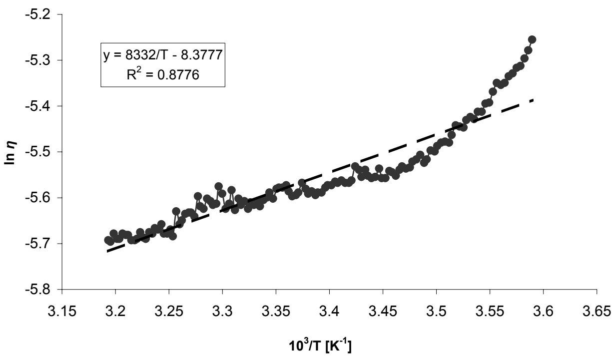

Fig. 4. Evaluation of the Arrhenius model of a disintegrated sludge.

Activation energy E_A has been performed using this equation with regression analysis. Arrhenius' mathematical model applied to untreated activated sludge is shown in Fig. 3. Coefficient of determination R^2 = 0.7362 has been obtained by using regression analyses – linear dependence. When the sixth degree polynomial was used determination coefficient was R^2 = 0.9776. The value of activation energy E_A of untreated activated sludge was 59.994 kJ·mol^{-1}. According to Yang the activation energy of activated sewage sludge from membrane technology was 9.217 kJ·mol^{-1} [20]. This difference is caused by different wastewater treatment technology, where change in the structure of the activated sewage sludge occurs.

Arrhenius' mathematical model applied to untreated activated sewage sludge is shown in Fig. 4. Determination coefficient has been R^2 = 0.8776. In the case of application of polynomial of sixth degree this coefficient has been R^2 = 0.9866. The activation energy E_A value of disintegrated sample has been higher than the value of untreated samples. The value has been 69.272 kJ·mol^{-1}.

The progress of shear stress dependence on shear rate of untreated activated sewage sludge shows signs of thixotropy. This correlates with other papers, where authors reached the same conclusion [7, 11]. Signs of thixotropy behavior were detected in disintegrated activated sewage sludge, where the ultrasonic waves were used for disintegration [19]. A rheogram of untreated and disintegrated activated sludge is shown in Fig. 5. Thixotropy behavior of

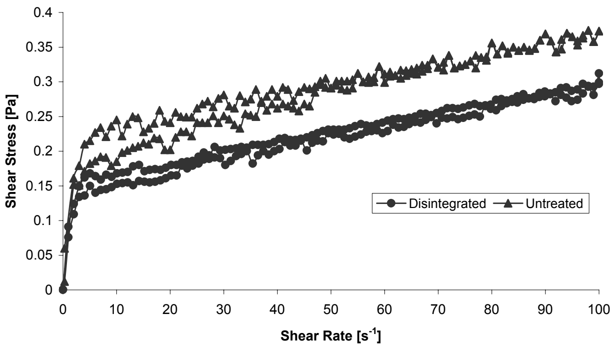

Fig. 5. Rheogram of disintegrated and untreated sludge.

activated sewage sludge is typical, because it also appears in different kinds of sewage sludge [21, 22], including materials in the mixture with sewage sludge [23, 24].

Conclusion

The disintegration of activated sewage sludge can be one way to improve operation costs of wastewater treatment plants. It can be expected that the number of device applications (which was designed for disintegration of sewage sludge) will increase in the future. For designing devices and technology for pumping and transporting disintegrated sewage sludge (such as pumps, pipes) it is important to know the rheological properties of this fluid.

Currently there is not much information about rheological properties of disintegrated activated sludge. This paper confirms the assumption that rheological properties of activated sewage sludge are changing during disintegration. Proof is the change of viscosity in the dependence on the temperature and also different values of activation energy for untreated activated and disintegrated activated sludge. In the case of shear stress, dependence on shear rate was confirmed through thixotropy behavior of disintegrated and untreated activated sludge.

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