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Pre-treatment of activated sludge: Effect of sonication on aerobic and anaerobic digestibility

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ABSTRACT

Aerobic and anaerobic digestions were compared in reactors fed with sonicated activated sludge. Sonication treatment of activated sludge led to solubilisation of matter and especially of organic compounds. An important improvement of aerobic and anaerobic biodegradability was observed for a sonication treatment of 108,000 kJ kg TS^{-1} due to the increase of the instantaneous specific soluble COD uptake rate. Sonication led to an increase of biogas production due to the increase of available soluble COD. In this study, sludge sonication prior to aerobic digestion in the aim of enhancing sludge reduction was inconclusive. Under anaerobic conditions, the enhancement of sludge reduction due to sonication depended on the disintegration degree of the sludge. The combination of high disintegration degree of sonicated sludge prior to an anaerobic digestion led to very good results in term of sludge reduction (80%). Energy balance was also studied.

1. Introduction

Treatment and disposal of excess sludge represent a bottleneck of wastewater treatment plants, due to environmental, economic, social and legal factors. Many treatments such as dewatering, digestion, burning, land filling and use in agriculture have been carried out for the disposal of excess sludge. Because of the high cost of these treatments, interest for solutions allowing sludge volume and mass reduction is increasing [1].

Most mechanical and physico-chemical pre-treatment tested so far has targeted cell lysis: ultrasound disintegration [2,3], shear stress forces [4], alkaline pre-treatment [5,6], thermal pre-treatment [7], alkaline combined with thermal hydrolysis [8,9] as well as other oxidation processes (ozone, hydrogen peroxide, etc.) [10,11]. Ultrasonic treatment is one of the most promising recent technologies to reduce sludge production in wastewater treatment plants [12]. Ultrasonic treatment has positive effects: reliability of operation (high degree of research and development), no odour generation, no clogging problems, easiness to implement in a WWTP, good dewaterability of the final sludge but unfortunately negative aspects: erosion of the sonotrode, negative energy balance due to the high energy consumption of the equipment [13].

The major effects of sonication on physico-chemical characteristics of sludge are well known: solubilization and release of organic components measured as COD, proteins, nucleic acids, polysaccharides [14–16], reduction of flocs size [14,17–19], biodegradability improvement [14,20]. So, an ultrasonic pre-treatment of sludge could increase the extent of WAS biodegradability through enhanced hydrolysis. In order to reduce the global production of the sludge, the treated sludge could be recycled in the activated basin (that mean aerobically digested) or injected in a digester (anaerobic treatment) [1,3,21,22]. In both cases, the coupled process (pre-treatment plus digestion) leads to a global reduction of the quantity of effective sludge.

According to the above results, different works have been achieved on the optimization of sonication on waste activated sludge, and then on the enhancement of anaerobic digestion [3,23–28]. On the contrary, literature on the effect of sonication on aerobic digestibility of activated sludge is scarcely available and the effectiveness of aerobic digestion after sonication remains unclear [29]. For [30] the gain in sludge reduction is about 5% when comparing untreated and treated sludge while for [31] the gain of sludge reduction reaches 10%. Simplicity of process and lower capital costs are the advantages of aerobic digestion when compared to anaerobic process and because of these merits, aerobic digestion has been a popular option for the small scale WWTPs. However, high energy cost and lower pathogen inactivation could be the main disadvantages of aerobic digestion [32].

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Nomenclature

COD	chemical oxygen demand ($mgO_2\,L^{-1}$)
COD_{NaOH}	soluble COD after an alkaline hydrolysis ($mgO_2\,L^{-1}$)
DD	disintegration degree (%)
EB	energetic balance ($kJ\,kgTSS^{-1}_{removed}$)
Index 0	initial value
Index f	final value
Index S	parameter value in the soluble phase
Index T	total parameter value
Index P	parameter value in the particulate phase
P	power (W)
q_{COD}	Instantaneous specific soluble COD uptake rate ($mgCOD_S\,gVSS^{-1}\,d^{-1}$)
q_{BG}	instantaneous specific biogas production ($mLBG\,gVSS^{-1}\,d^{-1}$)
S	solubilisation (%)
SE	specific supplied energy ($kJ\,kgTS_0^{-1}$)
t	sonication time (s)
TN	total nitrogen ($mg\,N\,L^{-1}$)
TP	total phosphorus ($mg\,P\,L^{-1}$)
TS	total solids ($g\,L^{-1}$)
TSS	total suspended solids ($g\,L^{-1}$)
V	sample volume (L)
VS	volatile solids ($g\,L^{-1}$)
VSS	volatile suspended solids ($g\,L^{-1}$)
WAS	waste activated sludge
Y	global yield of biogas production ($L_{BG}\,gCOD_S^{-1}$)

The aim of this work is to understand and to compare performances and dynamics of aerobic and anaerobic digestion of sonicated activated sludge; this comparison should permit to choose the most suitable process in regard to sludge reduction.

