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Drying of Drilling Sludge: Conventional and Microwave Drying

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ABSTRACT

Drilling sludge (DS) is one of the most important waste generated during drilling activities and management of drilling sludge (DS) is highly complicated because of its high moisture content, complex constituents and chemical characteristics. Treatment, transportation and disposal costs of DS are important issues about the management of DS. Restrictive environmental legislation has led to the optimization of solid–liquid separation. Drying process can be defined as an effective solution to reduce sludge mass and thus to reduce management cost.

In this study, conventional and microwave drying of DS were compared in terms of process efficiency. Microwave power levels, drying temperature, drying times, moisture content of the DS and energy consumption of drying processes were defined as control parameters. Microwave power levels of 120 and 700 W and 60 and 80 °C were performed to dry the DS sample for microwave and conventional drying, respectively. The results showed that the microwave drying was more effective than conventional method in the view of drying times and energy consumption.

Keywords:
Drilling sludge; Moisture, Energy; Conventional drying; Microwave drying

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INTRODUCTION

Increasing numbers of petroleum and natural gas exploration, in parallel with rapidly increasing rise in fuel demand of the mankind, created a rise in the amounts and the types of the wastes, as well as environmental pollution problems.

In the oil industry, there are several steps namely exploration, drilling, production, transportation, handling, and refining from starting the exploration of oil and/or natural gas to their consumption. During these activities, solid, liquid, and gas wastes are emerged due to use of various chemicals and techniques. One of the most important wastes of these activities is drilling mud waste. Drilling mud (also known as drilling fluid) is used for cleaning the hole of cuttings created during the drilling process and other special purposes. Drilling mud is prepared by adding various organic, inorganic and antibacterial chemical additives for controlling the physical and chemical properties. During the drilling process, the cuttings are also carried to the ground within the drilling mud and thus drilling waste mud is produced.

There are on-site (in-situ) and off-site (ex-situ) methods for the removal of hydrocarbon-based (petroleum and natural gas) pollution from soil and groundwater. The ex-situ methods are defined as treatment for polluted soil, rubble material, sludge or hazardous materials and wastes in mobile or fixed installations established outsides. The applications used within this method are usually soil washing, thermal treatment, biological treatment (pump & treat technology), chemical treatment, ion exchange, use of organic solvents or water based washing solutions, metal extraction, and solidification/stabilization [1]. On the other hand, applicable in-situ methods include bioremediation, phytoremediation, soil washing, soil vapor extraction, vitrification, solidification/stabilization, thermal desorption etc.

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As mentioned above, there are many different treatment methods for drilling sludge. However, the drilling sludge is characterized by its high moisture content and low bulk density, which result in a low conversion efficiency as well as difficulties in its collection, storage, and transportation. The high moisture content of the drilling sludge is a critical factor determining its disposal options [2, 3].

Drying process is an effective solution to reduce the mass of the sludge and thus to reduce its management cost. Drying is an energy intensive processes, and for that reason it is more important to select the technology that consumes less energy [4].

Microwave drying differs markedly from conventional drying methods. In conventional heating systems, the energy is transferred through conduction, convection and radiation. Due to the temperature difference between the hot surface and the colder interior, the heat is gradually transferred from the surface to the interior of the material in conventional drying. In microwave heating, energy is supplied directly to materials by molecular interaction with the electromagnetic field generated. In the case of microwave drying, the electromagnetic field influences the material as a whole. The water molecules in the material vibrates millions of times a second. The energy occuring by this vibration makes the moisture in the material evaporate quickly [5-7].

Microwave drying is a method used for the treatment of a wide variety of waste types and has many potential advantages. Microwave application is a fast and flexible process that can be controlled quickly (selectable) and easily (remotely controllable) and accessible to high temperature values. Microwave heating requires less than 1% of the time required for conventional heating methods. Compared to other conventional systems such as conventional drying, it has the advantage of being a cleaner energy source and energy saving. Microwave application, which can also be used for in-situ treatment of wastes, is a method that has significant gains in terms of providing a significant reduction in waste volume, treating or immobilizing hazardous compounds that meet the legal requirements for waste handling and storage.

Microwave drying has been one of the topics investigated in the treatment of various wastes in recent years due to its outstanding features compared to conventional heating methods [8- 12].

