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THE DRYING OF SEWAGE SLUDGE BY IMMERSION FRYING

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Abstract - The objective of this work was to dry sewage sludge using a fry-drying process. The frying experiments were carried out in commercial fryers modified by adding thermocouples to the setup. During frying, typical drying curves were obtained and it was verified that, in relation to the parameters: oil temperature, oil type and shape of the sample, the shape factor the most effect on the drying rate, at least within the range chosen for the variables studied. Oil uptake and calorific value were also analyzed. The calorific value of the samples increased with frying time, reaching values around 24MJ/kg after 600s of frying (comparable to biocombustibles such as wood and sugarcane bagasse). The process of immersion frying showed great potential for drying materials, especially sewage sludge, obtaining a product with a high energy content, thereby increasing its value as a combustible.

Keywords: Sewage sludge; Drying, frying; Calorific value.

INTRODUCTION

Increasing urbanization and industrialization have resulted in an enormous increase in the volume of wastewater all around the world. Concerns about public health have obliged governments to create strict environmental laws that require the treatment of these wastewaters for their safe discharge.. Sewage sludge, a by-product of the process in wastewater treatment plants (WTP), is a bulky residue (95-99% water) with a problematic composition (fermentable products, pathogenic organisms, heavy metals and PCBs, etc). Large volumes of wastewater mean big volumes of sewage sludge that cannot be disposed recklessly.

BACKGROUND

There is a series of methods of sewage sludge treatment, and the most common are stabilization and dewatering. Sludge stabilization can be done three different ways (thermal, chemical and biological treatment).

Dewatering of sewage sludge can be achieved by mechanical and thermal means. Mechanical dewatering consists of processes like gravitation settling, centrifugation and filtration (belt, vacuum and pressure). Examples of thermal dewatering are drying, incineration, pyrolysis, gasification, wet oxidation, etc.

Combustion, or incineration, is an attractive and necessary element of waste management (Niessen, 1995) and offers the potential advantages of volume reduction, detoxication and energy recovery, among others. Work has been done to estimate the quality of sewage sludge as fuel and on the recovery of energy that would otherwise be wasted during incineration processes (Zanoni and Mueller, 1982). Incineration of sewage sludge requires that the solids content should be raised to about 33% for the sludge to be autothermic (Furness et al. 2000).

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One of the biggest problems in the field of wastewater engineering is the dewatering of waste sludges (Katsiri and Kouzeli-Katsiri, 1987). In general, whatever the process of sludge production in a WTP or the route of its final disposition, sludge dewatering is a critical and essential condition, serving at least to reduce the cost of transportation and facilitate handling.

The types of water in sludge are classified according to their bonding to the solids in the sludge (Kopp and Ditchl, 2000), which are

- Free water, which is not bound to the particles;
- Bound water, that can be broken down into
- Interstitial water, which is bound by capillary forces between the sludge flocks;
- Surface water, which is bound by adhesive forces, and
- Chemically bound water, intracellular water.

According to Kopp and Ditchl (2000) free water can be separated by means of a mechanical dewatering process, but to achieve the removal of bound water, a drying process is necessary.

Drying solids is possible by several means, and one of them is frying in hot oil. Deep-fat/oil frying is the immersion of the product in a fat/oil bath at a temperature higher than the boiling point of water. The contact of the product with the hot medium induces of a series of chemical and physical reactions that results in changes in color and texture, development of a crust and of flavor, and most importantly, high rates of heat and mass transfer.

A drying process is well characterized by a drying curve, or a curve that shows the variation in moisture content of the sample with time. Moisture content is expressed here in terms of dry basis; however, a different expression is used for the specific case of the fry-drying process:

$$X_{db}^{*} = \frac{\text{moisture mass (g)}}{\text{solids mass} + \text{oil mass}} \qquad (1)$$

Equation (1) is different from the normal definition of moisture content because the oil mass was computed.

Most of the literature is on the frying of foods, especially potatoes (Mittelman Ashkenazi et al, 1984; Gamble et al., 1987 ; Gupta et al., 2000). Mittelman Ashkenazi et al. (1984) fried synthetic materials, like rigid urea-formaldehyde foam, to simulate some kind of food product. Vitrac (2000) did an extensive work on frying food products like manioc and plantain and also studied the frying of wood (nonfood product).

There is no published work on the drying of sewage sludge using hot oil. The objective of this paper is to discuss the use of frying to process sewage sludge. Deep fat frying is a complex and not fully understood process, even when applied to foodstuffs. As an initial step in this new application, this work aims at examining the removal of water from sewage sludge and also the increase the sludge heating value after frying.