In a first part, the effect of ultrasonic treatment on sludge solubilisation and membrane integrity was evaluated under different sonication energies. In a second part, the calculation of kinetic parameters, yields and removal efficiencies was done to assess the driving parameters of biodegradability and sludge reduction enhancement due to sonication. The real impact of sonication on aerobic and anaerobic digestion enhancement in term of sludge reduction and energetic balance was finally discussed.

2. Materials and methods

2.1. Waste activated sludge samples characteristics

The activated sludge came from the municipal wastewater treatment plant of Limoges (France) (advanced biological activated sludge treatment of 47,000 m^3 per day of influent composed by 85%, v/v of domestic and 15%, v/v of organic industrial wastewater). Samples of activated sludge were collected from the recirculation loop. Before sonication, activated sludge was concentrated. The characteristics of the sludge are reported in Table 1.

2.2. Ultrasonic treatment

The ultrasonic apparatus was a Sonopuls Ultrasonic Homogenisers (*BANDELIN – GM 70*). This apparatus was equipped with a probe and worked with an operating frequency of 20 kHz and a supplied power of 60 W. For each sonication experiment, 50 mL of sludge were filled in a stainless steel beaker and the ultrasonic probe was dipped 2 cm into the sludge. The range of the specific supplied energy varied from 0 to 108,000 $kJ\,kgTS_0^{-1}$. Three specific energies (SE) were investigated: 3600; 31,500; 108,000 $kJ\,kgTS_0^{-1}$. SE was determined by using ultrasonic power (P), ultrasonic time (t), sample volume (V) and initial total solid concentration (TS_0) according to the following equation [27]:

$$SE = \frac{P\,(W) \times t\,(s)}{V\,(L) \times TS_0(g\,L^{-1})} \quad (1)$$

Table 1
Characteristics of the concentrated activated sludge before sonication

pH	7.12
COD_{T0} $mgO_2\,L^{-1}$	18750
COD_{S0} $mgO_2\,L^{-1}$	920
COD_{P0} $mgO_2\,L^{-1}$	17830
COD_{S0}/COD_{T0} (%)	4.91
TS_0 $g\,L^{-1}$	17.81
VS_0 $g\,L^{-1}$	14.25
TSS_0 $g\,L^{-1}$	17.12
VSS_0 $g\,L^{-1}$	13.96
TN_{T0} $mg\,N\,L^{-1}$	2100
TP_{T0} $mgP\,L^{-1}$	1560

2.3. Aerobic and anaerobic reactors

The anaerobic and aerobic digestions were studied in eight stirred tank reactors (magnetic agitator (Fisher-Bioblock-France, P = 40 W at 10 rpm). Four of them were dedicated to the anaerobic digestion experiments and the others to aerobic digestion. In this last case air was supplied through a sparger and an air compressor (P = 135 W) to ensure a uniform concentration of 2 $mgO_2\,L^{-1}$. Each reactor had a working volume of 3 L. The reactors were initially filled with 500 mL of inoculum, collected respectively in the aeration tank or in the digestor of Limoges WWTP, and 2.5 L of sonicated sludge (SE respectively: 0; 3600; 31,500; 108,000 $kJ\,kgTS_0^{-1}$). The digestions were carried out at usual temperatures (room temperature for aerobic digestion and 37 °C for the anaerobic digestion (as in the plant)). The produced biogas was collected in calibrated glass cylinders. The cylinders were filled with deionised water acidified with HCL (pH is close to 2) to avoid the solubilization of CO_2 [3].

2.4. Analysis

2.4.1. Chemical analysis

2.4.1.1. Chemical oxygen demand (COD_T, COD_S), total nitrogen (TN_T, TN_S) and total phosphorus (TP_T, TP_S). COD, TN and TP were measured in the total sludge (T) and in the soluble fraction (S). The soluble fraction was evaluated after centrifugation (*SORVALL T 6000 D)* at 3600 × g's for 20 min and filtration through a 1.2-μm membrane. The difference between soluble fraction (S) and total sludge (T) was called particulate (P). COD, TN and TP were evaluated using the micro-method HACH.

2.4.1.2. Total solids (TS) and volatile solids (VS). TS and VS were measured on the total sludge and TSS and VSS on solids of centrifugation (*SORVALL T 6000 D)* at 3600 × g's for 20 min. TS, VS, TSS, VSS measurement were achieved according to normalised methods (ref APHA): samples were heated at 105 °C for 24 h (determination of the total dry matter concentration) and then heated at 550 °C for 2 h (determination of mineral matter). Organic matter concentration was then deduced.

2.4.2. Biological analysis: evaluation of membrane cells integrity

2.4.2.1. Sample preparation. In order to obtain a single cell suspension, sludge pre-treatment was performed according to the method described by [33] using a mechanical blender (IKA-Turrax-