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A new methodology for measurement of sludge residence time distribution in a paddle dryer using X-ray fluorescence analysis

Christophe Charlou, Mathieu Milhé*, Martial Sauceau, Patricia Arlabosse

Université de Toulouse, Mines Albi, CNRS, Centre RAPSODEE, Campus Jarlard, 81013 Albi, France

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ABSTRACT

Drying is a necessary step before sewage sludge energetic valorization. Paddle dryers allow working with such a complex material. However, little is known about sludge flow in this kind of processes. This study intends to set up an original methodology for sludge residence time distribution (RTD) measurement in a continuous paddle dryer, based on the detection of mineral tracers by X-ray fluorescence. This accurate analytical technique offers a linear response to tracer concentration in dry sludge; the protocol leads to a good repeatability of RTD measurements. Its equivalence to RTD measurement by NaCl conductivity in sludge leachates is assessed. Moreover, it is shown that tracer solubility has no influence on RTD: liquid and solid phases have the same flow pattern. The application of this technique on sludge with different storage duration at 4 °C emphasizes the influence of this parameter on sludge RTD, and thus on paddle dryer performances: the mean residence time in a paddle dryer is almost doubled between 24 and 48 h of storage for identical operating conditions.

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1. Introduction

Sewage sludge (SS) is the main by-product from wastewater treatment plants (WWTP): this mixture is globally nitrogen- and sulfur-containing organic material, microorganisms and minerals (mainly P, K, Fe, Ca, but also trace elements). SS is treated according to several pathways for stabilization of the biological activity (anaerobic or prolonged aerobic digestion for example), and/or dewatering (centrifuges, belt filters). In large-scale WWTPs, continuous dewatering equipment allows increasing the dry solid (DS) content of SS up to 20–30% wt. (Chen et al., 2002). The traditional ways of disposal for this dewatered sludge are landfilling, agricultural reuse or incineration. While they still represent the major solutions in most countries, some have decided to limit or even prohibit agricultural reuse, considering SS as a waste due to heavy metal contents. In the mid-2000s, EU produced around 10 Mt of dry sludge (Fytili and Zabaniotou, 2008), but due to legislation evolutions and population growth resulting in an increasing number of WWTP, the amount of SS produced will increase globally, so other ways of valorization of this carbonaceous material are worth investigating (Gendebien, 2010).

Whatever the outcome, SS requires a drying step after its dewatering for several reasons. Increasing the DS content in sludge leads to an increase in its calorific value, which is necessary in order to make energetic valorization such as co-incineration or gasification feasible (Arlabosse et al., 2011;

* Corresponding author.
E-mail addresses: mmilhe@mines-albi.fr, mathieu.milhe@hotmail.fr (M. Milhé).
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Ferrasse et al., 2003; Manara and Zabaniotou, 2012; Mininni et al., 1997). Moreover, storage is unavoidable when one considers agricultural usage, since amendment cannot be realized anytime: this implies that the product is dry enough to be stable and easy to handle and store. The main challenge in SS drying and processing is the existence of a sticky state of the sludge while it is dried: it behaves as an elastic lump when reaching around 40% of dry solid (DS) content up until the point where granulation occurs and SS is free flowing (Kudra, 2003). This can be particularly problematic for processes where sludge is put in motion during drying because of sticking or clogging issues, resulting in mechanical damage in the installation. Moreover, when this pseudo-solid forms, it has a tendency to agglomeration that reduces the gas-to-solid or the heated-walls contact area. This sticky state results in both an increase in mechanical power needed for stirring as well as a decrease in the drying rate. Among the different industrial designs, paddle dryers appear as the most interesting: compact installations, low exhaust volumes and the ability to overcome efficiently the sticky phase make them very suitable for SS drying (Arlabosse et al., 2011). However, their design and operation remain largely empirical, and in most of the existing installations, SS reaches a DS content of about 95% at the outlet of the dryer, which is more than necessary for the possible energetic applications (specific incineration, co-incineration, pyrolysis, gasification). Drying is very energy-consuming, around 900 kWh/ton of water removed (Arlabosse et al., 2011). Adapting the operating conditions of paddle dryers in order to reach a sufficient DS content with regards to the subsequent application might result in more economically realistic solutions for SS valorization.

