Water Research 105 (2016) 320–330

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

The potential use of shear viscosity to monitor polymer conditioning of sewage sludge digestates

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ARTICLE INFO

Article history:
Received 13 April 2016
Received in revised form
21 July 2016
Accepted 3 August 2016
Available online 2 September 2016

Keywords:
Digestate management
Digested sewage sludge
Storage conditions
Conditioning requirements
Polymer dose monitoring
Rheological characteristics

ABSTRACT

The work assessed the use of shear viscosity at 0.1 s^{-1} ($\eta_{[0.1\ s^{-1}]}$) as a parameter to detect changes in the conditioning and dewatering of digestates. Total and soluble fractions of organic matter of digestate samples before and after storage were also assessed in regards to their conditioning and dewatering performance. Digestate from a conventional mesophilic anaerobic digestion (CMAD) and advanced anaerobic digestion (AAD) plants were used. Linear regression and correlation analysis of 29 different parameters showed that soluble and total fractions of organic matter (N_{org}, Sc, Sp, Tp, TKN/COD, tCOD and sCOD) during plant operation and storage conditions correlated (*r* between 0.80 and 0.99) with the variation in polymer dose, floc strength and CST of conditioned digestate samples. The variations occurred within the content of soluble and total fractions of organic matter, and showed to correlate with both conditioning requirements and the variation in $\eta_{[0.1\ s^{-1}]}$. The work concluded that $\eta_{[0.1\ s^{-1}]}$ measurements of unconditioned digestate samples have the potential to be used as a parameter to monitor conditioning requirements during digestate storage or during process changes. It was found important to analyse soluble and total fractions of organic matter in order to understand the changes in $\eta_{[0.1\ s^{-1}]}$ within specific process conditions.

1. Introduction

The management of sewage sludges from wastewater treatment works (WwTW) has been an important topic of research because rapidly increasing population, urbanization and industrialization, extended sewer distribution and new installations of WwTWs have elevated sludge production rates. Sewage sludge generation has been increasing and the requirements for enhanced treatment and resource recovery has become higher on the agenda of the waste water treatment sector since the implementation of the water framework directive (Directive 2000/60/EC) (WssTP, 2015). For many years anaerobic digestion (AD) has been the chosen process for the management and final treatment of biosolids in WwTW, it is estimated that 66% of sewage sludge in the UK is treated via anaerobic digestion (EBA, 2015). With the need to comply with the Nitrates Directive (1991) and local competition for land based markets, the costs of transportation and spreading of digested sludges will likely increase. Digestates will therefore be required to find alternative markets, and as part of this the need to dewater will become even more important. The economic performance of WwTW is critically dependent on the 'dewatering' process that is applied to the biosolids before and after AD. It is estimated that biosolids management can contribute to 60% of the annual WwTW operating costs (Bharambe and Van Der Schyff (2014)). Additionally, the expense of conditioning chemicals may constitute a significant portion of the wastewater treatment operating costs, and may, in some instances be as high as 20% of the total treatment plant operating costs (Abu-Orf et al., 2004). Reduction in chemical costs and improvements in dewatering are thus very desirable and increased knowledge on how to accomplish this is required.

Dewatering is a process that usually involves three key stages: coagulation and flocculation, filtration of the conditioned sludge and consolidation phase of the remaining solids cake

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http://dx.doi.org/10.1016/j.watres.2016.08.007
0043-1354/

Abbreviations

AAD	Advanced Anaerobic Digestion
AC	Ash Content (% DM)
AD	Anaerobic Digestion
CMAD	Conventional Mesophilic Anaerobic Digestion
CST_{min}	Minimum capillary suction time
DM	Dry Matter (%)
EPS	Extracellular Polymeric Substances
HT	Holding Tank
N_{org}	Total organic bound nitrogen
ODM	Organic Dry Matter (% DM)
PD_{max}	Polymer dose required to achieve the maximum network strength (g/kgTS)
PD_{min}	Polymer dose required to achieve the minimum capillary suction time (g/kgTS)
Sc	Soluble fraction of total carbohydrates (mg/l)
Sc/Tc	Ratio between soluble and total fraction of carbohydrates (%)
sCOD	Soluble fraction of chemical oxygen demand (mg/l)
sCOD/tCOD	Ration between soluble and total fraction of chemical oxygen demand (%)
SMP	Soluble microbial products
sN_{org}	Soluble organic bound nitrogen
Sp	Soluble fraction of total protein (mg/l)
Sp/Sc	Ratio between soluble fractions of protein and carbohydrates (%)
Sp/Tp	Ratio between soluble and total fraction of protein (%)
sTKN	Soluble fraction of total kjeldhal nitrogen (mg/l)
sTKN/sCOD	Ratio between soluble fraction of total kjeldhal nitrogen and chemical oxygen demand (%)
sTKN/tTKN	Ratio between soluble and total fraction of total kjeldhal nitrogen (%)
suCOD	Soluble fraction of unidentified chemical oxygen demand (mg/l)
suCOD/tuCOD	Ration between soluble and total fraction of unidentified chemical oxygen demand (%)
Tc	Total fraction of total carbohydrates (mg/l)
tCOD	Total fraction of chemical oxygen demand (mg/l)
TH	Thermal hydrolysis
Tp	Total fraction of total protein (mg/l)
Tp/Tc	Ratio between total fractions of protein and carbohydrates (%)
tTKN	Total fraction of total kjeldhal nitrogen (mg/l)
tTKN/tCOD	Ratio between total fraction of total kjeldhal nitrogen and chemical oxygen demand (%)
tuCOD	Total fraction of unidentified chemical oxygen demand (mg/l)
Wu_{max}	Maximum network strength (MJ/gTS)
$\eta_{[0.1\ s^{-1}]}$	Limit shear viscosity measured at 0.1 s^{-1} for 600 s (Pa.s)