Chien (2012) previously conducted laboratory-scale studies on the microwave heating remediation of petroleum hydrocarbons contaminated sites to field measurements. The study suggested that the microwave heating was a permanent remediation method as well as cost effective and time efficient. Moreover, the results showed that polluted areas could be improved to such an extent that they can later be used for agricultural purposes [8].

Shang et al. (2006) investigated the microwave heating as a new method for the treatment of petroleum-contaminated drill cuttings by examining the thermal desorption of petroleum from the perspective of the influence of power, duration of treatment and moisture content. In the study, it was found that residual oil concentration would decrease considerably due to the microwave treatment for only 20 sec of petroleum-contaminated waste residues [10].

In this study, the drying of drilling sludge via conventional and microwave processes was studied, and the energy consumptions and drying times of these two methods were compared.

MATERIALS AND METHODS

Material and Sample Preparation

In this study, the drilling sludge (DS) was obtained from the petroleum and natural gas drilling operations carried out by Turkish Petroleum (TP) in Thrace Region. The sludge samples were stored at 4 ^{o}C. Triplicate samples was retrieved to room temperature before using for the experimental studies. The sample with a mass of 183,5±0,5 g was put into glass container having a diameter of 15 cm and 0,5 cm height both for the conventional and microwave drying processes. The initial moisture content of the sample was determined according to the method of ASTM 3173 using 10 g of raw material to dry at 105 ^{o}C in an oven for 24 h. The determined moisture content of DS was 45%.

Experimental Setup

Microvave drying experiments were was conducted according to procedure in Çelen et all., 2015 [13]. Microwave drying of DS samples was performed with modified domestic type Beko brand microwave oven having 2450 MHz frequency (Fig. 1) and 19 liters of internal volume. During the experiments, the moisture losses were calculated from the weight measurement by precision scale (Presica XB 620 M) which was put on the microwave oven. Performed microwave power levels were selected as 120 and 700 W in this study. The drying experiments were continued until the sample mass decreased below the pre-measured sample mass with moisture content of 20%. Preliminary studies were conducted to determine this value.

Two different temperature degrees of 60 and 80 ^{o}C were chosen for conventional drying experiments. The drying experiments were continued until the moisture con-

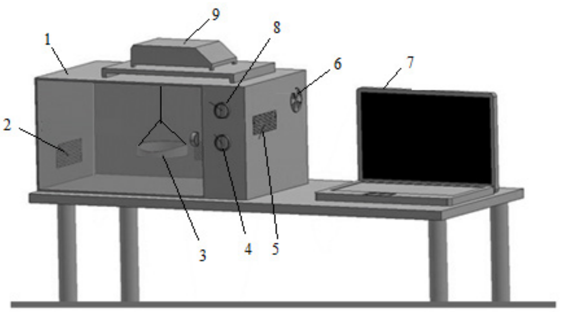

Figure 1. Microwave Drying System (1: Microwave oven, 2: Ventilation holes, 3: Tray, 4: Timer, 5: Magnetron, 6: Fan; 7: Computer, 8: Power switch, 9: Scales) The oven used in the conventional drying experiments was Kenton GX brand.

tent of the sample reached up to the same content as the microwave drying study.

Moisture content according to wet basis (Eq. 1) and dimensionless moisture ratio (Eq. 2) were calculated with the following equations:

$$\%m_{wb} = \left[M_w / \left(M_w + M_d\right)\right] \times 100 \quad (1)$$

$$m_r = \left(m - m_e\right) / \left(m_o - m_e\right) \quad (2)$$

where;

M_d: Dry mass of DS (g),

M_w: Wet mass of DS (g),

m_r : Dimensionless moisture ratio,

m: Moisture content of DS at a specific time,

m_e: Equilibrium moisture content,

m_o: Initial moisture content,

m_{wb}: Moisture content according to wet basis (g water/g wet matter).

Equilibrium moisture content in the microwave (m_e) accepted as zero [4, 13, 14].

