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Experiences with the dual digestion of municipal sewage sludge

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Abstract

The dual digestion process was investigated using sludge samples collected at the WWTP of Tomaszow Mazowiecki (Poland). Mixed sludge was treated in a laboratory setup under batch and semi-continuous conditions. Dual digestion with a 1 d SRT aerobic thermophilic pretreatment followed by an anaerobic step with 20 d of SRT turned out to be optimal, since a 44–46% VS reduction and a biogas yield of 480 dm^3/kg VS fed were achieved. In the course of the process, the concentration of nitrogen in supernatant increased over 5 times and its major portion was converted into ammonia. Phosphorus also entered the supernatant, reaching over 200 g/m^3. The dual digestion noticeably deteriorated the sludge dewaterability. Following completion of the process, capillary suction time measurements averaged 64 s for the raw sludge, 400 s for aerobically pretreated sludge and 310–360 for the anaerobically digested sludge. Aerobic pretreatment consistently reduced Enterobacteriaceae content to below detectable limits.

Keywords: Sludge digestion; Sludge stabilization; Dual digestion; Aerobic thermophilic pretreatment; Pathogen inactivation; Nutrient control; Sludge dewatering

1. Introduction

The principal objective of sewage sludge treatment is its stabilization, that is a controlled decomposition of easily degradable organic matter resulting in a significant reduction of volatile solids content, a change of an unpleasant smell into an earthy one, and an elimination of sludge putrescibility. The most common methods of sludge stabilization are biological processes of anaerobic mesophilic digestion and aerobic digestion at ambient conditions, both of which are not without disadvantages. Anaerobic mesophilic digestion, due to relatively long SRT, high sensitivity and biogas production, needs large reaction volumes, gas collecting tanks and complex instrumentation (Kelly, 1989). Aerobic biological stabilization at ambient conditions also needs large operation volumes as well as energy consuming aeration devices and has traditionally been undertaken for small communities (Kelly, 1989).

An alternative system that overcomes the above mentioned problems is autothermal thermophilic aerobic digestion (ATAD). This unique and relatively new process was developed by Hubert Fuchs, and has been operated successfully in several countries including Germany, USA and Canada (Fuchs and Schwinning, 1997; Kelly, 1989; Kelly et al., 1993; Schwinning et al., 1997). ATAD represents a biological system that converts biodegradable organic matter to lower-energy forms (mainly CO_2 and H_2O) through aerobic and fermentative processes. Part of the energy obtained during the oxidation of organic matter is dissipated into sludge as heat, which, if conserved, will yield operation at thermophilic temperatures (Kelly and Warren, 1995).

A modification of the ATAD system, known as the dual digestion process, utilizes an aerobic thermophilic pretreatment (ATP) prior to anaerobic digestion. In the first stage of this technology, sludge is "pretreated" through efficient solubilization and partial digestion (acidification) of particulate organic matter. Due to a very short retention time, usually 12–24 h, very little sludge stabilization takes place in the aerobic reactor – only to the degree that the heat generated biologically maintains thermophilic temperatures.

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Nomenclature

AD	anaerobic digestion	TAL	total alkalinity ($gCaCO_3/m^3$)
ATAD	autothermal thermophilic aerobic digestion	TC	total carbon (gC/kg TS)
ATP	aerobic thermophilic pretreatment	TKN	total Kjeldahl nitrogen (gN/kg TS) or (gN/m^3)
COD	chemical oxygen demand (gO_2/kg TS)	TOC	total organic carbon (gC/kg TS)
CST	capillary suction time (s)	TP	total phosphorus (gP/kg TS) or (gP/m^3)
HRT	hydraulic retention time (d) or (h)	TS	total solids (g/kg)
MPN	most probable number	VFA	volatile fatty acids (gCH_3COOH/m^3)
$N–NH_4$	ammonium nitrogen (gN/m^3)	VS	volatile solids (g/kg)
PE	population equivalent	WAS	waste activated sludge (excessive sludge)
SRT	solids retention time (d)	WWTP	wastewater treatment plant

