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# IMPACT OF EXTENT OF DIGESTION ON THE SHEAR RHEOLOGICAL BEHAVIOUR OF ANAEROBIC DIGESTED SLUDGE

Tanmoy Das[1], Shane P. Usher[2], Damien J. Batstone[3], Maazuza Othman[1], Anthony D. Stickland[2], Nicky Eshtiaghi[1]

[1]RMIT University, Melbourne, Victoria, Australia
[2]The University of Melbourne, Melbourne, Victoria, Australia
[3]The University of Queensland, St. Lucia, Queensland, Australia

## ABSTRACT

Anaerobic digestion of sewage sludge is widely used in wastewater treatment facilities to produce biogas and reduce solids disposal[1,2]. Although well-mixed digester configuration is the most common, technologies such as covered anaerobic lagoons (CALs), biofilm or plug flow reactors are also used[2]. To maintain design hydraulic retention time (HRT) and consistent temperatures, microbes and solids distribution, effective mixing of the digester content is necessary during anaerobic digestion[3]. Mixing is energy intensive and dependent on the shear rheological properties especially viscosity[4,5], which is non-Newtonian for anaerobic digested sludge[6,7]. Hence, the shear rheological behaviour of the digested sludge is critical for effective heat and mass transfer during anaerobic digestion. The evolution of sludge rheology has been studied widely and it has been observed that the shear yield stress and viscosity decrease (improves) through the anaerobic digestion process[8,9]. This can be attributed to the simultaneous impact of the reduction in solids concentration due to the degradation of organic matter and changes to the microstructure due to digestion. The degree of degradation is expressed as the volatile solids destruction (VSD). There is a need for systematic and comprehensive characterization of shear rheological properties across a wide range of solids volume fractions and VSD to quantitatively differentiate the impacts of digestion and solids concentration, which is currently unavailable in existing literature. The evolution of shear rheological properties in anaerobic digestion reflects the complex changes in the sludge microstructure as organic matter is degraded and microbial colonies exude extracellular polymeric substances (EPS)[10,11]. These EPS networks have been reported as responsible for higher viscosity of the digested sludge[10], indicating the presence of a strong correlation for the shear rheological properties of anaerobic digested sludge as a function of VSD, which has not yet been rigorously developed. In addition, most of the existing studies on the shear rheological behaviour have been conducted in the mesophilic temperature range (37°C)[9,12]. Efficient digestion of organic matter is influenced by the operating temperature[13,14]. Some anaerobic digestion processes such as anaerobic lagoons are unheated systems where there is a significant seasonal variation in operating temperature typically in the psychrophilic temperature range

(15-25°C) which has lower VSD than mesophilic digestion[15,16]. Hence, understanding the shear rheological behaviour in these psychrophilic conditions can have potential application in the modelling and optimization of unheated anaerobic digestion systems.

In this study, the simultaneous impact of VSD and solids concentration on the shear rheological behaviour of anaerobic digested sludge was investigated in the psychrophilic temperature range. To obtain a wide range of VSD (42% to 70%), two continuous digesters were operated at different combinations of digestion temperatures (15°C and 25°C) and HRT (16, 24 and 32-d). Shear rheological measurements (generating experimental rheograms) were conducted for digested sludge samples collected at each set of operating condition and corresponding VSD at varying solids concentrations. The Herschel-Bulkley (HB) model parameters, shear yield stress and consistency, for sludge samples at different VSDs were fitted as continuous functions of the solids volume fraction using power law and exponential correlations. The impact of key physicochemical and operational factors (volatile solids fraction, temperature, HRT and VSD) was analysed on each fitting parameter of the power and exponential correlations via linear modelling. In general, VSD had a strong impact on all parameters and no other operating parameters had significant impact compared to VSD. This implied that the proportion of volatile solids that had been consumed plays significant role on shear rheology rather than the total amount of volatile solids of sludge. This observation further supports the hypothesis that the EPS which is a product of digestion drive rheological changes. The power law and exponential fitting parameters for shear yield stress and consistency and flow behaviour index were correlated as continuous functions of VSD. The correlations for shear rheological properties as functions of solids volume fraction and VSD can be used to predict the viscosity of digested sludge for any given combination(s) of solids volume fraction and VSD. This facilitates designing the mixing systems of the digesters as non-Newtonian viscosity model for digester content is a critical input for mixing systems design.

To demonstrate the impact of VSD on shear rheology independent of the solids volume fraction, the viscosities of digested sludge samples were calculated at four different solids volume fractions using developed models at a shear rate of 10 $s^{-1}$, which approximates the average shear rate of 6.8 $s^{-1}$ in industrial digesters[17]. The viscosity of the digested sludge increased with the increase of VSD at the same solids concentration, which might reflect the microstructural changes in the EPS network.

Analysis of a hypothetical digester was conducted to understand the combined impact of solids volume fraction and VSD on the viscosity. The digester was fed with a sludge with 80% volatile solids and the feed solids concentration was varied 5%, 6% and 7%. Outlet concentrations were determined for these feed concentrations at different VSD values (40%-90%). The viscosity of digested sludge at shear rate of 10 $s^{-1}$ were calculated to determine the optimum viscosity level where the increase in viscosity caused by VSD is balanced by the decrease in viscosity caused by lower solids concentration due to digestion. There was an asymmetric shallow optimum generally in the 65%-80% VSD range depending on feed concentration. In general, it is better to achieve a higher VSD to achieve optimal viscosities, with the increase in viscosity caused by more EPS than compensated for by the decreased effluent solids except at very high VSDs.

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