Eq. 2 was defined as follows for the microwave drying (Eq. 3);

$$m_r = m \ / \ m_o \quad (3)$$

RESULTS AND DISCUSSION

In this study, microwave drying and conventional hot air drying were compared in the view of process efficiency. The microwave power levels of 120 and 700 W and hot air temperature degrees of 60 and 80 °C were selected to dry the drilling sludge sample. Obtained values of drying times, moisture ratio and energy consumption correlated with microwave power levels and hot air temperatures are presented in Table1. The drying experiments were continued until the equal moisture content/ratio obtained within MW drying and hot air drying process. Final moisture ratio was obtained about 20±1% for both microwave power levels and hot air temperature degrees while

Table 1. Obtained moisture ratio and energy consumption values

Type of heating	Power/ Temperature	Time	Initial Sample Weight (g)	m_{wb}* (g water/g wet matter)
Microwave	700 W	5,5 min	183.367	0,2139
	120 W	48 min	183.842	0,1926
Conventional	60 °C	18 h	183.937	0,2044
	80 °C	12 h	183.184	0,2022

*Calculated according to Eq-1.

the initial moisture ratio was 45%.

As seen from Table 1, as the MW power level was increased from 120 W to 700 W, the drying time decreased from 48 minute to 5,5 minute. The energy consumption for 700 and 120 W was 0,11 and 0,16 kW/h, respectively. According to this result, the energy consumption increased 45,45% because of the increasing drying time.

When the hot air temperature degree was increased from 60 °C to 80 °C, the drying time decreased from 18 h to 12 h which indicated about 33% decrease in the drying time. According to Fig. 2, energy consumption for 60 °C and 80 °C was determined as 0,9 and 0,99 kW/h, respectively. Accordingly, it is found that the energy consumption increased about 9,1%.

When comparing the energy consumption of the microwave and conventional drying applications for the same moisture content, the conventional drying process, was resulted in 84% more energy consumption based on the minimum energy consumption (700 W and 60 °C,) and 88% maximum energy consumption (120 W and 80 °C) compared

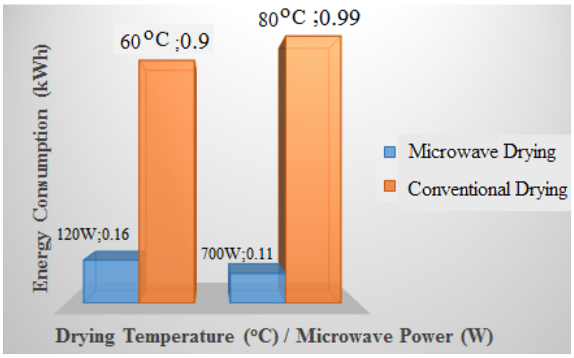

Figure 2. Energy consumption values for drying experiments

to the microwave drying process.

There was a significant difference among the microwave and conventional drying processes in terms of drying time for the same moisture content of the sludge. According to Fig. 3, a linear decrease was shown in moisture ratio for microwave and conventional drying process time. The increase in drying time resulted with high energy consumption.

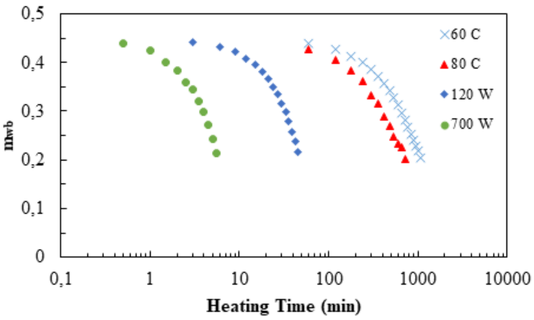

Figure 3. Drying ratio of DS at various MW power level and hot air temperature degree

As seen from Fig. 3, while there was no significant change on the drying of the sludge using the conventional heating, the microwave heating showed considerable decrease in the sludge mass, particularly at 700 W. These results clearly indicate that the microwave heating can be effectively used on the drilling mud drying following determination of the optimum parameters. Moisture content of sludge, reduced rapidly when drying time is increased. It is derived from the increase in drying temperature and microwave power. When microwave and conventional drying is compared, microwave drying has advantage on account of volume heating, drying time and energy consumption.

CONCLUSION

According to the result of the study, the drying of the drilling mud at microwave power level of 700 W seems to provide the lowest energy consumption and drying time compared to the conventional drying. It has been seen that the microwave drying of DS was much more effective than conventional drying in terms of drying time and energy consumption. It was determined that the moisture of the sludge decreased rapidly with the microwave drying which also decreased the drying time providing energy saving. Furthermore drying of DS, with reducing weight and volume, will also reduce the sludge collection, treatment, transportation, storage, and disposal costs as well as adverse environmental effects.

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