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# Analysis the fry-drying process of oily sludge sample

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ABSTRACT

Oily sludge is one of the hazardous materials if not properly treated. Thus, recovering oil from oily sludge could reduce environmental problems and have substantial commercial benefits. However, prior to oil recovery, dehydration is extremely necessary to effectively reduce energy consumption. Fry-drying is a novel dehydration method which characterized by low energy consumption and high drying efficiency. In this study, the spent lubricating oil of vehicle was used as frying medium, which enabled a drying operation that was environmental friendly and economically competitive. A modified Dean-Stark apparatus-II was designed to accurately and efficiently measure the water and oil contents of the fried sample. Considering the oil adsorption mechanism that occurred during the fry-drying of oily sludge, a suitable equation for the forced convective heat transfer coefficient ($h$) was established using the fundamental of energy balance. Results showed that the $h$ change tendency and the calculated maximum value were distinct from previous food frying findings. Finally, the entire fry-drying process of oily sludge was divided into four periods according to the different sample drying rate change tendencies. The heat and mass transfer processes of each period were also analyzed.



*Keywords:* Fry-drying; Modified Dean-Stark apparatus II; Heat and mass transfer processes; Convective heat transfer coefficient

## 1. Introduction

Oily sludge is a waste generated during crude oil exploration, refining, and storage (Jean et al., 2001). This substance has a complex composition of 5–60 wt% crude oil, 30–80 wt% water, and 15–60 wt% soil. The oily sludge composition varies depending on different sources. In China, the oily sludge amounted to more than five million tons last year, and it was listed in the country's Dangerous Waste List because of its high oil content (Xu et al., 2009). Effective recovery of oil from oily sludge is attracting considerable attention because of increased oil demand and oil price. At present, oil recovery technologies are classified in two parts, namely, chemical method and physical method. The former includes solvent extraction and demulsification, whereas the latter includes ultrasonication and freeze-thawing (summarized in Table 1).

The oil recovery rates shown in Table 1 indicate that the methods cannot effectively recover oil from oily sludge. Although chloroform extraction exhibits 90% recovery rate, the high cost of this extraction method limits its use. Pyrolysis was developed in the last decade and was widely used to recover oil from the shale (Golubev, 2003).

We have performed some studies on recovering oil from oily sludge by pyrolysis. Our results show that the quantity and quality of recovered oil are satisfactory, but high energy is consumed and a large amount of contaminated water is produced. These problems are mainly due to the substantial quantity of water in the oily sludge. Therefore, the oily sludge must be dried before performing oil recovery.

To date, several drying methods, such as hot air drying, superheated steam drying, spray drying, freeze drying, fry drying, have been used to dry materials. Based on published

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**Nomenclature**

| | |
|---|---|
| $m_w$ | mass of water in the sample (g) |
| $v_w$ | volume of water in the sample (mL) |
| $\rho_w$ | density of water at room temperature ($g\,mL^{-1}$) |
| $m_o$ | mass of oil in the sample (g) |
| $m_{s0}$ | mass of original the sample (g) |
| $m_{se}$ | mass of the oven dried sample (g) |
| $S_w$ | sample water content ($g\,g^{-1}$) |
| $S_o$ | sample oil content ($g\,g^{-1}$) |
| $h$ | forced convective heat transfer coefficient ($W\,m^{-2}\,{}^\circ C^{-1}$) |
| $h_n$ | natural convective heat transfer coefficient ($W\,m^{-2}\,{}^\circ C^{-1}$) |
| $H_v$ | latent heat of water evaporation ($kJ\,kg^{-1}$) |
| $Cp_i$ | specific heat capacity of composition $i$ ($kJ\,kg^{-1}\,{}^\circ C^{-1}$) |
| $A$ | surface area of the sample ($m^{-2}$) |
| $R$ | radius of the cylindrical sample (m) |
| $L$ | length of the cylindrical sample (m) |
| $t$ | frying time (s) |
| $T$ | frying oil temperature (°C) |
| $T_v$ | sample volume average temperature (°C) |

