IMPORTANCE OF RHEOLOGICAL PROPERTIES WHEN DRYING SLUDGE IN A FIXED BED

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Abstract: Belt drying is a commonly used technology to remove residual water from sludges. An extrusion step is usually performed to produce a layer of product with a high specific area, allowing efficient mass and heat transfers. However, when the sludge is too soft, the resulting bed of extrudates is quite compact and weakly permeable to hot air, giving lowered drying rates. This study shows that both backmixing and liming may have a positive effect on the drying kinetics of wastewater sludges because they lead to an improvement of the rheological properties of the sludge. The increase of sludge extrudates rigidity gives a bed with higher permeability and enhanced exchange area for heat and mass a transfer, leading to an increase of the drying rate. On the contrary, the destructuring due to the passage of sludge through a cavity pump was found to have a negative effect on the drying behaviour.

Keywords: urban sludge, convective drying, fixed bed, rheological properties, liming, back-mixing, bed permeability, destructuring

1. INTRODUCTION

According to stringent environmental regulations, the production of sludge from wastewater treatment plants has been continuously increasing worldwide for several years (Spinosa 2001). The management of these growing amounts of sludge has become a key issue. Two major options prevail for sludge disposal after mechanical dewatering: energy valorization and landspreading. It is now well established that a thermal drying operation, after dewatering, is an essential step. By decreasing the water content below 5% dry solids, it reduces the mass and volume of waste and, consequently, the cost for storage, handling and transport. The removal of water to such a low level transforms the sludge into an acceptable combustible. Furthermore, the dried sludge is a pathogen free, stabilized material provided the temperature is sufficiently high.

Convective belt dryers (Sevar Entsorgungsanlagen GmbH, EMO-procédé, Dry.Rex[MC], Huber, …) are commonly used to remove residual water from sludges. A pelletizing system is usually employed to produce granules or extrudates at the entrance of the dryer. The pelletized wet product is distributed uniformly on the belt, forming a fixed bed whose height depends on the belt speed. The structure of the bed, mainly its permeability and the developed solid/air exchange area, has a direct impact on the performance of the drying process. A high permeability will reduce the pressure drop across the bed and enhance air circulation. High exchange areas available for heat and mass transfer will contribute in reducing the required drying time. In some cases, the wet sludge is very soft and pasty so that the resulting bed of extrudates is quite compact and weakly permeable to hot air. As a consequence, the drying rate is lowered and the drying time increases.

This study shows two different ways of improving the texture or rheological properties of soft sludges. The first option consists in pre-conditioning the feed by mixing with recycled dried product. This operation is frequently used in the case of pasty products (Kudra 2003). Concerning wastewater sludges, backmixing is mainly used to avoid the sticky phase that can produce damages in indirect dryers (Ferrasse *et al.* 2002). However, backmixing is sometimes used in industrial sludge convective belt dryers equipped with an extruder as feeding system. The second option refers to sludge liming, which is a widely used stabilization method. Liming raises the pH of the sludge. At a pH of 12 or higher, pathogens and microorganisms can be either inactivated or destroyed provided that adequate mixing and sufficiently long contact times are realised. Moreover, due lime hydration reaction, its addition contributes to increase sludge dryness. Sludge liming can be performed before or after the dewatering step. For pre-liming, lime is combined with other conditioners in order to enhance dewatering while for post-liming, lime is mixed with the sludge cake.

Even though the number of publications related to residual sludge drying has been progressively growing since the beginning of the nineties (Gruter *et al.* 1990; Smollen 1990; Gross 1993; Vaxelaire *et al.* 1999; Vaxelaire *et al.* 2000; Chen *et al.* 2002; Ferrasse *et al.* 2002; Leonard *et al.* 2002; Vaxelaire and Puiggali 2002; Arlabosse *et al.* 2004; Leonard *et al.* 2004a; Leonard *et al.* 2004b; Leonard *et al.* 2005), almost no scientific study dealing with backmixing can be found. Similarly, although the texturing effect of liming is well known (Hil *et al.* 2005), especially for landspreading purposes, its impact on a subsequent drying operation has never been deeply investigated until recently (Huron *et al.* 2008).

