Journal of Environmental Chemical Engineering 5 (2017) 6122–6131

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

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

Research Paper

Assessment of pressure-driven electro-dewatering as a single-stage treatment for stabilized sewage sludge

Simone Visigalli[a], Andrea Turolla[a], Hai Zhang[a], Paolo Gronchi[b], Roberto Canziani[a,*]

[a] Politecnico di Milano, Department of Civil and Environmental Engineering (DICA)—Environmental Section, Piazza Leonardo da Vinci 32, 20133 Milano, Italy
[b] Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

ARTICLE INFO

Keywords:
Sewage sludge
Electro-dewatering
Dry solids
Energy consumptions

ABSTRACT

The pressure-driven electro-dewatering (EDW) of sewage sludge was assessed using a lab device. The sludge samples were supplied from four different Wastewater Treatment Plants (WWTPs) around the metropolitan area of Milan (Italy), including both aerobically and anaerobically stabilised samples. The test results show that the EDW treatment enabled to dewater the sludge samples to a dry solids content of 18.4–31.1% (wt%), which means 2.0–12.7% improvement as compared to the conventional mechanical dewatering treatment used in these WWTPs. A follow-up test was carried out with the sample giving the best dewatering performance. A dry solids content of 39.3% (wt%) was achieved. Apart from the technological performance, the economic feasibility of EDW was evaluated. The energy consumption and sludge treatment cost associated with the EDW process were compared with the reference case (the corresponding WWTP currently operating with mechanical dewatering line). It was found that for the best performance case, technology upgrade from the conventional mechanical dewatering to the EDW dewatering will enable the WWTP to reduce its sludge management cost up to 35% per year.

1. Introduction

The latest statistics indicates that the sewage sludge produced in the EU has reached 13.25 million ton per year [1]. In the light of the EU's strategy in circular economy, sludge is being regarded as a resource, which can be valorised in various forms, e.g. energy recovery from incineration [2], nutrient recycling in agriculture [3], biopolymer extraction [4] etc. In particular, sludge energy recovery from incineration has drawn considerable attention for its environmental and economic benefits [5]. In this technology route, the incineration efficiency strongly depends on the sludge dewatering and drying. On average, mechanical dewatering enables a dry solids (DS) content of 20–30% (wt%) [6–8], which is not yet enough to achieve a satisfactory incineration efficiency. Therefore, the incineration unit is usually equipped with a heat exchanger to dry the sludge or a thermal drying unit before the incineration process to increase the calorific value of the sludge [9]. However, both solutions can considerably increase the operating cost of the incineration plant.

On the other hand, conventionally, the sludge treatment and disposal account for half of the WWTP operating cost [10]. Therefore, dewatering sludge to a higher DS content for disposal means great saving for the WWTP operators [11]. This is especially true for the case of sludge used for land application [3].

As an alternative dewatering technique, pressure-driven electro-dewatering (EDW) is shown to be efficient in sludge dewatering and is able to increase the DS to 40–45% (wt%) [12–15]. The process has been investigated in many publications, with a focus on the process performance and various operating parameters, such as pressure, electric potential, current, treatment time, delaying the application of the electric field, chemical conditioning dosage and cake thickness in the EDW cell [6,7,12,15–23]. Citeau et al. have shown that the use of a DC power supply at constant electric potential, instead of constant electric current, allows to achieve a higher DS content [20] and a better control of the temperature at the end of the tests, preventing from ohmic heating [17]. The EDW process has also been used as post-treatment to further dewater the sludge samples [8,11,14,24–26]. Visigalli et al. [27] tested sludges from different treatment processes and found that the EDW can achieve higher final DS than the conventional mechanical dewatering processes.

In addition, the EDW process also enables to lower the concentrations of the heavy metals [13] and cations such as Na^+ and K^+ [28] contained within the sludge. As these species tend to migrate towards the cathode, where the water is collected. Furthermore, the EDW leads to the inactivation of pathogenic bacteria such as *Salmonella* spp., faecal

* Corresponding author.
E-mail addresses: roberto.canziani@polimi.it, roberto.canziani3@tin.it (R. Canziani).

https://doi.org/10.1016/j.jece.2017.11.034
Received 9 August 2017; Received in revised form 7 November 2017; Accepted 11 November 2017
Available online 12 November 2017
2213-3437/

Table 1
Characteristics of sludge samples taken from the four WWTPs. (DS_i: initial dry solids content). Sample 3-D was used for the follow-up test and was collected from the WWTP in a different batch.