*Subscript*

| | |
|---|---|
| w | water |
| o | crude oil |
| s | soil |
| l | spent lubricating oil of vehicle |

studies, we conclude that most of these methods are not suitable for drying oily sludge, because of high equipment investment or poor processing capacity. At present, hot air drying is widely used in industrial scale drying of oily sludge. Fry-drying is generally used in food processing, although some innovative applications of this technique have been suggested for non-food materials such as timber, sewage sludge, and brown coal (Peregrina et al., 2006; Sugita et al., 2003, 2006). The Chemical Engineers' Handbook (Perry et al., 2008) reveals that evaporating 1 kg of water through traditional hot air drying consumes a total energy of 5000–7350 kJ. By contrast, the fry-drying consumes approximately 2450 $kJ\,kg^{-1}$ water. Moreover the fry-drying exhibits superior drying efficiency compared with the hot air drying (Chen et al., 2002; Ohm et al., 2009, 2010). Therefore, fry-drying is a preferred oily sludge drying technology.

In this study, the spent lubricating oil of vehicle (SLOV), which is an environmental and human health hazardous waste (Guerin, 2008), was selected as the medium for fry-drying oily sludge. This operation enables waste processing using another type of waste, thereby generating economic and environmental benefits.

Only a few studies on municipal sludge fry-drying process have been done, which used recycled edible oil as frying medium. Given that fry-dried products are usually considered as an alternative solid fuel, a higher oil content of the final product is better. To our knowledge, few studies on heat and mass transfer properties during fry-drying have been conducted. Accordingly, this work aimed to support the findings of heat and mass transfer analyses using experimental results.

## 2. Materials and methods

### 2.1. *Materials*

Oily sludge was collected from the Liaohe oil field in China. The sludge was black, viscous, and in the form of a semi-solid cake at ambient temperature. The characteristics of the sludge are listed in Table 2.

As shown in Table 2, the oily sludge sample exhibited high water content, high solid content, and relatively low oil content.

The SLOV used in this work was from a garage, and its characteristics are listed in Table 3.

### 2.2. *Experimental design*

#### 2.2.1. *Novel measuring apparatus*

Most studies on fry-drying have been mainly performed in the food industry. The water and oil contents of fried food were measured by hot air drying and Soxhlet extraction, respectively (Baik and Mittal, 2002; Grenier et al., 2007; Hubbard and

**Table 1 – Oil recovery technologies from the oily sludge.**

| Method | | Conditions | Results (oil recovery, wt%) | Reference |
|---|---|---|---|---|
| Solvent extraction | MEK[a] | S/S[b] = 4:4 T (°C) = 22–24 t (min) = 120 | 39.2 | Zubaidy and Abouelnasr (2010) |
| | Hexane and xylene | S/S = 4:1 T (°C) = 30 t (min) = 120 | 67.5 | Taiwo and Otolorin (2009) |
| | Chloroform | S/S = 3:1 T (°C) = 30 t (min) = 120 | 90.0 | Chengwu (2000) |
| Demulsification | AEO-9 | S/S = 5:1 pH = 9 T (°C) = 70 t (min) = 30 | 78.2 | He and Chen (2002) |
| | NP-10 | S/S = 5:1 pH = 9 T (°C) = 70 t (min) = 30 | 78.4 | |
| | Sodium silicate | S/S = 6:1 pH = 9 T (°C) = 60 t (min) = 30 | 78.9 | |
| Ultrasonication | | F (kHz) = 20 Power (W) = 66 T (°C) = 50 t (min) = 10 | 80.0 | Zhang et al. (2012) |
| Freeze-thawing | | T (°C) = −20 t (min) = 720 | 65.7 | |
| Ultrasonication and Freeze-thawing | | F (kHz) = 20 Power (W) = 66 T (°C) = −20 t (min) = 10/720 | 64.2 | |

[a] Methyl ethyl ketone.
[b] Solvent to oily sludge mass ratio.