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The effects of temperature, organic matter and time-dependency on rheological properties of dry anaerobic digested swine manure

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ABSTRACT

An efficient way to avoid the pollution of swine wastewater is the application of dry anaerobic digestion, which needs rheological parameter for stirring and pipe designing. The rheological properties of this kind of sludge have been studied for many decades, yet their effects only solid concentration has been investigated widely. In this paper, the influences of temperature, organic and time-dependency on the efficiency of anaerobic digested swine manure were studied. The viscosity decreased with temperature arranged from 10 to 60 °C which caused increase in protein from 7.18 to 8.49 g/kg. 60 °C can make the digested swine manure with TS from 16.6% to 21.5% reach to the same rheology state. The added peptone decreased the viscosity because of its function of water-reducing admixture and air entraining mixture. Time-dependent experiment showed the decrease of shear stress over time. The first and the second yield stress of dry anaerobic digested swine manure were evaluated through time-dependent model.

1. Introduction

Anaerobic digestion would be a good choice for the treatment of swine manure. Considering the post-treatment of digested wastewater from conventional processes needs more energy and investment, dry anaerobic digestion is getting more attention because it has the benefits of smaller reactor and less effluent water (Abouelenien et al., 2009). However, the rheological properties of dry anaerobic digested swine manure need to be known clearly for the design and efficient operation of the pumping systems (Wolny et al., 2008). This kind of sludge shows shear-thinning behavior, plastic behavior, thixotropy and viscoelasticity (Seyssiecq et al., 2003). The rheological properties of these sludges most studies mentioned are low solid concentration, displayed some changeful characteristics like the yield stress and viscosity increase with solid concentration (Baudez et al., 2011), the viscosity decrease with increasing temperature (Mu et al., 2006), the viscosity and shear modulus increase with organic (Khongnakorn et al., 2010), etc. In addition, the property of time dependency of these rheological properties cannot be ignored (Coussot et al., 2002b; Read et al., 2011). The polytropy of rheological behavior indicates that accurate estimation of sludge rheological properties is essential.

The rheological properties of low concentration digested sludge and active sludge are widely studied. Because their operations involving pumping, storage, dewatering, etc. linked to rheological behavior and low concentration sludges are more common. Less early work studied the rheology of semi-dry anaerobic digested municipal solid wastes (Battistoni et al., 1993, 1991). However, it rarely saw the researches about rheological properties of dry anaerobic digested swine manure let alone the effects on its rheological property.

Dry anaerobic digested swine manure is heterogeneous and a type of complex mixtures with inorganic matter and organic matter from the physical perspective. Consequently, their rheological properties were affected by many factors, like temperature, solid concentration, surface charge, organic matter (protein and polysaccharide take major effect), bound water, pH etc. However, the main factor seems to be solid concentration (Baudez et al., 2011; Dak et al., 2007; Eshtiaghi et al., 2012; Mu et al., 2006) which leads to a more rigid structure of the sludge network and to an enhancement of the sludge cohesion (Khongnakorn et al., 2010). Actually, temperature and organic concentration still have significant effect on sludge rheological properties (Battistoni et al., 1993; Baudez et al., 2013; Khongnakorn et al., 2010; Mu et al., 2006), especially for high solid content sludge (Battistoni et al., 1993) which was less studied. In addition, time is also an important influencing factor on thixotropy, viscoelasticity and the first/second yield stress. The yield stress is the critical stress of fluid before flow, it should be clearly understood in practical biogas engineering.

In this paper, the influences of temperature, organic concentration and time-dependency on the effect of anaerobic digested swine manure were displayed, as well as the relationship between

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the first/second yield stress and time-dependent characteristics. The purpose is to try to figure out that the impact factors of temperature, organic concentration and time-dependent are also important as solid concentration on rheological property of dry anaerobic digested swine manure. Furthermore, considering the significance of yield stress (especially the second yield stress) in practical application, a new method which is used to calculate the first/second yield stress through time-dependent characteristic was proposed.

2. Materials and methods

2.1. Dry anaerobic digested swine manure

The sludge samples used in this study were obtained from a laboratory scale cylindrical anaerobic reactor. The ratio of height to diameter of this reactor is 1. It has a treatment capacity of 20 L and working volume of 15 L. The total solid (TS) and volatile solid (VS) of swine manure were 26% and 20% respectively. Meanwhile, the inoculum were 17% and 11% respectively. The swine manure to inoculum ratio is 2. It is being operated in batch mode at temperature of 30 ± 2 °C and lasted for 80 days. In this study, the TS concentration of anaerobic digested swine manure was lower than 22%.