EXPERIMENTAL PROCEDURE

Materials

The sewage sludge used in the experiments was obtained at the Samambaia Wastewater Treatment Plant in Campinas, SP. The sewage is essentially domestic and the sludge is produced via anaerobic digestion and partially dehydrated via centrifugation (addition of cationic polymer). The initial moisture content of the sewage sludge is 80% ($X_{db} = 4.0$).

Two types of frying oil were used: palm fat and soybean oil (used). Their compositions can be seen in Table 1. Palm fat was donated by Agropalma S.A. and the used soybean oil by a restaurant.

Table 1:Average chemical composition of palm fat and soybean oil (Stauffer, 1996)

Oil/Fat	**C12:0**	**C14:0**	**C16:0**	**C17:0**	**C18:0**	**C20:0**	**C22:0**	**C16: 1**	**C18: 1**	**C18: 2**	**C18: 3**
Palm	0.3	1.1	42.9	0.1	4.6	0.3	0.1	0.2	39.3	10.7	0.4
Soybean	-	0.1	10.6	0.1	4.0	0.3	0.3	0.1	23.2	53.7	7.6

Experimental Apparatus

The experiments were carried out in a commercial fryer with a capacity of 5 liters of oil and a power of 3300W. The fryer model comes with a metallic basket, which was used to plunge the sludge and to remove it after the frying time was finished. The major modification of the set up was the use of three thermocouples (K type) to monitor the oil temperature.

Methodology

The sludge was kept under refrigeration (4-6ºC). For ease of handling and to standardize the experiments, the sludge was molded into cylinders using two different syringes, both with the edge cut off. This procedure produced cylinders 4 cm long with diameters of 2.6 and 2.0 cm.

Each experiment consisted of plunging a cylinder into the oil bath (5 liters) and frying it for a specified period of time, which varied from 30 to 1240 seconds. On average, a series of 12 experiments was necessary to produce a frying curve varying with time. At the end of each frying time, the sludge was removed with the basket and left to drain out the excess oil. Then it was also blotted with absorbent paper and kept in a moisture-free vessel. The next step was weighing the sample and separating it for future analysis.

Three parameters were varied in the experiments, cylinder diameter, oil temperature and oil type, in accordance with the two levels shown in Table 2. In total, 105 frying experiments were carried out.

The fried sludge was analyzed for moisture content and oil content, using the gravimetric and Soxhlet methods, respectively. The calorific values of the fried sample were determined using a calorific bomb.

Table 2: Experimental parameters and their levels

Parameter	Low level	Upper level
Oil temperature (°C)	190	215
Cylinder diameter (cm)	2.0	2.6
Type of oil	Used (soybean oil)	Fresh (palm oil)

RESULTS

During the frying experiments some parameters (oil temperature, oil type and size of the sample) were varied in order to analyze their effect on the drying of sewage sludge in a deep fryer. The analysis of variation in moisture content throughout the experiments produced a set of drying curves.

Effect of the Frying Oil

In Figure 1, drying curves obtained from the frying experiments were for samples of sludge of the same size were plunged into hot oil and processed at the same temperature. These experiments provided two curves, each for a different type of frying oil. This result shows that, under the conditions of the experiments, the type of oil is not relevant to the drying process.

Effect of Oil Temperature

Temperature of the drying agent is normally an important operational parameter in drying processes and in the case of frying here oil temperature is of importance. It was expected that the rise in temperature would increase the rate of drying of the material.

Figures 2 and 3 show the drying curves when hold some conditions unchanged and raising the temperature of the oil. It is possible to observe in these figures the slight effect of temperature, seen as a difference in the drying curves. The effect is more evident in Figure 3, which shows the drying of a bigger cylinder, than in Figure 2 which shows the drying of a smaller cylinder. However, even when the difference between the highest temperature and the lowest is the greatest, the curves do not show a big change.

Therefore, it is not possible to conclude that the oil temperature has a large effect, at least not in this temperatures range.

Effect of Cylinder Diameter

A bigger cylinder diameter has a larger mass transfer area, which will result in a higher rate of drying, because the latter is proportional to the area of transfer. In Figure 4, it can be seen that the diameter has an effect on the drying rate of sewage sludge. A considerate fraction of the moisture in the sludge is somehow bound to the particle matter. Free water is lost in the first seconds of process (approximately 60s), when drying is fast and linear.

After this period, internal moisture is evaporated and a decrease in the rate is observed. It is in this phase of the process, when the controlling mechanism seems to be diffusion of the moisture inside the material structure, that the size of the material or the path that the moisture has to take, has an effect.

