INFLUENCE OF THE PARTICLE SIZE DISTRIBUTION ON THE CONTACT DRYING KINETICS OF AGITATED SEWAGE SLUDGE

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Abstract: In the literature, divergences exist on the characteristic size that should be used to model the contact drying kinetic of agitated sewage sludge. The influence of particles size distribution of the pasty sludge on the drying kinetic was investigated experimentally. A premixing was applied to a sewage sludge to decrease the particle size. Results emphasized that premixing breaks the biggest aggregates in the pasty sludge into smaller ones and improves the drying rate. As a consequence, the characteristic size to be used for the heat and mass transfer modeling should be connected to a structural dimension of the pasty sludge.

Keywords: Municipal sludge, Premixing, Penetration model, Contact resistance, Drying rate

INTRODUCTION

To improve the understanding of the mechanisms involved in contact drying of agitated sewage sludge, the penetration theory developed for mono (Schlünder and Mollekopf, 1984; Tsotsas and Schlünder, 1986a) and multi (Tsotsas and Schlünder, 1986b) dispersed packing, was successfully used to represent experimental drying kinetics from laboratory scale batch dryer (Arlabosse and Chitu, 2007; Deng et al., 2009; Yan et al., 2009). To compute the drying kinetics through the penetration theory, a stochastic homogeneous multi-granular packing model, with a time dependent particle size distribution, would have been required. But to avoid cumbersome calculations, the pasty sludge was considered as a saturated mono-dispersed particulate phase. In other words, the dry product in the paste regime is assumed to be the same as the dry product in the granular regime, even if the drying process is both a dewatering process and a solid forming process with a "reverse granulation" phase from the wet to the dry solid. The choice of the characteristic dimension of the packing bed is crucial. Indeed, under an atmosphere of superheated steam, the model postulates that contact drying is a purely heat transfer controlled process, with “in series” resistances, i.e. the contact resistance and the penetration resistance of the bulk, and, according to simulation, sludge drying is controlled by the contact resistance between the wall and the sludge. This contact resistance is a function of the surface coverage factor, the particle size, the surface roughness of the particle and the mean temperature between the wall and the first layer of particles. A sensitivity analysis (Arlabosse and Chitu, 2007) emphasized that the surface coverage factor, the particle size and the wall temperature are the most influential parameters at high moisture content (Xdw>0.7kg.kg⁻¹). Divergences exist on the choice of the characteristic size: Arlabosse and Chitu (2007) used the size of the biggest particles in the pasty sludge while Yan et al. (2009) and Deng et al. (2009) used the mean particle diameter of the dried sludge. Recently, Tunçal (2010) investigated the influence of commonly used chemical additives in sludge mechanical dewatering processes on the sludge drying rate. Increasing the polyelectrolyte dosage, and thus increasing the flocs size in the pasty sludge, affects the sludge drying rate negatively. According to those elements, the influence of the particle size distribution of the pasty sludge on the drying kinetics needs to be clarified. A pre-processing by mixing was applied to a municipal sewage and the drying kinetics of the raw and the pre-mixed sludge were characterized in a batch contact dryer. After a short description of the material and method in section 2, the influence of the pre-mixing on the particle size distribution of the pasty sludge and the drying kinetics are analyzed in section 3.

MATERIAL AND METHOD

Batch contact dryer

Only the main characteristics of the experimental set-up are described in the present paper. A full description is available in Ferrasse et al. (2002). The
batch dryer, capable of processing up to 5 kg of raw sludge, consists of a 0.2m diameter Teflon®
cylindrical vessel screwed onto the top of metallic plates, which simulate the wall of the dryer
(S=0.0314m²) and its heating system. The stirring device consists of three 0.02 m wide and 0.16 m long
blades, sloped at 45°, fixed on a vertical shaft. The distance between the first blade and the dryer wall
was set to 0.001 m. Static scrapers are fixed on the Teflon cell to break up the sludge. A motor supplies a
constant rotation speed \( \omega = 40 \text{ rpm} \) to the stirrer.

This setup operates in a closed drying loop to control the temperature, velocity and nature of the gaseous
environment. For the present study, flow of superheated steam (1atm, 130°C) was maintained
with a velocity less than 0.3 m/s, and the wall temperature was heated at 160°C.

**Feed material**

The sewage sludge was sampled in the urban wastewater treatment plant (WWTP) of Albi city
(France). The WWTP, designed for a capacity of 91 000 population equivalent (PE) but operating at
60 000 PE, implements a conventional extended aeration process, a denitrification process and a
biological phosphorus removal system.

The sludge was sampled after the mechanical dewatering stage, performed by centrifugation. The
sample has a lumpy appearance and contains 20.4% of solid matter by weight. The sludge was stored at
4°C in a tight container and experiments were performed within 1week after sampling.

**Experimental procedure**

The sludge was used as it is or after premixing. A planetary mixer BE5 (Dito Sama , Senlis, France)
was used to pre-treat the raw sludge at \( \omega =40 \text{rpm} \) and
\( \omega=200\text{rpm} \) during 10 or 20 minutes.