The present work aims to show that both backmixing and liming can be used to improve the texture of sludge, leading to a decrease of the residence time in convective belt dryers. On the contrary, the negative impact of a pumping operation on the sludge texture, and consequently on its drying behaviour is illustrated. A non invasive visualisation technique, i.e. x-ray tomography has been used to quantify the structure of the sludge extrudates bed obtained at increasing levels of backmixing. Cone penetrometer testing has been performed on lime samples to have an idea of the cohesion and the adhesiveness of the samples.

2. MATERIALS AND METHODS

1.1 Sludge samples.

Sludges have been collected after the mechanical dewatering step in three wastewater treatment plants (WWTPs) called A, B and C. Principal characteristics of the sludges are listed in Table 1. The dry solids (DS) and volatiles solids (VS) contents have been determined according to Standard Methods (ASAE 1996). Before drying, sludge samples were extruded through a circular die of 12 mm. The influence of backmixing has been studied with sludge A. The reference case corresponded to drying 1 kg of initial sludge. Backmixing was simulated by adding increasing quantities of dried sludge, *i.e.* 0.1, 0.2, 0.3 and 0.4 kg to the initial amount (1 kg) of fresh material before extrusion. In this way, the same amount of water to be removed was kept during each trial. The influence of liming has been evaluated with sludge B. Pre- and post-limed samples were produced at an industrial level within the WWTP. Sludge C has been used to examine the effect of a pumping operation: raw and pre-limed sludge samples were collected after their passage through a cavity pump used to convey the dewatered product to containers.

Table 1. Sludges samples and their characteristics

WWTP	Type of sludge	Samples collected	DS (%)	VS (%DS)
A	Anaerobicaly digested	Raw dewatered sludge	12.5	65.7
B	Anaerobicaly digested	Raw dewatered sludge	32.0	41.3
		Pre-limed dewatered sludge (21% CaO)	39.1	26.0
		Post-limed dewatered sludge (21% CaO)	38.2	27.6
C	Biological	Raw dewatered sludge	16.6	61.1
		Pre-limed dewatered sludge (25% CaO)	18.7	41.0
		Destructured raw sludge	15.6	57.0
		Destructured pre-limed dewatered sludge (25% CaO)	18.3	41.5

2.2 Sludge dryer.

The drying experiments have been carried out in a discontinuous pilot scale dryer reproducing most of the operating conditions prevailing in a full scale continuous belt dryer (Leonard *et al.* 2008). A fan sucks ambient air that is heated up to the required temperature by a set of electrical resistances. Hot air flows through the bed of sludge extrudates which lies on a perforated grid linked to scales. In this work, we report on results obtained at temperatures and air velocities close to 105 °C and 1.1 m/s. No additional air humidification has been carried out. During the whole study, the ambient air humidity was close to 0.007 $kg_{water}/kg_{dry\ air}$. At the adopted drying temperature (105°C), the daily variations of the ambient air humidity can be considered as negligible. The sample was continuously weighed during the drying test and its mass was recorded every 30 s.

3. RESULTS AND DISCUSSION

3.1 Impact of sludge backmixing on the drying kinetics

Fig. 1a shows the drying curves, the drying rate *vs.* the water content expressed on a dry basis, obtained for sludge A. The shape of the curves is classically encountered when drying sludges in a convective system (Leonard *et al.* 2002). Three zones can be observed: first, a preheating zone during which the solid temperature and the drying rate increase and reach progressively their maximum value, secondly a narrow plateau, during which the solid temperature and the drying rate remain at their maximum and finally a decreasing rate zone, during which drying proceeds up to completion. A short constant rate period is observed for the reference experiment. When some dry product is added, the constant rate period disappears: a preheating phase followed by a long decreasing drying period is observed. A positive effect of backmixing is clearly observed: the drying rate globally increases with increasing dry product additions. The ratio between the maximum drying rates corresponding to the reference experiment on the one hand, and to the highest level of backmixing, on the other hand, is equal to 1.65. The corresponding drying time for the removal of 90% of water drops from 88 to 59 min.

