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Evolution of Rheological Characteristics of High-solid Municipal Sludge during Anaerobic Digestion

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Abstract:
Rheological characterization of high-solid sludge is a fundamental requirement for optimizing the mixing and transport of high-solid sludge during anaerobic digestion in waste water treatment systems. We investigate the time evolution of physico-chemical properties and rheological characteristics of high-solid digested sludge with total solids (TS) 15–20 wt.% during anaerobic digestion. A series of experiments are carried out over a period of 26 days during the operation of an anaerobic sequencing batch reactor. In equilibrium flow curves, high-solid digested sludge exhibits shear thinning behavior with a yield stress. Strong viscoelastic behavior is exhibited in the linear and non-linear regimes in dynamic and creep tests. A critical shear stress is found in the equilibrium flow curve, which accounts for the viscoelastic property. To accurately model the flow curves, a piecewise Herschel-Bulkley function separated by the corresponding critical shear rate is proposed. The digestion time plays an important role in determining the rheological behavior. Longer digestion times lead to a decreased yield stress in creep tests, and a decreased viscosity and a reduced critical shear stress in the steady flow curve. In addition, the storage modulus G' and the loss modulus G'' are reduced as digestion proceeds, leading to a shorter linear viscoelastic regime. Moreover, we find that the storage modulus G' varies linearly with the concentration of total organic matter in the sludge, suggesting that G' could be used as a new control parameter for monitoring of the anaerobic digestion process.

Key words:
Anaerobic digestion, high-solid sludge, organics content, viscoelasticity

1 INTRODUCTION

In waste water treatment plants, anaerobic digestion is a favorable choice to reduce the quantity of sewage sludge as well as to stabilize its biochemical activity. The anaerobic digestion process is a biological transformation that takes place in the absence of oxygen and that decomposes the big organic flocs in sludge into small organic and inorganic compounds, with biogases such as methane and carbon dioxide produced. Following treatment, sludge becomes a homogeneous mixture with more colloidal particles included [1] and less extracellular polymeric substances (EPS) [2]. This technology has also been widely utilized in treating agricultural manure and food waste.

Compared to traditional low-solid anaerobic digestion, high-solid anaerobic digestion refers to the digested sludge containing total solid (TS) more than 15 % by weight (wt.%) [3]. Generally, the feedstock of high-solid anaerobic digestion is sludge that has firstly been conditioned and then dewatered by either plate-and-frame filter press or centrifugation. Owing to the high TS content, high-solid anaerobic digestion usually takes place in relatively small volume reactors and has high organic loads, resulting in a relatively high volumetric biogas production rate [4]. These technological benefits have promoted the application of high-solid anaerobic digestion [5]. However, a high energy input is required to homogenize and transport the feedstock and significant improvements in the efficiency of the process may be possible. This can be achieved by robust design of the fluid machinery systems involved in anaerobic digesters (e.g. mixers [6, 7], pumps [8], and pipelines [7, 9]) based on a thorough understanding of the fluid flow and mass transfer mechanisms of high-solid sludge in anaerobic digesters. Such knowledge is essential in order to accurately predict the flow behavior and calculate head losses and required pumping power. In this context, it is vital to thoroughly characterize the rheological behavior of high-solid sludge [10, 11].

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results show that all high-solid digested sludges at different digestion time exhibit shear thinning behavior with yield stress, and also strong viscoelastic behavior. A critical shear stress that can reflect the viscoelastic properties, was found in the equilibrium flow curve of each sample. All corresponding critical shear rates are around 1.6 s^{-1}. To model the flow curves, a two-part Herschel-Bulkley model, split by the corresponding critical shear rate was proposed. Secondly, the results indicate that rheological properties, such as yield stress, apparent viscosity, critical shear stresses (τ_c, τ_1, and τ_2), G', G'' and LVE regime, decreased with digestion time. With regard to the dynamic viscoelasticity, anaerobic digestion has a greater influence on the elastic behavior than it does on the static viscous behavior of high-solid sludge. Furthermore, our results suggest G' could serve as a possible new controlling parameter of the anaerobic digestion process because it shows good linear relationships with VS/TS and TOC (but has no relationship with LB-EPS). Therefore, rheological behavioral changes, especially with regard to the change of G', could reflect the progressive effect of anaerobic digestion with time. Still, the feasibility of utilizing sludge rheology as a controlling parameter for the anaerobic digestion process should be further confirmed in additional future studies.

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