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Research paper

Effects of suspended solid and polyelectrolyte on settling and rheological properties of municipal activated sludge

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ABSTRACT

Studying sludge rheology is an important factor for the management and disposal of produced sludge in a wastewater treatment plant. In this paper, the rheological characteristics of fresh and conditioned municipal sludge at different total solid contents (ranging from 1.8 to 3.7 g/l) were investigated. The selected conditioning agent was cationic polyacrylamide high molecular weight (CPAM-80). It was found that all samples behaved as shear thinning and limiting viscosity increased with increasing total solid concentration which followed Bingham model. In addition, settling index was increased by 50% with increasing solid content by 50%. The use of conditioning agent improved settling properties and the increased concentration of this agent reduced yield stress and limiting viscosity.

1. Introduction

Wastewater treatment processes and disposal of waste activated sludge have been described as some of the most difficult and costly processes within the wastewater treatment plants. The limitation of the current technology utilized in wastewater treatment plants requires the development of more efficient and optimized methods for sludge treatment and disposal, which accounts for about 50% of the operating costs and 20–30% of the capital costs of wastewater treatment plants [1]. In order to enhance the settling and dewatering in a wastewater treatment plant, conditioning with polyelectrolytes were performed by Roult et al. [2] and Nguyen et al. [3]. The experimental study of Roult et al. [2] indicated that replacing alum by using diallyl dimethyl ammonium chloride as coagulate improved the overall efficiency of raw water and they achieved a 25% cost reduction. Similarly, the work of Nguyen et al. [3] on the conditioning of synthetic activated sludge using polysaccharide polyelectrolyte showed that the capillary suction time was decreasing with the successive addition of polymer which finally resulted in a good dewatering behavior. The effect of conditioning on the rheological behavior of sludge also plays an important role in cost effective design; equipment selection and sizing, handling and transportation as shown by many researchers [4–8].

The surface electrical charges of the sludge particles have direct effect on their natural flocculation properties. As a result of physio-chemical interactions between bacteria and inorganic components, activated sludge particles in wastewater are negatively charged [9]. The surface charge influences the stability and bulk rheology of many colloids. The particles charges can be modified by changing pH or changing the ionic species of the solution by using coagulants that adsorbed on the particles surfaces changing their electrical characteristics [10]. The result of these measurements is zeta potential which is considered to measure an electrophoretic mobility of the solution. A high value of zeta potential prevents flocculation, on the other hand low values of zeta potential allows the particles to approach each other and flocculate. Faster flocculation occurs when zeta value approaches zero. This mechanism is counteracted by an attraction force termed Van der Waals attraction [11].

However, particles with high zeta potential (negative or positive) are electrically stabilized while particles with low zeta values tend to flocculate. The addition of coagulant agents is used to reduce the energy barriers between particles leading to an efficient agglomeration and settling [12]. Improvement of separation processes in wastewater treatment can be done by controlling the sludge properties as suggested by Bennoit and Schuster [13].

Since the polyelectrolyte flocculants frequently exist in the concentrated sludge that is ready to transport, it is of essential importance to understand the implications of flocculation on the sludge rheology. Thus the aim of this work was to investigate and provide insights into the rheological nature of the sludge in order to understand the implications of polyelectrolyte flocculation on

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its rheological characteristics for improved sludge processing and disposal. In this work, the municipal sludge was selected, for possessing a high organic content and continuously unstable composition [14]. The addition of polyelectrolyte may lead to different rheological behaviors. Other objectives were to determine the electrical surface of sludge particle and its effect on the flocs sizes of the sludge particles which can be used to understand the relationship between flocs sizes and strength using different polyelectrolyte concentrations. Bacteria presented in the conditioned sludge were also examined during all tests. The rheological behavior of the municipal sludge, viscosity, shear stress-shear rate and yield were investigated in detail.

2. Rheological theory

It was stated that wastewater sludge had a non- Newtonian fluid behavior and possessed both viscous and elastic properties [15–17]. Mostly, sludge is rheologically characterized using various pseudoplastic or Bingham plastic models [15,18]. The behavior of thickened sewage sludge was considered as thixotropic and modeled by Herschel-Bulkly model [19].

