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Impact of gas injection on physicochemical properties of waste activated sludge: A linear relationship between the change of viscoelastic properties and the change of other physiochemical properties

Veena Bobade [a], Geoffery Evans [b], Jean Christophe Baudez [c], Nicky Eshtiaghi [a, *]

[a] RMIT University, School of Civil, Environmental and Chemical Engineering, 124 La Trobe St, Melbourne, Vic 3000, Australia
[b] School of Chemical Engineering, The University of Newcastle, Australia
[c] LIST, Environmental Research and Innovation Department (ERIN), 41, rue du Brill, L-4422 Belvaux, Luxembourg

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A B S T R A C T

Aeration process in the waste activated sludge treatment accounts for 75% of total energy consumption of the treatment plant. The main purpose of the aeration process is to enhance the biodegradation of the liquid waste. Gas bubbles, rising through the liquid, improves mixing, reduces inhomogeneities in the treatment tank and enhances biological reactions. Thus aeration intensity and several physicochemical properties of feed such as viscosity, total suspended solids, and surface charge play a significant role in the biological reaction.

This paper examines the impact of the gas injection rate on some physicochemical properties of waste activated sludge namely rheological properties, suspended solids, soluble COD (sCOD), surface tension, and zeta potential. The impact of four different gas flow rates on four different concentrations of waste activated sludge properties was analysed.

The results showed that in linear viscoelastic regime the viscous and elastic modulus decreases linearly with an increase in gas flow rate. The amount of stress imposed by gas injection also showed a direct relationship with gas velocity. Gas injection also showed a substantial impact on soluble COD, suspended solids, and zeta potential. Additionally, a linear relationship was observed between the percentage change in the above mentioned physical properties and stress imposed by gas injection. These results confirm that gas injection produces additional shear impacting sludge physicochemical properties and therefore changes its rheological behaviour. The extra stress induced by gas injection can be predicted using a simple model based on sludge concentration and gas velocity.

1. Introduction

The waste activated sludge process is the most versatile and commonly used biological treatment (Seyssiecq et al., 2008). The efficiency of the waste activated sludge process depends upon an aeration operation. Aeration provides oxygen to the microorganisms to breakdown the complex organic compounds into carbon dioxide and water and reduces the volume of sludge produced (Bailey et al., 2002). However, the oxygen transfer rate in the aeration tank decreases with an increase in the total solid concentration of sludge and strongly influences the efficiency of the process (Rosenberger et al., 2002). This is because with increasing solid concentration of sludge results in an increased viscosity of sludge that causes variations in system hydrodynamics and impacts on bubble buoyancy, bubble shape and turbulence (Bajón Fernández et al., 2015).

Waste activated sludge is composed of water, microorganisms, and macromolecules grouped in bioflocs (Laspidou and Rittmann, 2002). Hence it's structure depends on many factors and can remarkably change when exposed to shear stress. Therefore, sludge is known to exhibit shear thinning behaviour (Eshtiaghi et al., 2013; Baudez and Coussot, 2001; Baudez, 2008). Thus, rheology plays a crucial role in optimising and designing the aeration system. Since the sludge characteristics and rheology affect each other, the

* Corresponding author.
E-mail address: Nicky.eshtiaghi@rmit.edu.au (N. Eshtiaghi).

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impact of aeration on rheology and sludge physical properties should be considered when studying the sludge flow behaviour in the aeration tank.

Increase in aeration intensity results in a severe breakup of sludge flocs, and promotes the release of colloids and solutes from the microbial flocs to the bulk solution (Meng et al., 2008). Consequently, it influences the sludge physical properties like total suspended solids (TSS), sludge volume index (SVI), etc. and impacts on sludge settleability, filterability, and compressibility (Pollice et al., 2007). The impact of shear stress generated by aeration intensity increased the soluble contents of sludge (SMP, EPS) (Menniti et al. 2009, 2010). Moreover, the induced shear stress by microbubbles broke down the sludge that reduced the floc size and released the organic content such as EPS and it also changed the viscosity and surface tension of sludge (Liu et al., 2012). Almost all the studies that have conducted to date have only focused on membrane bioreactor to study the impact of aeration intensity on sludge physical properties and for the solid concentration less than 2%.

Provided that aeration intensity impacts on sludge physical properties and consequently changes its rheological properties, currently there isn't any study that showed the relationship between sludge rheology (especially in a linear viscoelastic region that can be measured online) and physiochemical properties of sludge.