Literature on SS drying in paddle dryers is very scarce, and the state of the art in research does not allow predicting process performances. Indeed, predicting the DS content of sludge at the outlet of a paddle dryer would require calculating both the drying rate and the residence time distribution (RTD) of the sludge in given operating conditions. The first point has already been studied by several authors, and it is now accepted that the penetration theory can be used to describe accurately SS drying (Arlabosse and Chitu, 2007; Deng et al., 2009). However, RTD measurements remain a technical bottleneck for sludge processing and could bring valuable information for understanding sludge behavior in dryers.

RTD concept was first introduced by Danckwerts (1953) as a tool allowing characterization of fluid flows in reactors in a process. It relies on the measurement of a tracer concentration at the outlet of a reactor, the injection of this tracer being supposed not to disturb the flow. A lot of tracing techniques have been developed: they can be basically divided in two categories depending on whether they rely on online or offline analyses. The RTD concept can be employed for the characterization of any conservative flow (Gibilaro, 1979): for example, for the solid part of sludge flow in a dryer in our case. However, for solid flows, online tracing techniques such as magnetic field or radioactivity detection are complicated to set up. Optical techniques have also been tested, but most of the time they are operated offline (color analysis, fluorescence, and absorbance for example) since they might require pretreatment of the samples (Gao et al., 2012). These optical techniques and other colored particle tracking techniques are not applicable with SS, since it is a very dark product. To date, only two studies focused on the determination of sludge RTD in paddle dryers: Tazaki et al. (2011) worked on an industrial scale installation in which they injected pulses of sludge enriched in nickel and manganese chloride. RTD was determined from the measurement of metal concentration in the samples (taken from different locations in the dryer) by flame atomic absorption spectrometry after mineralization. In a previous work, Charlou et al. (2013) worked on a pilot-scale continuous paddle dryer and validated a method of RTD determination by conductivity measurement. A pulse of sodium chloride dissolved in raw sludge was injected and processed sludge was sampled at the outlet of the pilot. Conductivity of the samples was then measured after leaching for 24 h. The main drawbacks of these techniques are the time required for samples preparation in both cases, and for the conductivity technique the inability to make several measurements in a single experiment. In this paper, an original experimental methodology allowing measuring the residence time of SS in a pilot-scale continuous paddle dryer is presented. X-ray fluorescence allows detecting any mineral tracer and only requires drying and grinding of the samples. The repeatability of the technique and its equivalence to conductivity measurements are illustrated. Finally this methodology is applied to illustrate the influence of storage duration on SS flow during drying.

2. Material and methods

2.1. Description of the installation

Experiments were conducted on a continuous pilot-scale paddle dryer (Fig. 1). A full description of the experimental set-up is available in a previous paper (Charlou et al., 2013). The main characteristics are summarized hereafter. The dryer is composed of a 1 m long U-shaped jacketed trough housing a single rotating shaft equipped with 17 regularly spaced wedge-shaped paddles. Two additional blades, tilted at 45°, are placed at each end of the shaft to feed and extract the product more easily. An asynchronous motor rotates the shaft. A variable frequency drive permits a precise adjustment of the rotor's speed between 10 and 60 rpm. Scrapers are attached on the trough. Formed to interact with the paddles,

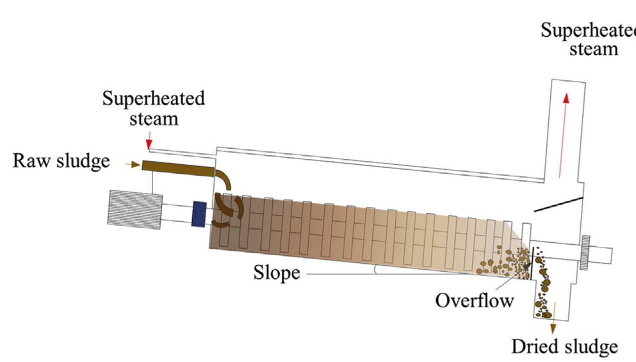

Fig. 1 – Scheme of the continuous paddle dryer.

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