Particles size distribution (PSD) of the pasty raw or the premixed sludge was determined with a
Mastersizer 2000 particle size analyzer (Malvern Instrument Ltd., Worcestershire, United Kingdom).
This laser diffraction system uses the Mie theory to characterize the particles over a wide size range,
from 0.2 to 2000µm. If particles and aggregates are not spherical, the ‘equivalent size particle’ concept is
applied. The given particle or aggregate is replaced
with an imaginary sphere that has the same volume
as the given particle, when the PSD is determined in
volume for instance.

For the drying experiments, 2.7kg of pasty sludge
was introduced manually in the dryer. The sludge
was progressively dried with a wall temperature
heated to 160°C. Samples were taken every hour to
follow the drying kinetic. The moisture content was
measured according to the AFNOR standard
procedure n° X31-505, which recommends a drying
at 105°C for 24 hours.

**RESULTS AND DISCUSSION**

Impact of pre-mixing on the particles and aggregates size distribution

Figure 1 represents the PSD, measured in volume, for raw and premixed sludges. As can be seen,
premixing at \( \omega=200 \text{ rpm} \) during 20 minutes increases the volume of fine particles with a diameter
ranging between 0.4µm and 30µm and decreases the volume of particles bigger than 30µm, compared with
the raw sludge. No change is detected on the volume when the diameter of the colloidal particles is lower
than 0.4µm.

![Figure 1: Effect of a premixing on the particle size distribution: raw sludge (---), premixed sludge during 20min at \( \omega=40\text{rpm} \) (- - -) or \( \omega=200\text{rpm} \) (-).](image)

Table 1 compares the values of the volume-moment mean particle diameter, \( D_{[4, 3]} \), and the size of the
biggest particles, \( D_{\text{max}} \), in the raw and premixed
sludges.

<table>
<thead>
<tr>
<th>Table 1: Influence of the premixing on some characteristic dimensions of the pasty sludge</th>
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<tr>
<td>Raw sludge</td>
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<td>( D_{[4, 3]}(\mu m) )</td>
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<tr>
<td>( D_{\text{max}}(\mu m) )</td>
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In comparison with the raw sludge, the size of the
biggest particles was cut by ten times and the
\( D_{[4, 3]} \) by four times when sludge was
premixed at a 200rpm speed rate during 20 minutes.

In other words, the premixing treatment breaks the
biggest aggregates or particles into smaller ones. Visually, this pre-treatment generates a modification
of the sludge texture, which becomes more sticky.

**Influence of premixing on the drying rate**

Figure 2 represents the drying kinetics for the raw
and a premixed sludge. For this experiment, the
sludge was premixed at \( \omega=200\text{rpm} \) during 10
minutes.

As can be seen, the premixing treatment clearly modifies the drying kinetic. After a drying time of
12 000 seconds, the dry basis moisture content has
decreased from 25%. The maximum drying rate, calculated with the four first points of the kinetic, is significantly enhanced by the premixing treatment: the drying rate of the premixed sludge reaches $1.35 \times 10^{-4}$ kg kg\text{DM}^{-1} s^{-1} which is twice more than the drying rate of the raw sludge ($7.15 \times 10^{-5}$ kg kg\text{DM}^{-1} s^{-1}). These results clearly emphasized that a reduction in the size of the biggest aggregates of the pasty sludge significantly enhances the drying rate. From the theoretical point of view, the characteristic size of the particles to be used for the heat and mass transfer modeling must be connected to a structural dimension of the pasty sludge.

**CONCLUSIONS**

In this study, a pre-mixing treatment has been used to modify the particle size distribution of the pasty sewage sludge. Drying experiments were performed with the raw and the premixed sludge to investigate the influence of the particle size distribution on the drying rate. As expected from the model based on the penetration theory, the decrease in the particle size, resulting from the premixing treatment, significantly enhances the drying rate. Compared with raw sludge, the drying rate observed for a sludge premixed at $\omega=200$ rpm during 10 min was twice higher. Unfortunately, the particle size distribution analysis emphasized that premixing also modifies the size of some colloidal particles, in the range from 0.4 to 1 µm. This may also affect the surface coverage factor used in the penetration model. Additional experiments are required to identify the characteristic dimension and the surface coverage factor that must be used in the drying model. These results will be presented by the time of the conference.

**NOMENCLATURE**

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<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$\omega$</td>
<td>Stirrer rotation speed</td>
<td>rpm</td>
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<tr>
<td>D [4, 3]</td>
<td>Volume-moment mean diameter</td>
<td>µm</td>
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<tr>
<td>DM</td>
<td>Dry Matter</td>
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**REFERENCES**


Schlünder E.U. and Mollekopf N. (1984), Vacuum contact drying of free flowing mechanically agitated particulate material, Chemical Engineering and Processing, 18 (2), 93-111.