As both the physical and rheological properties simultaneously change in the aeration process and impact on the efficiency of the waste activated sludge process, monitoring shear and its effect on complex physicochemical properties through online tools (e.g. rheometers) with any minor change provides useful information to adjust operating conditions accordingly. However, there is lack of detailed analysis on the change in sludge rheology with anaeration rate and its impact on the sludge physicochemical properties. This study wants to elucidate and correlate the stress generated by aeration intensity with sludge physicochemical properties. Therefore this research primarily aims at investigating the impact of gas injection on viscoelastic properties, zeta potential, soluble COD and surface tension to get the detailed insight of the shear induced by the gas intensity and its effect on sludge physicochemical properties. The second objective is to develop relationships between change in rheological properties and physical properties at the different gas flow rates.

2. Materials and methods

2.1. Sample preparation

Waste activated sludge with 3 wt% (TS 30 g/l; TSS 26.833 g/l; sCOD 3720 mg/l; zeta potential −16.4mv; surface tension 46.04 mN/m) was collected from a wastewater treatment plant (Mt.Martha Treatment Plant) in southern region of Victoria, Australia. Sewage sludge of 600,000 customers after girt removal and primary tank settling is areated in ambient temperature. The sludge samples were collected after the dissolved air flotation tank before the polymer dosing. The sludge was thickened to higher concentration (6%) using a centrifuge at 7 °C and 8000 rpm (i.e., at 12,200 g maximum relative centrifugal force) for 30 min. The homogeneous samples of 3.0%, 4.0%, 5.0% & 5.5% total solids concentration (TS) were prepared by diluting the 6% concentrated sludge with the original sample.

2.2. Apparatus

Rheological measurements were performed using commercially available hybrid stress controlled (HR3) rheometer from TA Instruments using a grooved bob geometry with an outer diameter of 14.9 mm, and 42 mm length. A custom designed plexiglass cup (inner diameter: 100 mm, length: 100 mm) with a stainless steel porous disk (outer diameter: 100 mm, thickness: 1.6 mm, porosity: 40%, from SINTEC Australia) at the bottom was used for sparging gas while it connected to rheometer (Bobade et al., 2017). The gas flow rate was varied from 0.001 m^3/min to 0.007 m^3/min using a gas mass flow meter from AALBORG at a pressure of 10 Psi.

2.3. Rheometric technique

To monitor the evolution of structural changes in sludge due to gas injection, dynamic time sweep measurement was carried out. The experimental procedure for the time sweep measurement was carried out in the following pattern:

- Step 1: Pre shear the sludge at high shear rate (350s^{-1}) for 900s to ensure that identical condition is achieved before each measurement.
- Step 2: The sludge was allowed to rest for a short time (120s) to start the test in the same condition (Baudez, 2008; Markis et al., 2014).
- Step 3: The dynamic time sweep test at 0.09% strain and 1HZ frequency in a linear viscoelastic range was carried out for 1500s.
- Step 4: Preshearing of sludge was repeated (step 1) and the nitrogen gas was injected for 1500s before repeating the time sweep measurement (step 3). Similar experimental procedure was repeated for four different sludge concentrations (3%, 4%, 5% & 5.5%) at four different gas flow rates (1LPM - 7LPM).

The experimental procedure to measure the extra stress induced by gas injection on sludge was carried out as follows:

- Step 1: Preshearing of sludge at 350s^{-1} for 900s; resting for 120s;
- Step 2: Dynamic time sweep measurement at different strains and 1 HZ frequency without areation;
- Step 3: Compare the viscoelastic response (G', G'') of non aerated sludge with the aerated sludge at 0.09% strain, the difference between the two strains showed the extra strain imposed. The detailed sketch diagram of the rheological measurement process is provided else where, Bobade et al. (2017).

2.4. Physicochemical properties

Soluble COD (sCOD) and Zeta potential were examined to study the sludge solubilisation after gas injection. The sample collected for measuring the sCOD and Zeta potential was centrifuged at 10,000 rpm (i.e., 20913 g at maximum relative centrifugal force) for 20 min for separating the liquor from solid. The small volume of obtained liquor was used directly for zeta potential measurement and rest of the liquor was filtered through a 0.45 μm filter membrane. The collected filtrate was used to determine sCOD following standard American methods (Eaton et al., 2005). All measurements were carried out in duplicate. To avoid any alteration of sludge properties the samples and liquor are stored in a fridge at 4 °C.

The zeta potential measurement was performed using zetasizer Nano Range from Malvern Instruments, using disposable folded capillary cells (DTS 1070). The measurement was carried out at 20 °C, keeping the time lag of 10s between each set of readings. Each measurement was repeated for three times. The standard maximum deviation is 5%.

A surface tension of fluid changes with any change of