Sewage Sludge Drying with Microwave Irradiation: Influence of Salt Addition and Energy Consumption

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Introduction

There is an emerging interest in the use of microwave technology for sewage sludge drying. High-frequency radiation interacts with the dipolar molecules within the sludge, which results in rapid heating and drying. Microwave radiation is reported to help the decomposition the floc structure of the sludge and facilitate the release of bound water and therefore dewatering (Yu et al., 2009). Other researchers also reported that microwave radiation technology is successful to decompose the floc structure and thus improve the anaerobic digestion (Gil et al., 2018; Kumar et al., 2010), and also to sanitize the sludges (Mawioo et al., 2017).

Mawioo et al. (2017) developed a microwave-based reactor on a pilot scale and reported a volume decrease of 60%. Domínguez et al. (2004) dried different types of sewage sludges by using microwave ovens and obtained a volume reduction ranging between 65-90%.

Bennamoun et al. (2016) investigated the influence of mass and microwave power on the drying behavior of the sewage sludge and developed a mathematical model on moisture diffusion. Jinping et al. (2015) obtained drying curves by applying microwave radiation to sludge samples with different thickness and diameter. Application of microwave radiation is a proven technology in the food industry for pasteurization and sterilization. Research showed that it has the potential to both pasteurize and dry sewage sludge (Tyagi and Lo, 2013).

The present study adds to this knowledge by reporting on the optimization of the drying process including the addition of salt to improve ionic conduction, and on the energy consumption in comparison to electrical heating. Electrical conductivity is about the transport of electrical current with the replacement of ions and electrons. It was hypothesized that ionic conduction might have a considerable role to heat different materials while dipole rotation is an effective mechanism in heat production in microwave systems. Therefore salt was introduced to the sludge before microwave drying in this study.

Materials and Methods

The objective of this study was to determine the efficiency of microwave radiation technology as a drying method, compare the energy consumption with that of electrical heating and investigate the influence of addition of ionic species such as salt to the drying performance. Mechanically dewatered sewage sludge samples taken from the outlet of city wastewater treatment plant, which had a dry solids content ranging between 20-25%, were dried under varying conditions by using a microwave oven of 2.45 GHz, which is the resonance frequency of water molecules.

Salt was added to the sewage sludge with a percentage of 15% to improve the heating within the microwave energy. The microwave oven was operated in fixed mode and rotary mode to dry the sludge. Sludge samples were exposed to a microwave power of 900 W, for the time intervals ranging between 1 to 10 minutes. Sludge samples were air cured for 10 minutes, after microwave drying. Moisture contents of the samples were measured in every stage, and evaporation rates and drying performances were determined. As a result, the hot and cold regions on the dried sludge and the microwave oven, and the parameters influencing the drying performance were determined.

Energy consumption was also monitored for the microwave drying period. Samples with the same content were subjected to electrical drying to compare the energy consumption levels. Thermal camera images were taken to verify the hot regions.

Results & Discussion

It was found that salt addition slightly affected the drying performance during microwave radiation. Figure 1 shows a comparison of the moisture loss levels of the sludge samples prepared with salt and without salt. The location of the sample within the oven was also investigated. Moisture loss levels from the sample located to the floor of the oven and the 6 cm above the floor did not show considerable differences as can be seen from the Figure 1.

The operation mode differences such as rotary of fixed mode did not show a considerable difference although rotary mode showed a higher energy consumption. Air-cure after microwave drying resulted in the continuation of moisture loss. Table 1 shows the influence of salt addition on the dielectric properties of the sludge.

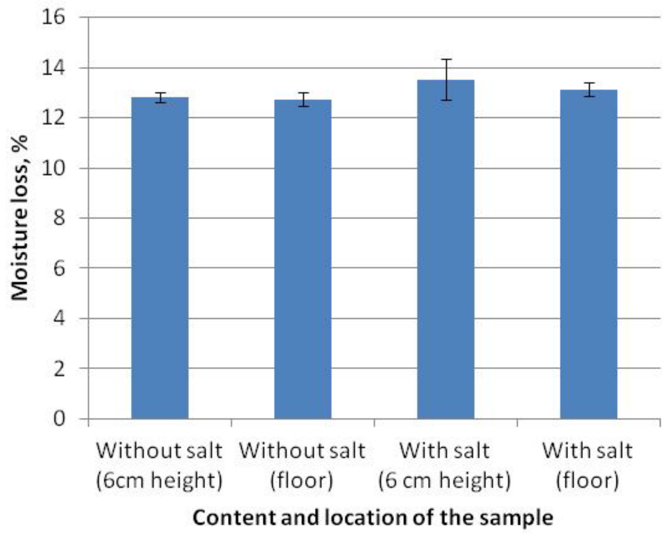
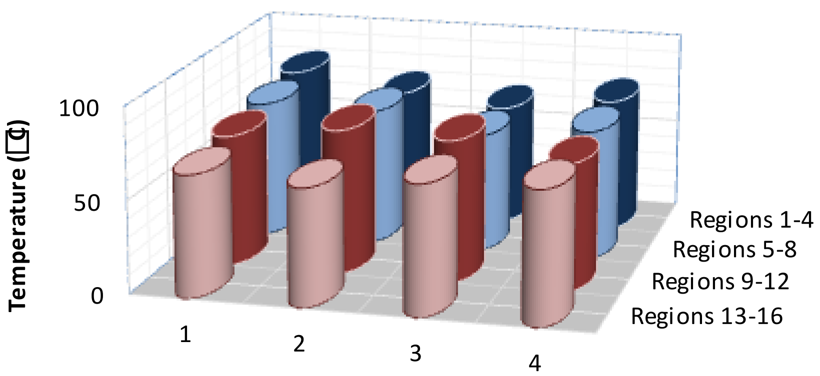