The decrease in the diameter of the cylinder being fried seems to have an effect on the drying rate. A smaller cylinder dries faster than a sample with a bigger diameter.

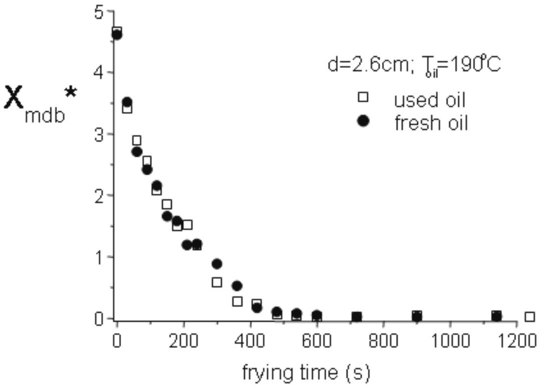

Figure 1: Drying curves for different types of oil

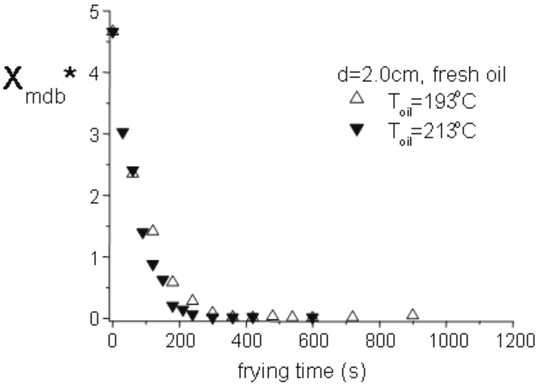

Figure 2: Drying curves for different frying temperatures (smaller cylinder)

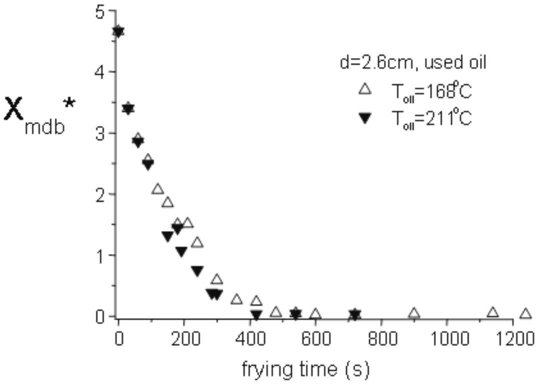

Figure 3: Drying curves for different oil temperatures (bigger cylinder, used oil)

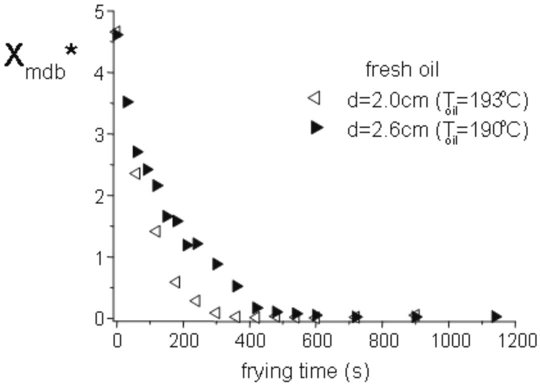

Figure 4: Drying curves for different cylinder diameters (lower temperature)

Relationship between Oil Content and Moisture Content

The material being fried takes up oil as it loses water. A relationship between these two parameters, i.e., oil content and moisture content, can be very useful in controlling the process, because the measurement of oil content is rather easier than the measurement of oil content.

The oil contents of the samples fried in the fresh oil were determined and related to the moisture contents. The resulting curves can be seen in Figure 5. It shows four curves, each of them for different condition of oil temperature and sample size.

Regardless of condition, it can be observed that they are very similar, confirming that oil is directly related to the moisture being lost and that this relation could be expressed by a second-order equation.

Curiously, at the end of frying, when the moisture content is very low, there no longer seems to be a relationship between these two parameters and the value of oil content is random.

During the frying process, vapor is formed and starts to diffuse out from the material. It opens paths and holes in the material structure due to pressure. Oil adheres to the surface of the material and then, enter the pores and the paths opened by the water vapor. This is why there is a relationship between these two phenomena. At the end of the process, when the pressure is lower and the rate of moisture lost is almost zero, the water lost no longer effects oil uptake.

