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Immersion frying for the thermal drying of sewage sludge: An economic assessment

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Abstract

This paper presents an economic study of a novel thermal fry-drying technology which transforms sewage sludge and recycled cooking oil (RCO) into a solid fuel. The process is shown to have significant potential advantage in terms of capital costs (by factors of several times) and comparable operating costs. Three potential variants of the process have been simulated and costed in terms of both capital and operating requirements for a commercial scale of operation. The differences are in the energy recovery systems, which include a simple condensation of the evaporated water and two different heat pump configurations. Simple condensation provides the simplest process, but the energy efficiency gain of an open heat pump offset this, making it economically somewhat more attractive. In terms of operating costs, current sludge dryers are dominated by maintenance and energy requirements, while for fry-drying these are comparatively small. Fry-drying running costs are dominated by provision of makeup waste oil. Cost reduction could focus on cheaper waste oil, e.g. from grease trap waste.

Keywords: Drying; Frying; Oil; Sewage sludge

1. Introduction

1.1. Overview of thermal drying of sewage sludge in the European context

According to the European Environment Agency (EEA) (Christiannsen, 1999), thermal drying or the removal of moisture by evaporation will become an important process step in the disposal of sewage sludge. Indeed, due to a dramatic increase in the volume of wastewater treated in EU countries, about 10.7 millions tons of total dry solids of sewage sludge are generated every year (Bresters et al., 1997). In addition, from 2001 the progressive elimination of landfill as an acceptable method of sewage sludge disposal has resulted in an increase in material going to the two other approved disposal options, namely land spreading and incineration. For both of these methods thermal drying represents a potential intermediate unit operation, having advantage in providing volume reduction, stabilization through inactivation of pathogenic biological organisms and increasing the energy value of the dry material (Grüter et al., 1990; Hasserbrauck and Ermel, 1996).

Three general classes of sludge dryers are reported (Chen et al., 2002): convective or direct dryers, conductive or indirect dryers and mixed dryers.

In *direct drying*, hot gases from the combustion of an external fuel or the dried sludge itself are contacted with the dewatered cake in the dryer to evaporate the remaining water. Some examples of such equipments are drum, rotary, belt, spray and fluidized bed dryers. The heat transfer mechanism is predominantly convective and the evaporated water is mixed into the hot gas stream. For the *indirect drying*, (e.g. thin-film, discs or paddle dryers among others) the heat transfer is mainly conductive and occurs through the walls of the dryer. The heating medium, typically hot gas or thermal oil, is separated from the sludge and the evaporated water is not intermingled with the heating fluid. Although this requires more complicated

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apparatus, the advantage of this approach is that the latent heat of the evaporated water may be recovered. Mixed dryers try to combine both conduction and convection to evaporate the water. Technical details are available in the literature (e.g. Arlabosse, 2001; Chen et al., 2002; Lowe, 1995; Ressent, 1998).

The thermal dryers currently applied for sewage sludge service have generally been adapted from industrial dryers used in other processes such chemicals, food or pharmaceuticals (Arlabosse, 2001), with mixed results. In most cases, thermal drying is not a cost effective operation because the energy demand is high and the product is a waste material requiring final disposal (Arlabosse, 2001). Drying consumes significant energy (Kudra, 2004), contributes to consumption of non-renewable natural resources and to greenhouse gas production. Efficiencies in energy consumption, e.g. though the use of heat pumps to transform low quality into high quality heat (IEA, 2004), are consequently desirable where possible. However, this is seldom applied in the design of waste thermal dryers which often lack proper optimization and integration in the processes they serve. Nevertheless, a few commercial systems show the potential for efficiency using such technologies, with low energy consumption ranging between 130 and 560 kWh ton^{-1} of evaporated water (Arlabosse, 2001). Moreover, the rapid increase of crude oil prices and concerns about climatic change caused by the greenhouse emissions, support a radical reconsideration of heat pumps in thermal drying (Kudra, 2004).

Two main technical difficulties are regularly referred to for sewage sludge drying (Lowe, 1995; Ressent, 1998):

1. All types of sewage thermal dryers produce vapor containing volatile organic compounds, creating an odor nuisance (Chavez, 2004; Hwang et al., 1995; Lambert et al., 2000; Nurul et al., 1998; Winter et al., 2004), toxicity hazard or even a real risk of explosion (Whipps, 2004).
2. Secondly, at a moderate total solids content typically between 40% and 50%, the sludge undergoes a *plastic phase* (Kudra, 2003; Lowe, 1995). This phase is characterized by exceptionally sticky behavior that complicates movement of the material through the dryers.

In summary, there are three main issues related to current thermal sludge drying processes which require innovative improvement: better energy efficiency; control of the VOCs in the exhaust gas for odor, toxic and explosive chemicals; and avoidance of the problems related to the plastic phase.

1.2. The fry-drying process for thermal drying of sewage sludge

1.2.1. Process concept

Frying is widely used in food processing as a cooking operation mainly to transform the sensory qualities of the foods (Moreira et al., 1999). Nevertheless, frying can also be a very effective drying method for a large variety of products (Vitrac, 2000). Operations using direct contact between the sludge and a liquid as a basis for drying have been reported in the literature, though incompletely (Bress et al., 1987; Kuntschar, 1996; Lue-Hing et al., 1996). The first systematic work about the drying of sewage sludge by immersion frying was presented by Pires da Silva (Silva et al., 2005, 2003). These reported experimental tests which were carried out by immersing a cylinder (about 40 mm length $\times$ 20–26 mm diameter) of municipal sewage sludge into bath containing 5 L soybean oil which was maintained at temperatures between 168 and 213 °C, well above the water boiling point. These conditions provided a dried sludge with $<5\%$ moisture in about 600 s. Moreover, due to the impregnation of oil the lower heating value (LHV) of fry-dried sludge was 24 MJ/kg which is significantly higher than air-dried sludge with comparable water content (14 MJ/kg).

Peregrina et al. (2006a) have also done similar experiments using waste cooking oils instead of vegetable oils, with a view to improving both the economic and environmental outcomes.

The mass and transfer phenomena occurring during the fry-drying of sewage sludge were characterized (Peregrina et al., 2006a) by four drying stages similar to those involved in frying of foods (Farkas and Hubbard, 2000). There is an initial period of sample heating, followed by boiling, initially at the surface but then proceeding as a front into the interior of the sample. During the third stage, when the water is depleted, oil penetrates into the material and finally there may be a period during which the material undergoes a phase change. The studies reported that the optimal frying temperature is 140–160 °C and that higher rates of vaporization are achieved for smaller individual samples. The waste cooking oil acts both as heating medium during the process and to improve the energy value of the material in the final fried product. The process naturally leads to co-disposal by incineration of these two waste materials.

1.2.2. Technical performance of the fry-drying process

Fry-drying offers many advantages over conventional dryers for processing sewage sludge. It provides for simple direct drying, with the product in direct contact with the heating medium (i.e. frying oil); avoids the *plastic phase* related problems; and the high temperatures completely hygienize the product, reducing handing issues. Moreover, the vapor removed is essentially evaporated water, so the latent heat is easy to recover by condensation.

A significant technical advantage of fry-drying lies in the rapidity of the process. Table 1 compares some typical dryers on the basis of their characteristic heat transfer resistances: the higher the resistance the slower the drying. Convective dryers have thermal resistances an order of magnitude higher than fry-drying and thin layer agitated contact dryers. The latter are mechanically and operation-