Figure 1. Comparison of the moisture loss from the sludge samples prepared with salt and without salt, located to the floor of the oven and the 6 cm above the floor

Table 1. Dielectric characteristics of the sludge samples

	Dielectric Properties		
	ε' (Relative Permittivity)	**ε'' (Relative dielectric loss factor)**	**ε''/ε' (loss tangent)**
Salt added sewage sludge	58.18	18.90	0.325
Sewage sludge	76.22	10.18	0.134

Figure 2 shows the temperature distribution within the oven during the drying of sewage sludge for 10 minutes in fixed operation mode. It can be inferred that side regions receiving more reflections and the corner points are heated more than the other regions.



	1	2	3	4
Regions 13-16	65,6	63,1	69,6	71,1
Regions 9-12	71	78,2	76,8	68,5
Regions 5-8	74,3	73,7	64,3	70,6
Regions 1-4	78,6	69,8	65,3	72,9

Figure 2. Temperature distribution within the oven during the drying of sewage sludge (10 min, fixed mode, located on the floor of the oven, 900W, salt added)

Figure 3 shows the comparison of moisture loss and energy consumption levels of sludge samples dried in an electric oven and microwave oven. It can be seen from the figure that moisture loss level around 33% was achieved in 10 minutes by using a microwave oven while that level was achieved in 30 minutes when the electric oven was used. Energy consumption when microwave oven was used for 10 minutes was 0,231 kW, while that level was measured as 0,444 kW when the electric oven was used for 30 minutes, which is almost twice of the level of the microwave oven.

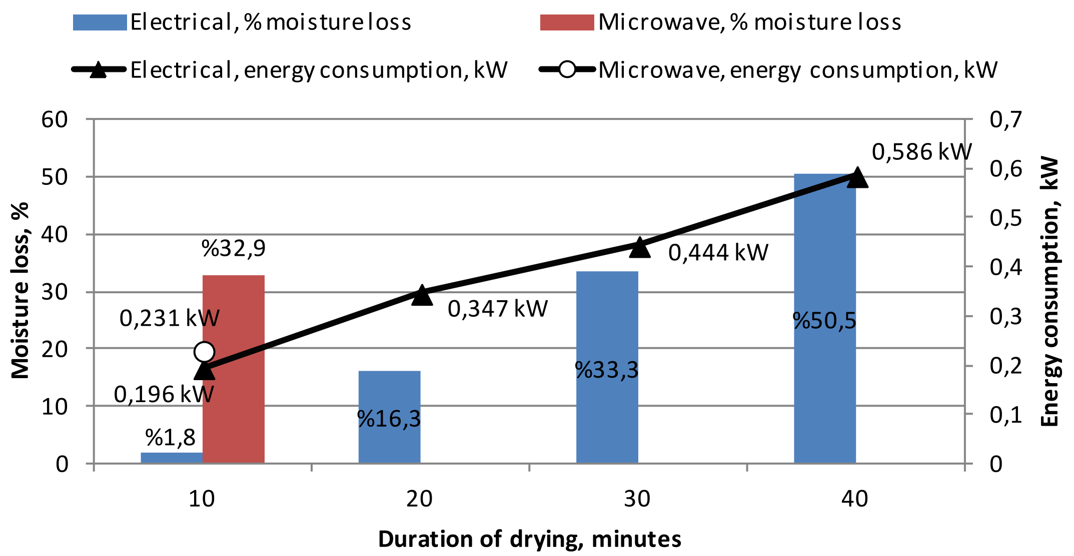


Figure 3. Comparison of moisture loss and energy consumption levels of sludge samples dried in the electric oven and microwave oven

Conclusions

No significant difference was found between the microwave oven operating modes, fixed or rotary drying modes, regarding moisture loss. Addition of salt was found to slightly enhance the drying behavior of the sludge during the microwave irradiation. Salt addition decreased the relative permittivity, increased the relative dielectric loss factor, and increased the loss tangent of the sewage sludge. The side regions of the microwave oven receiving more reflections and the corner points are heated more than the other regions. Moisture loss level around 33% was achieved in 10 minutes and 30 minutes by using the microwave oven, and electric oven, respectively. Energy consumption levels for 33% moisture loss were 0,231 kW and 0,444 kW for the microwave oven and electric oven, respectively. It can be concluded that electrical drying consumes more energy than the microwave oven for a certain moisture loss targeted in sewage sludge.

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