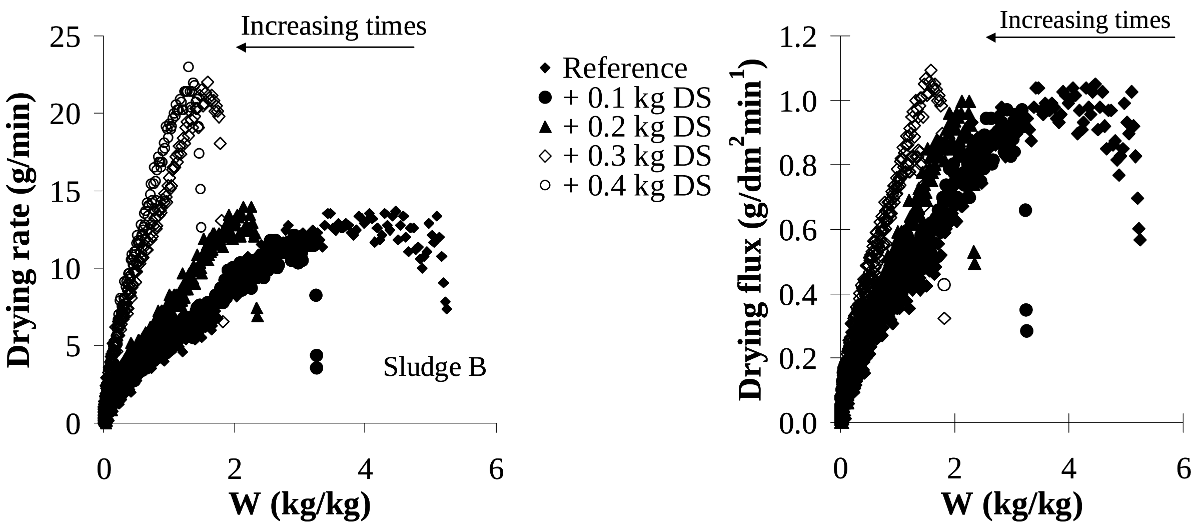

Fig. 1. (a) Drying rate *vs.* water content for sludge A at different levels of backmixing and (b) the corresponding drying flux obtained by dividing the rate by the initial exchange area.

A rigorous comparison of the kinetics should be made on the basis of drying fluxes. Indeed, the addition of dry product leads to an expansion of the bed of extrudates, and consequently the exchange area increases. This is illustrated by Fig. 2 showing 3D images obtained by X-ray tomography. A quarter of the bed was numerically cut in order to see the internal positioning of the extrudates. Figs. 2a. and 2b. represent the sludge bed before drying for the reference experiment and for the addition of 0.4 kg of dry product, respectively. An expansion of the beds is clearly observed on Fig. 2b: sludge extrudates present a more individual character while they were stuck together before backmixing. . This observation can be related to extrudates rigidification, *i.e.* reinforcement of sludge texture, as the mean initial moisture content increases with backmixing. The influence of sludge dryness on the rheological properties has already been reported (Leonard *et al.* 2004b). Bed expansion has been quantified by analysis of the images obtained by X-ray tomography (Leonard *et al.* 2008). Results clearly show an increase of the initial porosity and of the total developed exchange area with the degree of backmixing. Knowing the exchange area of the wet bed, it is possible to estimate the drying flux by dividing the drying rate by the obtained value. By doing so, one can obtained pseudo-Krischer's curves, representing the drying flux *vs*. the water content on a dry basis. Even though the exchange area evolves according to sample shrinkage (Leonard *et al.* 2004a), the use of the initial area is a first approach to explain the influence of backmixing on the drying kinetics. Fig. 1b shows that the maximum drying flux was almost the same for all the experiments, from 0.8 to 1 g/dm²min. This is in agreement with externally controlled heat and mass transfers, as drying operating conditions were identical. These results confirm that the positive effect of backmixing on the experimental drying time is mainly related to the production of a fixed bed with enhance exchange area.