(Tchobanoglous et al., 2014). Dewatering can be a complex process to optimize since each stage is directly dependent on sludge chemical and physical characteristics (Christensen et al., 2015), polymer type and dosage (Saveyn et al., 2005) (Ayol and Dentel, 2005), mixing energy applied during conditioning (Wang and Dentel, 2010) (Sievers et al., 2008) and pressure applied during filtration and expression phases (Olivier and Vaxelaire, 2005) (Skinner et al., 2015). Typical practices for measuring dewaterability include jar test settling rates, specific resistance to filtration (SRF) test, time to filter (TTF) test and capillary suction time (CST) measurements. However, these measurements are all 'off-line' techniques that require manual sampling and thus are poorly suited to the monitoring of full scale plants. In a treatment facility with existing dewatering equipment and with digestate flows and characteristics that could both vary over time, improved conditioner use and control may be an important way to improve and optimize dewatering operation (Örmeci, 2007). Several researchers Yen et al. (2002), Abu-Orf and Örmeci (2004), Ayol and Dentel (2005) , Dentel and Dursun (2009) and Wang and Dentel (2010), have chosen rheology as a way to predict, control, or optimize conditioning and dewatering processes using different rheometric measurements. However, as conducted by Marinetti et al. (2010) the correlations between rheological parameters and dewatering properties were not consistent or strong enough to indicate that these rheological tests (dynamic and rotational measurements) could be used to provide useful information regarding full scale dewatering performance. The sludge dewaterability was only related with its rheological properties in an indirect manner, as polymer dose increased network strength increased up to a threshold beyond which further network strength conferred no improvement in dewatering.

It has been reported that there is a positive correlation between soluble EPS (measured as soluble proteins and carbohydrates) with polymer demand (Novak et al. (2003), or increased resistance to filtration for sludges with higher EPS and SMP (Li and Yang, 2007). In addition, in Miller et al. (2008) it is shown that the sludge biofloc structure (size, shape and strength) of unconditioned sludges influences the residual amount of water in the cake rather than the characteristics of the flocs produced after polymer conditioning. Nevertheless, more studies are required that relate these compounds and sludge biofloc characteristics with the conditioning and dewatering performance of full scale processes, which could potentially lead to the development of online tools that could measure digestate changes and adjust polymer dose accordingly. Significant operational performance changes can be realized by implementing process control techniques that use real-time monitoring and 'on-line' control of polymer dosing in dewatering processes (Gillette and Joslyn, 2000). The present work, aims to assess the applicability of shear viscosity ($\eta_{[0.1\ s^{-1}]}$) to detect small variations of total and soluble fractions of organic matter and its impact on flocculation and dewatering. Rheological measurements were chosen due to the potential ease of interpretation of the results, relative rapidity and the potential for online implementation. Two established rheometric tests were used to measure conditioned sludge network strength (Wu) and unconditioned sludge biofloc characteristics expressed as $\eta_{[0.1\ s^{-1}]}$.

2. Material and methods

Different types of digestates were used i.e. a conventional mesophilic AD digestate and advanced anaerobic digestion (AAD) digestate samples. Digestate samples were stored at different temperatures (20, 35, 80, 100, 120 and 165 °C), or stored for longer periods with and without aeration (from periods of a couple of hours to 1 and 9 days) to drastically change their initial characteristics for comparison purposes. Flocculation was assessed by determining the Wu of the conditioned samples using the method proposed by Abu-Orf and Örmeci (2004) and dewaterability was