Water Research 104 (2016) 53–71

Contents lists available at ScienceDirect

Water Research

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

Review

Thermal hydrolysis for sewage treatment: A critical review

W.P.F. Barber

Cambi, Inc., 5 Great Valley Parkway, Suite 210, Malvern, PA, 19355, United States

A R T I C L E I N F O

Article history:
Received 1 June 2016
Accepted 28 July 2016
Available online 30 July 2016

Keywords:
Anaerobic digestion
Dewatering
Rheology
Sewage treatment
Thermal hydrolysis

A B S T R A C T

A review concerning the development and applicability of sewage sludge thermal hydrolysis especially prior to anaerobic digestion is presented. Thermal hydrolysis has proven to be a successful approach to making sewage sludge more amenable to anaerobic digestion. Currently there are 75 facilities either in operation or planning, spanning several continents with the first installation in 1995. The reported benefits of thermal hydrolysis relate to: increased digestion loading rate due to altered rheological properties, improved biodegradation of (especially activated) sludge and enhanced dewaterability. In spite of its relative maturity, there has been no attempt to perform a critical review of the pertinent literature relating to the technology. Closer look at the literature reveals complications with comparing both experimental- and full-scale results due to differences in experimental set-up and capability, and also site-specific conditions at full-scale. Furthermore, it appears that understanding of thermodynamic and rheological properties of sludge is key to optimizing the process, however these parameters are largely overlooked by the literature. This paper aims to bridge these complexities in order to elucidate the benefits of thermal hydrolysis for sewage treatment, and makes recommendations for further development and research.

Contents

1. Introduction

Thermal hydrolysis of sewage sludge, which involves the application of heat at above autoclave temperature for a defined

E-mail address: bill.barber@cambi.com.

http://dx.doi.org/10.1016/j.watres.2016.07.069

time period prior to anaerobic digestion, is an established commercially available technology since the first full-scale plant in HIAS in 1995 (Ødeby et al., 1996). The heat is typically provided by live steam injection at design temperature and concomitant pressure which is then rapidly released (exploded), although some configurations use standard heat exchange (Pereboom et al., 2014). At the time of writing, there are 75 facilities of which 39 are operating and the remaining are in various stages of design. In total, 1.65 million metric dry tonnes of sludge per year are, or will be, processed with thermal hydrolysis. Although facilities cover most major continents, the vast majority are in Europe (57) within which the UK boasts 19 operational plants (Kleiven, personal communication). Drivers for installation are geographically market driven but typically include: increased loading rates (to minimize size of new digestion plants, or maximize use of existing facilities); improved sludge cake dewaterability which reduces downstream transport and processing costs; increased production of renewable energy, and sterilization of sludge. Lists of reported advantages and disadvantages are given in Tables 1 and 2.

Although most emphasis has been given to use of the technology to improve biodegradability of sludge with process efficacy being inversely proportional to the initial biodegradability of the material (Wilson and Novak, 2009), thermal hydrolysis was originally seen as a means to improve sludge dewaterability (Lumb, 1940, 1951). Interest gathered pace in the early 1970s when significant improvements in dewaterability were correlated with heat application to various sludges (Everett, 1972). A few years later, the concept of applying the technology to improve the biodegradability of sewage sludge – mainly that produced from activated treatment well known to be poorly biodegradable (Rudolfs and Heisig, 1929) – was conceived (Haug, 1977; Haug et al., 1978; Stuckey and McCarty, 1984).

Although the technology has been commercially available for 20 years and numerous laboratory-scale experiments have been conducted on the process, there has been no systematic review of the information available. Whilst there is a great deal of useful information in the literature, closer observation reveals that it is difficult to cross-reference findings on both laboratory- and full-scale. At laboratory-scale there appears to be no standardized apparatus for thermal hydrolysis testing, nor a standard protocol for running a thermal hydrolysis unit at that scale. This leads to inconsistent findings, such as steam explosion being highly influential (Abelleira-Pereira et al., 2015; Perrault et al., 2015) or insignificant (Ngwenya et al., 2015); the requirement for long reaction times (Li and Noike, 1992) or not (Neyens and Baeyens, 2003; Abelleira-Pereira et al., 2015; Donoso-Bravo et al., 2011), as examples. Furthermore, there is scarce information provided on the sludge being tested, especially on rheological, thermodynamic and bacteriological properties, which is surprising considering their importance in controlling the efficacy of the thermal hydrolysis and downstream anaerobic digestion and dewatering processes. Many studies present biogas production from BMP tests based on the pivotal methodology presented by Owen et al. (1979), however data is rarely provided on the inoculum source, such as previous exposure to thermal hydrolysis processed feed material. This becomes especially important if kinetic data is being collected for predictive modelling purposes as it may not be relevant for mature full-scale systems which have evolved bacteriological populations dependent on configuration (De Vrieze et al., 2015) and would therefore respond differently. At full-scale, difficulty comparing sites is attributable to site-specific variables involving: sludge type (configuration of wastewater treatment plant; aeration sludge age;

Table 1
Reported advantages of thermal hydrolysis.

Advantages	References
Significantly improves the biodegradability of activated sludge	Haug, 1977; Haug et al., 1978; Stuckey and McCarty 1978, 1984; Liao et al., 2016; Xue et al., 2015
Improves the biodegradability of primary sludge	Wilson and Novak, 2009
Allows significantly higher loading rates resulting in smaller digestion plants	Xue et al., 2015; Ngwenya et al., 2015
Increases rate of biogas production	Various
Reduces sludge viscosity	Liu et al., 2012; Higgins et al., 2015; Oosterhuis et al., 2014; Bougrier et al., 2006
Improves sludge dewaterability on all dewatering systems	Higgins et al., 2015; Phothilangka et al., 2008; Everett, 1972; Oosterhuis et al., 2014;
Sterilizes sludge providing pathogen-free biosolids	Barber, 2010; Haug et al., 1978 Lumb, 1951; Sheerwood and Philips, 1970
Reduces odour and pathogen regrowth from dewatering	Neyens and Baeyens 2003; Chen et al., 2011
Eliminates scum and foaming and produces conditions which do not encourage foaming	Jolis and Marneri 2006; Alfaro et al., 2014
Minimizes inhibition due to hydrogen sulphide	
Significantly reduces downstream requirements for drying and other thermal processes	Rawlinson et al., 2009; Merry and Oliver, 2015; Qiao et al., 2012, 2013; Pickworth et al., 2006
Numerous sites successfully operating at full-scale	

Table 2
Reported disadvantages of thermal hydrolysis.

Disadvantages	References
Parasitic energy demand with some configurations (depends on process)	
Higher ammonia concentration than standard digestion	Oosterhuis et al., 2014; Wilson and Novak, 2009; Tampio et al., 2014;
Potential for and production of refractory material especially with food-waste	Tampio et al., 2014; Liu et al., 2012; Dwyer et al., 2008
Potential increase in polymer demand for dewatering	Oosterhuis et al., 2014
More complex than standard anaerobic digestion	
Requires boilers	
Sludge needs cooling prior to anaerobic digestion	
Requires centrifuge thickening to 16–18% DS	
Higher release of nutrients with potential for salt crystalization and subsequent maintenance issues and deterioration of dewaterability	