2.2. Analytical methods

Rheological experiments were performed on a rotational controlled share rate rheometer (NXS-11B rotational Viscometer, Chengdu Instrument Co.), a coaxial cylindrical measurement device (system C) with a gap of 2.7 mm. The volume of the sample used for each test is 9 mL. The automatic discharging of sludge from digester creates a low shear rate in the pipe under the gravity. Thus, the shear rate below 163.1 s^{-1} was considered. The measurement protocol consists of an increase of the shear rate from 2.5 to 163.1 s^{-1} in 90 s and an increase of the time from 0 to 1000 s with the shear rates remaining unaltered. System C will be instead by system D (the gap is 5.7 mm; the sample volume is 10 mL; shear rate is from 1.4 to 96.6 s^{-1} when the measurement range be exceeded. From day 20, the rheological properties of sludge samples were measured every 15 days and the sludge showed different solid concentration. The variation of effects was set as follows. Temperature: The temperature increased from 10 to 60 °C through a water jacket which was heated by a thermostatic bath (HS-4 thermostatic bath, Chengdu Instrument Co.); Organic: Peptone was added to the sludge from 1% to 5% volatile solid in samples and then the samples were stirred for 1 min and relaxed for 2 h. Time: the value of viscosity was read once every two seconds under every invariant shear rate until the viscosity reached to a constant value.

The TS and VS were measured by standard methods (APHA, 2005). Carbohydrates were analyzed according to the anthrone method (Zhang et al., 2013). The amount of protein was analyzed by Thermo Scientific Varioskan Flash spectral scanning multimode reader (Varioskan, Thermo Electron Co, Waltham, MA) with SkanIt Software (wavelength: 562 nm). Volatile fatty acids (VFA) were analyzed using a gas chromatograph (GC-7AG, Shimadzu, Japan).

3. Results and discussion

3.1. Influence of temperature on rheology

The influence of temperature on digested swine manure was analyzed in four different TS. The correlation between temperature and apparent viscosity of sludge, at a special shear rate, can be generally expressed by the Arrhenius relationship (Eq. (1)) (Baudez et al., 2013; Pevere et al., 2009). Fig. 1 showed the plotting of $\ln\eta$ against $1/T$ at four solid concentration and the straight line was obtained with the slope of E_a/R. The high correlation between viscosity and temperature indicates that the temperature affected the rheological property of digested swine manure according to the Arrhenius equation (Table 1).

$$\ln\eta = \ln A_0 + \frac{E_a}{RT} \quad (1)$$

where A_0 is the pre-exponential factor (Pa s^{-1}), E_a the Activation energy of flow (kJ/mol), R the universal gas constant (8.314 J/mol), T the absolute temperature (K).

The viscosity decreased with a temperature increase at different shear rates under four solid concentrations (Fig. 2) agree with the activation energy theory (Mayr, 2006). On a molecular level, the higher temperature makes the thermal motion of the solid particles more violent, which weakened the network strength between the particles or broken some chemical bonds of long molecule chains and make them dissolvable. A direct proof was the increasing of soluble protein in digested swine sludge after heating treatment. However, the other soluble macromolecule organic content including polysaccharide and volatile fatty acids have no significant changes (Table 2). This might be caused by the larger amount of protein than polysaccharide and volatile fatty acids in dry anaerobic digested swine manure or the temperature was high enough for protein dissolving.

An interesting phenomena was that temperature, when it reached to 60 °C, seemed to have less effect on sludge viscosity at the solid concentration ranged from 16.6% to 21.5% (Fig. 3). This phenomena can be deduced from Arrhenius equation which showed a constant viscosity when temperature was high enough. The theory of the relationship between reaction rate and activation energy indicates that the relatively high temperature is beneficial to the reaction with a higher activation energy. Which means, in this study, the temperature about 60 °C can more easily reduce the viscosity of dry anaerobic digested swine manure which has a TS of 21.5%. Moreover, 60 °C was the common temperature which made the digested swine manure with TS ranged from 16.6% to 21.5% reach to a similar rheology state.

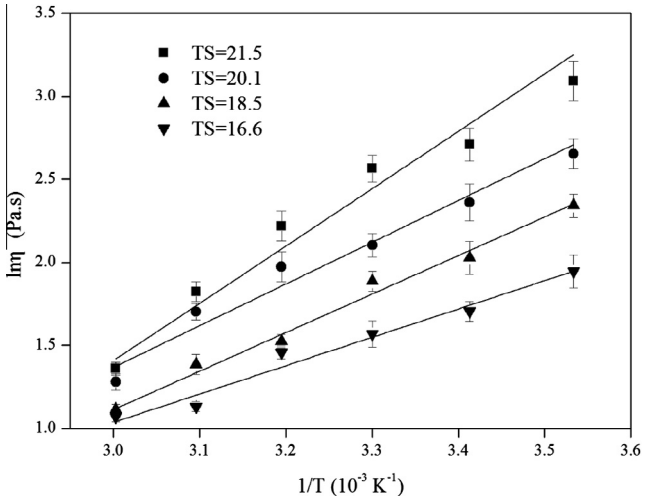

Fig. 1. Viscosity as a function of $1/T$ at a constant shear rate of 22.41 s^{-1} in a different fermentation stage which showed different solid concentrations.