Rheological characterizations of the activated sludge are very important in sludge management and design criteria for wastewater plant in respect to pumping over long distance, storage, spreading operations, and controlling stabilization and dewatering processes [17]. The sludge rheology is very significant phenomenon for understanding the characteristic of the sludge flow and treatment [20]. The most important rheological parameters are viscosity, yield point and solid concentration [5]. Due to the non-uniformity of sludge operation conditions, wastewater shows different rheological characteristics especially in empirical correlations [21]. Lee et al. [22] stated that conditioned sludge shifts its rheological characterization from viscoelastic liquid-like to solid-like behavior.

Shear yield stress may be defined as the minimum shear stress required for initiating the flow of sludge solution [22]. An elastic solid behavior would be shown by sludge sample during tests of shear stress ramp measurement, this act forces the viscosity to increase as more stress is applied. At point of reaching yield stress, sludge sample starts to flow and hence the viscosity starts falling accordingly [23]. Measurement of the shear yield stress provides valuable information regarding the handle ability of the filter and thickener output as a function of the solid concentration of flocculated sludge. There are many ways to evaluate the yield stress for fluid-like substances and no single “best” technique can be defined.

Shear yield stress of fluid-like substances is the most popular technique for fluid viscoelasticity measurement based on the extrapolation of shear stress versus shear rate. Most commonly applied models are [4,21]: Bingham Plastic Model (Eq. (1)) which assumes a linear relationship between shear stress and shear rate, the stress intercept being the Bingham yield value; Herschel-Buckley Model (Eq. (2)) and Casson Model (Eq. (3)) which are designed for determining the yield stress of non-linear plastic behavior; Ostwald de Waele (power law) Model (Eq. (4)) which is developed for a purely shear thinning depending if the flow model is considered to start from zero stress; Sisko model (Eq. (5)) which is designed for high-shear rate data containing infinite-shear-viscosity.

$$\tau = \tau_0 + k\cdot\gamma \tag{1}$$

$$\tau = \tau_0 + k\cdot\gamma^n \tag{2}$$

$$\tau^{1/2} = {\tau_0}^{1/2} + (k\cdot\gamma)^{1/2} \tag{3}$$

$$\tau = k\ \gamma^n \tag{4}$$

$$\tau = \mu_B\gamma + k\cdot\gamma^n \tag{5}$$

where, τ is the shear stress, γ (s^{-1}) is the shear rate, k is the consistency index that represents the cohesiveness of the fluid, the higher value reflect higher viscosities, and n is the flow behavior index (n = 1 is for Newtonian fluids and value far from 1 indicates deviation from Newtonian behavior) and the yield stress τ_0 indicates the resistance of the sludge to the deformation until sufficient stress is applied. The parameter μ_B is the high shear limiting viscosity where the shear rate imposed on the fluid tends to an infinite value [4].

Sludge creep happens frequently on the biological sludge which is difficult to dewater. Creep test, an instantaneous stress is applied to the sample and the change in strain (called the creep) is observed over time. When the stress is released, some recovery may be observed as the material attempts to return to the original shape [5,6]. For example, creep testing is a basic probe of polymer relaxations and a fundamental form of polymer behavior. Overloading of stress in a material can cause damage and failure in later use, thus, poor mechanical design can be indicated when creep in metals is at a failure mode [24].

3. Materials and methods

3.1. Sludge sample

The sludge samples were collected from the Nizwa city's municipal wastewater treatment plant in the Sultanate of Oman and their properties are presented in Table 1.

Polyacrylamide CPAM-80 was used for sludge conditioning and provided by Cytec industries Ltd. For each test, six different concentrations of conditioning solution were prepared to cover a range from 0.5 to about 14 mg of polyelectrolyte per one gram of

Table 1
Sludge samples characterization.

Total suspended solid (TSS) (g/l)	Volatile suspended solid (VSS) (g/l)	Fixed suspended solid (FSS) (g/l)	Conductivity (ms/cm)	pH	Zeta Potential (mV)
1.8236	1.4436	0.38	2.61	6.9	−12.1
1.9636	1.4836	0.48	2.75	6.9	−10.9
2.6236	1.9	0.7236	2.23	6.9	−10.7
2.7036	1.9836	0.72	2.66	6.9	−9.5
2.98	2.28	0.7	3.22	6.9	−7.15
3.18	2.5036	0.6764	2.91	6.9	−12.5
3.6836	2.8436	0.84	2.255	6.9	−13.4