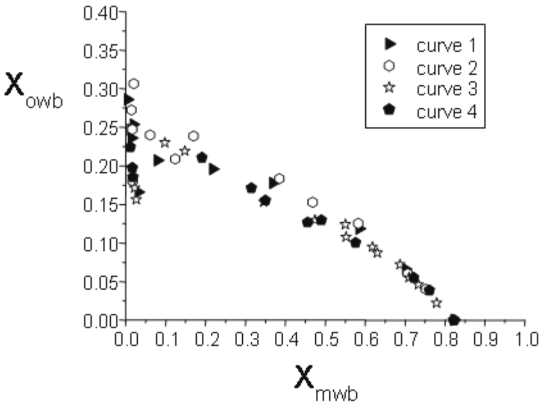

Figure 5: Relationship between moisture content and oil content of a fried sludge sample.

Heat of Combustion of the Fried Sludge

The calorific values of the fried samples were determined in a calorific bomb. With this apparatus quantification of the amount of ash present after the sample was burned was also possible. The samples analyzed were fried under the same conditions of temperature (180ºC) and type of oil (used oil), but during different periods of time. These results are shown in Figure 6; the point corresponding to time zero is the sludge sample that was not fried, but its moisture was dried in an oven at 110ºC for 24 hours.

It is clear that the heat value of the fried sludge increases with frying time. This occurs due to the loss of moisture and the incorporation of oil, and it is interesting to see that after 900s or 15 minutes, the heat value is 50% higher than that of the unfried, moisture-free sludge. At this point the calorific value is approximately 24MJ/kg of fried sludge, and this value is comparable to the heats of combustion of common biomasses like wood and sugarcane bagasse. Table 3 shows the heat values of a series of materials including sludges that underwent different processes.

Other results can be seen in Figure 7, where the ash content of the fried sludge is shown.

Also, the zero point corresponds to the air-dried sludge sample. The ash content of the fried sludge is reduced much more than the content of the air-dried one. This occurs mostly because the oil adhering to the sample enhances combustion. This result is of interest because if less ash is formed, it means that less particulate will be formed and combustion will have a lower rate of particulate emissions.

These results demonstrate that fried sludge has a great potential as a biocombustible for its high energy value and low quantity of ash produced during combustion.

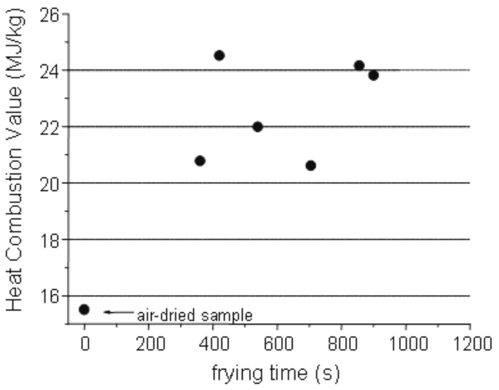

Figure 6: Heat of combustion of the sludge samples fried for different lengths of times. T_{oil} = 180ºC.

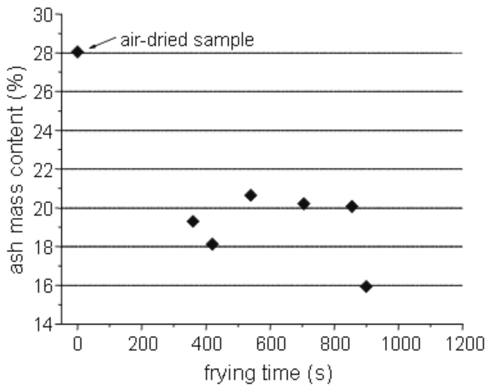

Figure 7: Ash content of the sludge samples fried for different lengths of times. T_{oil} = 180ºC.

Table 3: Values of heat of combustion found in literature for different materials

Author	Sample	Heat Value (MJ/kg)
Zanoni and Mueller (1982)	Biological WW sludge	13.50
Ogada and Werther (1996)	Wet WW sludge	1.098
Silva, et al. (1998)	Sugarcane bagasse	18.0-19.5
	Wood	23.0
	Green wood	8.0
Dermibas (2001)	Methane	55.0
	Coal	27.0
This work	Sludge fried for 900s	23.0-24.0

WW = wastewater

CONCLUSIONS

The drying of sewage sludge by deep fat frying was studied. The results showed that the fast process of frying is suitable for application to nonfood material, such as sewage sludge.

Water was removed from the sludge at a fast rate and at the same time oil adhered to it. Oil adhesion increases the heat value of the product, making the fried sewage sludge more valuable for energy recovery by incineration.

Uptake of oil also affected ash content, decreasing the latter as the former adhered to the material.

NOMENCALTURE

d	diameter of the cylinder	cm
T	temperature	ºC
X	mass content	g/g

Subscripts

m	moisture	(-)
o	oil	(-)
wb	wet basis	(-)
db	dry basis	(-)

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