However, the raw sludge should be externally preheated to the thermophilic temperatures. The aerobic reactor is operated under oxygen limiting conditions, which, in conjunction with the short HRT, results in the formation of significant concentrations of soluble products including volatile fatty acids, through the fermentative metabolism of thermophilic bacteria (Messenger et al., 1993; Mason et al., 1987; Häner et al., 1994; McIntosh and Oleszkiewicz, 1997; Pitt and Ekama, 1996). In the second anaerobic mesophilic digestion step final and full stabilization takes place. By aerobic thermophilic pretreatment, the anaerobic digestion efficiency is enhanced when compared to a conventional single stage process, resulting in shorter SRT (usually 8–15 d), higher VS destruction, greater pH stability through the production of alkalinity, and complete pathogen inactivation (production of Class A biosolids according to the EPA regulations) (McIntosh and Oleszkiewicz, 1997; Messenger et al., 1993; Pagilla et al., 1996, 2000; Ward et al., 1998).

This study was initiated to evaluate the dual digestion of municipal mixed sewage sludge by the determination of the impact of aerobic thermophilic pretreatment on the anaerobic digestion performance in the second step (VS reduction, SRT and biogas production). Of particular interest was the determination of changes in nutrient concentrations in the sludge supernatant as well as changes in sludge dewaterability during digestion. Pathogen inactivation efficiency of the stabilization process was also evaluated.

2. Methods

2.1. Materials

Laboratory scale experiments were conducted using mixed sludge, primary and waste activated in the average proportion of 1:2 respectively. The sludge was taken from the Municipal Wastewater Treatment Plant at Tomaszow Mazowiecki, Poland, serving a population equivalent of about 70,000 inhabitants. This plant was operated with a conventional activated sludge process for BOD removal only (without enhanced biological nutrient removal). Before the experiments the sludge was pre-thickened to approximately 5% TS. The elemental composition of raw sludge is shown in Table 1.

2.2. Experiments

The laboratory scale experiments were conducted using a 12 dm^3 aerobic thermophilic reactor with a working volume of 7 dm^3, followed by a 10 dm^3 anaerobic mesophilic digester (working volume of 7 dm^3). The control system consisted of a 10 dm^3 anaerobic mesophilic digester (working volume of 7 dm^3). The aerobic thermophilic reactor was operated at 55 ± 2 °C whereas the anaerobic digesters were operated at 35 ± 1 °C. The units were placed inside constant temperature chambers to maintain consistent temperatures. The aerobic reactor was supplied with air at a flow rate of 40 dm^3/dm^3 h by mean of a Secoh Air Pump laboratory blower. The reactor and digesters were operated with stirring and with no recycle, so that the system SRT and HRT were equal.

In *batch experiments* the ATP reactor was filled with the heated raw sludge and aerated under thermophilic conditions for 12, 24, 36 and 48 h depending on the process series. The aerobically pretreated sludge was then fed to the anaerobic digester where the mesophilic digestion took place, without addition of seed material. The anaerobic digestion was continued to the point when only a residual biogas production was found (no more than 20 cm^3/dm^3 digester active volume per day). The control anaerobic process was operated in the same manner with the exception that sludge was not aerobically pretreated (HRT of aerobic step was 0 h).

In *semi-batch experiments* the ATP reactor was fed an equal volume of heated raw sludge every 12 h, with effluent sludge removal before feeding. The operating SRT of the aerobic reactor was determined in batch experiments. Two anaerobic digesters were batch fed constant portions of aerobically pretreated sludge (depending on a selected SRT for each digester) every 24 h, also with effluent sludge removal before feeding. Digesters were operated at SRTs of 20, 30 and 40 d. To ensure steady state operation digesters were operated for a minimum of three SRTs at each retention time.