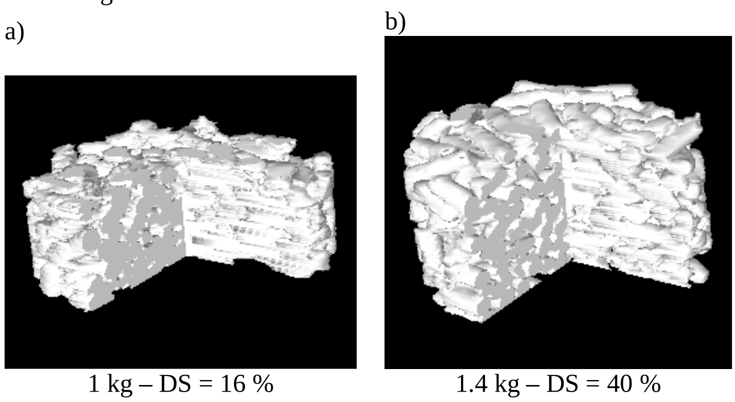

Fig. 2. 3D view of the wet sludge bed (a) for the reference experiments and (b) for the highest level of backmixing (Leonard *et al.* 2008)

3.2 *Impact of sludge liming on the drying kinetics*

Fig. 3 shows the drying curves obtained with sludge B. It can be clearly observed that both pre- and post-liming accelerate the drying process: for a given water content, the drying rate is higher when lime is added. Moreover, the results show that this positive effect is even more marked in the case of pre-liming. For a same initial amount of wet sludge, but different initial water contents, the drying time required to reach 90 DS drops from 48 min. to 27.6 min. and 36 min. after post- and pre-liming, respectively.

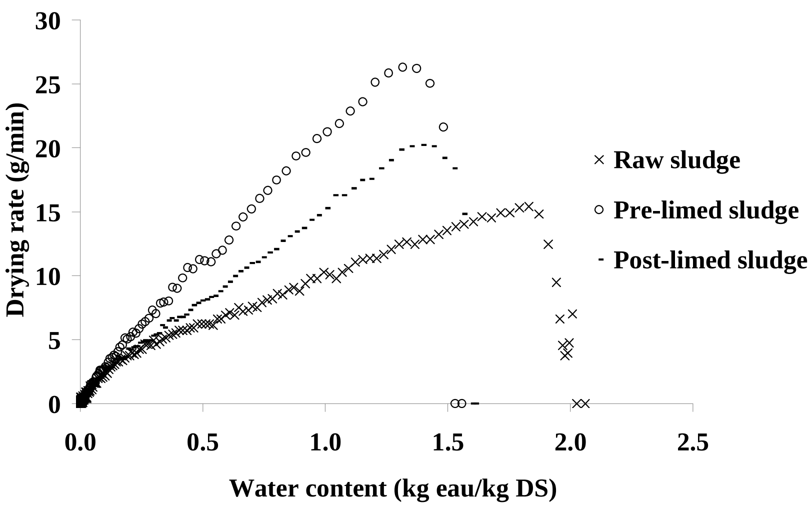

Fig. 3. Krischer's curves for raw, pre-limed and post-limed sludges.

As in the case of backmixing, the positive effect of liming can be explained by the evolution of sludge rheological properties. Lime addition increases the sludge dry solid content, and consequently sludge rigidity, and has a well-known texturing effect (Hil *et al.* 2005). Besides an expansion of the sludge bed, it is likely that liming has also an influence on the mobility of water. The difference between post- and pre-limed samples comes from the pumping step which is used to perform post-liming: as a result, the texturing effect is partly destroyed.

3.3 *Impact of sludge pumping on the drying kinetics*.

On the field, it is well known that the passage of the sludge through a pump will change its mechanical properties and leads to its destructuring. Dryer manufacturers are also aware of the negative impact of pumping operation on sludge drying kinetics. In some cases, they are forced to recycle dried solids at the dryer feeding in order to recover an acceptable initial sludge texture (Kreuzer 2005). However, no scientific study can be found dealing with that subject. Fig. 4a clearly confirms what is observed industrially. A strong decrease of the drying rate is obtained when the sludge is destructured due to pumping. For raw sludge, the maximum drying rate is lowered down to 5 g/min. Even though a decrease of the drying rate also occurs with pre-limed samples, it can be observed that the liming operation counterbalances partially the negative effect due to destructuring. This is confirmed by the drying times required to reach 90% DS: it increases from 92.5 to 200 min. after raw sludge pumping, while it increases from 58 to 115.5 min when pre-limed sludge was forced through the pump.

