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Review

Essence of disposing the excess sludge and optimizing the operation of wastewater treatment: Rheological behavior and microbial ecosystem

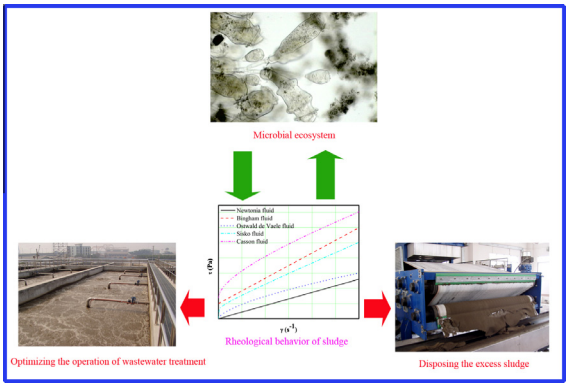
Bing Tang *, Zi Zhang

School of Environmental Science and Engineering, Guangdong University of Technology, 510006 Guangzhou, PR China

HIGHLIGHTS

- The key factors in determining the rheological behavior of sludge were demonstrated.
- The essence of operation and management of a WWTP was dissected.
- Future research direction in this area was recommended.

GRAPHICAL ABSTRACT



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ABSTRACT

Proper disposal of excess sludge and steady maintenance of the high bioactivity of activated sludge in bioreactors are essential for the successful operation of wastewater treatment plants (WWTPs). Since sludge is a non-Newtonian fluid, the rheological behavior of sludge can therefore have a significant impact on various processes in a WWTP, such as fluid transportation, mixing, oxygen diffusion, mass transfer, anaerobic digestion, chemical conditioning and mechanical dewatering. These are key factors affecting the operation efficiency and the energy consumption of the entire process. In the past decade—due to the production of large quantities of excess sludge associated with the extensive construction of WWTPs and the emergence of some newly-developed techniques for wastewater purification characterized by high biomass concentrations—investigations into the rheology of sludge are increasingly important and this topic has aroused considerable interests. We reviewed a number of investigations into the rheology of sludge, with the purpose of providing systematic and detailed analyses on the related aspects of the rheological behavior of sludge. It is clear that, even though considerable research has focused on the rheology of sludge over a long time period, there is still a need for further thorough investigation into this field. Due to the complex process of bio-treatment in all WWTPs, biological factors have a major influence on the properties of sludge. These influences are however still poorly understood, particularly with respect to the mechanisms involved and magnitude of such impacts. When taking note of the conspicuous biological characteristics of sludge, it becomes important that biological factors, such as the species composition and relative abundance of various microorganisms, as well as the microbial community characteristics that affect relevant operating processes, should be considered.

* Corresponding author. Permanent address: No. 34-5-703#, Wushan Campus, Guangdong University of Technology, Tianhe District, Guangzhou 510643, PR China. Tel.: +86 20 39322295; fax: +86 20 38457257.
E-mail address: renytang@163.com (B. Tang).

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Contents

1. Introduction

As a result of the massive increase in human population size during the past few decades, the amount of domestic sewage wastewater has increased significantly. Due to the oxygen-consuming organic pollutants present in such wastewater, it poses a serious threat to the aquatic environment. Purification of domestic sewage wastewater is therefore increasingly important in order to abate the pollution to the aquatic environment and to avoid a critical global water-shortage crisis. The biodegradable characteristics of organic substances contained in wastewater have led to the development of numerous biological processes for the treatment of wastewater, particularly for the treatment of organic pollutants in domestic sewage wastewater. Biological treatment of wastewater containing organic pollutants utilizes the metabolism of microorganisms to degrade organic pollutants and to improve effluent quality (Nielsen et al., 2010). During the process of bio-purification, organic pollutants are decomposed to smaller molecules, such as CO_2, H_2O, CH_4, N_2 and H_2S, either by aerobic or anaerobic processes. Uptake of some organic pollutants into somatic cells in certain microorganisms also takes place, leading to the growth of microorganisms and the accumulation of biomass in bioreactors. When microorganisms proliferate in abundance and flock together, they form a bio-sludge aggregation in aerobic or anaerobic operating bio-treatment tanks, referred to as mixed liquid suspended solids (MLSS), or "activated sludge". Bioactivity and concentration of activated sludge are essential components of bio-treatment processes (Han et al., 2012), but excessive solids may have a negative effect on the operation and the quality of effluents. The surplus sludge, generally with a synthesis yield in the range of 0.4–0.6 kg VSS (volatile suspended solids) kg^{-1} COD (Khursheed and Kazmi, 2011), must be discharged from the bioreactor. The bio-sludge thus acts as a substantial component for the removal of organic pollutants on one hand. On the other hand, it may also be the end-result of a bio-conversion of organic pollutants and is often discharged from bioreactors as excess sludge.

In the past decade, efforts to achieve effective purification of wastewater containing organic pollutants have aroused concerns on two related aspects. One aspect relates to the development of some bio-treatment techniques that are characterized by high biomass concentrations, i.e. the membrane bioreactor (MBR) (Lin et al., 2012; Skouteris et al., 2012; Smith et al., 2012). The other aspect relates to is the extensive construction of WWTPs, which has resulted in the creation of large volumes of excess sludge (Hazrati and Shayegan, 2011; Troiani et al., 2011; Imbierowicz and Chacuk, 2012). Both aspects have a close relationship with sludge in terms of hydrodynamic behavior (or fluid type) (Braak et al., 2011). For example, the MBR combines a traditional activated sludge process with membrane separation, leading to a high accumulation of biomass within the system, which results in improved effluent quality with a low demand for space. Due to the effective entrapment of sludge by the membrane modules, an operating MBR may accumulate very high concentrations of biomass (Krampe and Krauth, 2003), to as high as 20 g L^{-1} (Hasar et al., 2004), which is about ten times higher than that of a traditional activated sludge process (Mori et al., 2006). Such a concentration has a strong influence to the hydrodynamic type of sludge within the bioreactor and thus determines the efficiency of the operation process in terms of mass transfer, oxygen diffusion (Guimet et al., 2007), fluid flow, and membrane fouling (Meng et al., 2007; Al-Halbouni et al., 2008). Additionally, in terms of satisfying the increasing demand of wastewater purification, however, numerous facilities for treating domestic and industrial wastewater containing organic matter, have been successfully constructed and operated using bio-processes. As a result, huge volumes of excess sludge are produced, leading to serious environmental problems in many countries (Appels et al., 2008; Smith et al., 2009; Abe et al., 2011; Hait and Tare, 2011). Maximum volume-reduction of excess sludge is a great