Sample ID	Stabilisation treatment	Polymer dosage g/kg_{DS}	DS_i wt%	VS/DS %	CST s	Conductivity mS/cm	pH	Zeta potential mV
1-A		0	2.0	68.3	32.0	1.34	7.5	−11.9
1-B	Aerobic	4	2.4	68.3	22.5	1.33	7.4	−11.5
1-C		8	2.2	68.3	19.8	1.29	7.4	−11.5
2-A		0	3.3	78.4	103.3	1.84	6.9	−13.1
2-B	Aerobic	4	3.2	78.4	92.7	1.79	6.5	−12.6
2-C		8	3.2	78.4	68.8	1.68	6.6	−11.9
3-A		0	3.2	72.7	35.7	1.28	6.9	−13.4
3-B	Aerobic	4	3.0	72.7	28.3	1.26	6.9	−12.9
3-C		8	2.8	72.7	17.8	1.26	7.0	−12.1
3-D*		0	2.3	71.7	22.9	1.50	6.7	−12.6
4-A		0	4.3	64.8	155.6	4.00	6.7	−11.3
4-B	Anaerobic	4	4.3	64.8	81.6	4.00	6.7	−11.5
4-C		8	4.3	64.8	102.3	4.00	6.7	−11.0

coliforms, total coliforms and *Escherichia coli* [29,30], and this is partly attributed to the local rise of temperature (ohmic heating) [29]. These two effects are particularly interesting in the view of improved sludge quality for agriculture use.

The EDW enables to reach a higher DS at a reasonable energy consumption. It is possible to maintain a superior energy efficiency over thermal drying until reaching the DS of 38–45% (wt%) [19]. The system's efficiency can be further improved with finely designed operating protocols [20]. By taking a life cycle perspective, this part of additional input may be offset either by the reduction of polyelectrolyte in the conditioning stage, by the cost saving in the sludge transport and disposal, by the income from the energy recovery in the incineration, or by any combinations of the above-mentioned items. However, where the break-even point is situated is not known yet. In other words, in order to achieve a net positive economic performance, the energy efficiency of the EDW system needs to be carefully studied.

There are some early attempts to apply economic evaluation to the EDW process. For example, Saveyn [31] calculated the payback period, i.e. the time needed to offset the initial capital investment from the cost saving due to the use of EDW. However, the calculation lacks primary data from the industry (equipment supplier and WWTP). In another study [24] the author considered the EDW cost saving in one aspect only (sludge disposal). Similarly, in a latest research [32], the author only briefly evaluated the economic feasibility by considering the energy consumption and the cost of the conditioner. Therefore, a more comprehensive evaluation that includes all the relevant aspects is needed.

The present work is a follow-on of our last publication [27]. The sludge samples have been supplied from four different WWTPs around the metropolitan area of Milan (Italy), including both aerobically and anaerobically stabilised samples. These samples are dewatered in our "single-stage" EDW lab device, with the aim to provide guidelines for our industrial prototype machine which is currently under development. To this end, several operating parameters will be assessed and optimised, including the polyelectrolyte dosage, cake thickness, and electric potential. More importantly, the energy consumption and operating costs of using EDW will be derived from the tests. These results will be compared with the actual operating cost extracted from the four WWTPs, which are running with conventional mechanical dewatering lines. The objective is to justify the economic feasibility and cost saving potential for these WWTPs when upgrading to the EDW system, with a focus on the costs of polyelectrolyte, electrical energy for dewatering and sludge disposal.

2. Materials and methods

2.1. Sludge characterisation

Sludge samples were taken from four different WWTPs around the metropolitan area of Milan (Italy). WWTP 1, 2 and 3 provided aerobically stabilised sludge, whereas WWTP 4 provided anaerobically digested samples. The thickened sludge samples were collected before the conditioning step.

The conditioning tests were performed in three jar-test beakers, one used as control and the other two, among the typical dosages used in WWTPs [33], operated with two different doses (4 and 8 g/kg_{DS}) of polyamidic and high cationic polyelectrolyte (Tillflock CL-1480). Initial DS (DS_i) amount, volatile solids to dry solids (VS/DS) ratio and capillary suction time (CST) were measured according to Standard Methods (APHA/AWWA/WEF 2012). Electrical conductivity was monitored by a conductivity meter (B&C Electronics-C 125.2) and pH by a pH-meter (Metrohm 827 pH Lab). Sludge samples were filtered under vacuum with a Whatman 42 filter cloth (2.5 µm pores size) and the zeta potential of the filtrate was determined by the instrument Malvern Zetameter ZS90. Prior to use, sludge samples were stored at 4 °C up to a maximum of 1 week in order to keep their properties unaltered.

Table 1 lists the main characteristics of sludge samples collected from the four WWTPs. The A-named samples are related to the unconditioned (control) sludge, whereas samples B and C refer to the sludge conditioned with the two different doses of polyelectrolyte, 4 and 8 g/kg_{DS}, respectively. Sample 3-D refers to an unconditioned sludge sample. It was collected from WWTP 3 at a later time, and used in the follow-up test.

2.2. Mechanical dewatering in the four WWTPs

Table 2 lists some details of the sludge treatment in the four WWTPs: the polymer dosage, the dewatering treatment, the DS content and the VS/DS ratio achieved, the energy consumption and the main routes for sludge disposal are shown. Among the four WWTPs considered in the present work, WWTP 4 serves the highest population equivalent, with a consequently higher amount of sludge produced per year.

2.3. Experimental apparatus

The EDW device used is illustrated in Fig. 1. It is constructed with a cylindrical glass vessel (176 mm high, 80 mm inner diameter) and a pneumatic cylinder (SMC, CP96SDB32-200, 200 mm stroke), of which the piston generates compression pressure and acts as anode (DSA® Ti/MMO, Industrie De Nora, Italy). At the bottom of the cell, a PTT filter