Cone penetrometer testing was used to have an idea of the cohesion (Hil *et al.* 2005) and the adhesiveness of the samples. Results presented in Fig. 4b can be interpreted according two different ways. First, the texturing effect of liming is confirmed by an increase of cohesion. Secondly, the destructuring due to pumping leads to a decrease of the cohesion together with an increase of the adhesiveness. This reflects the visual stickiness character of the destructured sludge. Penetrometry results allows to interpret the observed drying behaviours: an increase of the cohesion will accelerate the drying process by improving the extrudate bed permeability while a increase of the adhesiveness could slow down the internal transport of water. Nevertheless, results seem to indicate that a high cohesion can partly counterbalances a high adhesiveness. Indeed, destructured pre-limed dewatered sludges dry more rapidly than destructured raw sludge, but they present a higher adhesiveness together with a higher cohesion. At the light of these results, some others tests were performed on post- and pre-limed samples produced from the same raw sludge. Higher cohesion values were obtained for pre-limed samples, which in agreement with the drying results obtained with sludge B. This is quite logical as post-liming required the use of a cavity pump

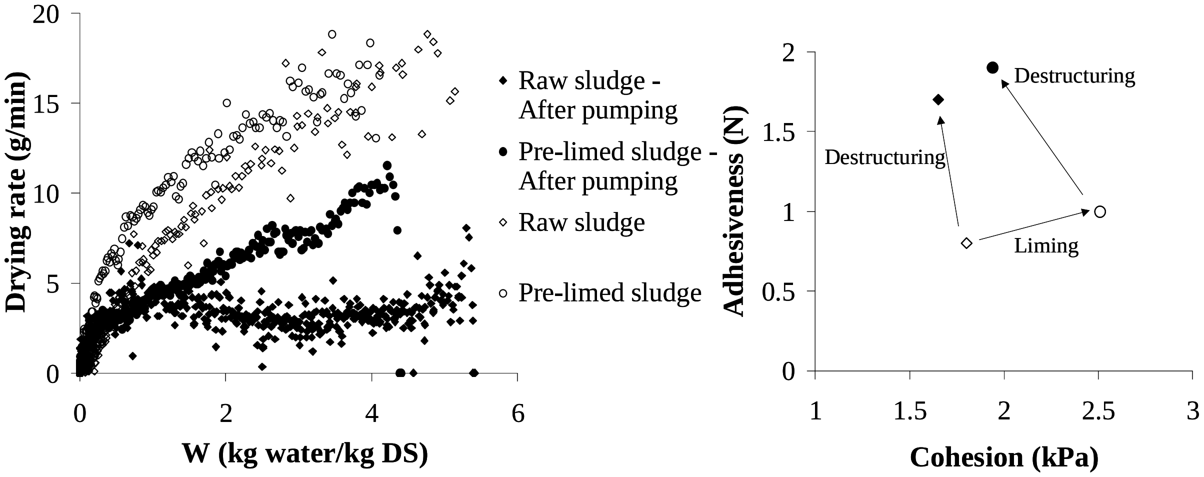

Fig.4. (a) Influence of a pumping operation on the drying kinetics; (b) Influence of pumping on the cohesion and the adhesiveness of raw and pre-limed sludges.

4. CONCLUSIONS

This study illustrates the importance of sludge rheological properties when they are dried convectively in a fixed bed. The texture has to be strong enough to produce a bed of extrudates will high exchange surface area for heat and mass transfer. Results show that backmixing and liming are two options to improve sludge rheological properties. Cone penetrometer testing seems to be a relevant characterisation techniques to evaluate the rheological properties as its response, in term of cohesion and adhesiveness, allowed to explain the impact of both liming and destructuring due to pumping on the drying behaviour.

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