MICROWAVE DRYING OF SEWAGE SLUDGE FROM A WASTEWATER TREATMENT PLANT IN TURKEY

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Abstract

Purpose: The objective of this study was to investigate the influence of the parameters such as sludge form (raw or ground), drying method (electric or microwave), and drying period (5 minutes or 10 minutes) on drying performance of sewage sludge.
Methods: A design of experiments approach was adopted and experiments were conducted on the mechanically dried sewage sludge obtained from a municipal wastewater treatment plant. Humidity losses were recorded immediately after drying and also after 10 minutes air-cure following microwave drying. Microwave drying of the sludge was modeled using Comsol Multiphysics software and temperature maps were generated.
Results: Microwave drying had a superior drying ability than classical drying using electric oven. Grinding of the sludge did not offer an advantage to the microwave drying. Electric field was dense on the corner points of the sludge plate, and temperature levels were higher on the edges of the sludge compared to the middle points.

Keywords

Humidity loss, dewatering, microwave modeling, grinding

Introduction

Sludge management is one of the most complicated tasks of wastewater treatment plants (WWTP) because of the large amounts generated and high moisture content, which is difficult to handle. Limited availability of sludge disposal routes leaded researchers towards the usage of microwave irradiation techniques in sludge management [1,2]. The ability of microwave irradiation to heat the material rapidly and provide instant on/off control [1] can make it a preferred option or a preferred step in sludge management.

Sludge dewatering is necessary for easy handling towards disposal. Mechanically dewatered sewage sludge generally contains a dry solids (DS) ratio ranging between 20-35% [3]. The DS content of the sludge can increase up to more than 90% with drying [4]. Dried sewage sludge has a potential to be used as an additional fuel in plants such as cement factory. Chen et al. [5] reported that microwave drying of sewage sludge can increase the calorific value from 5.65 MJ/kg to 18.75 MJ/kg due to the removal of large amount of moisture content.

Materials & Methods

Sludge drying experiments were conducted by using a microwave and electric oven. Mechanically dewatered sewage sludge of 78% dry solids content was obtained from the outlet of a municipal WWTP of a metropolitan city in Turkey, for the experiments. Characteristics of the sludge studied are given in Table 1.

Design of experiments was undertaken by using Minitab software. The factors applied were sludge form (levels: raw and ground), drying period (levels: 5 minutes, 10 minutes), and drying method (electrical or microwave), and the response was humidity loss. Humidity losses were recorded immediately after drying and also after 10 minutes air cure following microwave drying. The power applied by both microwave and electric ovens were 900 Watt. The thickness of the sludge on the drying plate was 1 cm, and the dimensions of the plate were 18x18 cm. Each experiment was repeated three times. Half of the experiments were conducted on the sludge which was ground and homogenized with a kitchen type blender for 15 seconds.

Microwave drying of the sludge was modeled using commercial software Comsol Multiphysics. Temperature maps were generated by using a laser thermometer on the identified fields of the drying plate. Dielectric characteristics of the sludge sample was measured using network analyzer (Agilent, E506 1B) and probe of 200 mm, at 2.45 GHz frequency in two parallels.

Table 1. Characteristics of the WWTP sludge studied

Parameter	Level	Method
pH	6.35	TS 8332, ISO 10390
Organic Matter (%) (550^{0}C)	66.3	TS EN 12879
TOC (%)	8.64	TS 12089, EN13137
Humidity (%)	78.21	ASTM D 7582
Volatile Matter (%)	63.58	
Ash (%)	27.32	ASTM E 1755
Total sulphur (%)	0.95	ASTM D 4239
Upper calorific value (cal/g)	4004	ASTM D 5865-12
Lower calorific value (cal/gr)	3750	ASTM D 5865-12
Elemental Analysis		
Carbon (C%)	41.15	
Hydrogen (H%)	5.03	ASTM D 5373-08
Nitrogen (N%)	6.62	
Oxygen (O%)	18.93	ASTM D 3176

Elute Analysis	
Arsenic (As mg/L)	0.016
Barium (Ba mg/L)	0.036
Cadmium (Cd mg/L)	0.00012
Copper (Cu mg/L)	0.048
Molybdenum (Mo mg/L)	0.004
Nickel (Ni mg/L)	0.128
Antimony (Sb mg/L)	0.005
Selenium (Se mg/L)	0.0023
Zinc (Zn mg/L)	0.675
Chlorine (Cl^- mg/L)	45.2
Fluorine (F- mg/L)	<0.2
Sulphate ($SO4^=$ mg/L)	<2
Dissolved organic carbon (DOC mg/L)	314
Total dissolved solid matter (TDS mg/L)	1823
Phenols (C6H5OH mg/L)	0.09
Original waste analysis	
BTEX (benzene, toluene, ethyl benzene, xylene mg/kg)	<0.05
PCBs (mg/kg)	0.32
Mineral oil (mg/kg)	765.6
Loss on ignition (%)	69.42

Results & Discussion

Impact of the Factors on Drying

Of the factors investigated, drying method was found to be the factor affecting the drying performance most. Fig. 1a shows the Pareto chart of the standardized effects on humidity loss. Microwave drying had a superior impact on the sludge than classical drying using electrical oven, in terms of humidity loss. Fig. 1b shows main effects on humidity loss, immediately after drying. It can be seen from Fig. 1b that grinding of the sludge had not a significant effect on the drying performance, whereas as would be expected, longer duration of drying (10 minutes) was more effective on humidity loss than the shorter duration of 5 minutes.

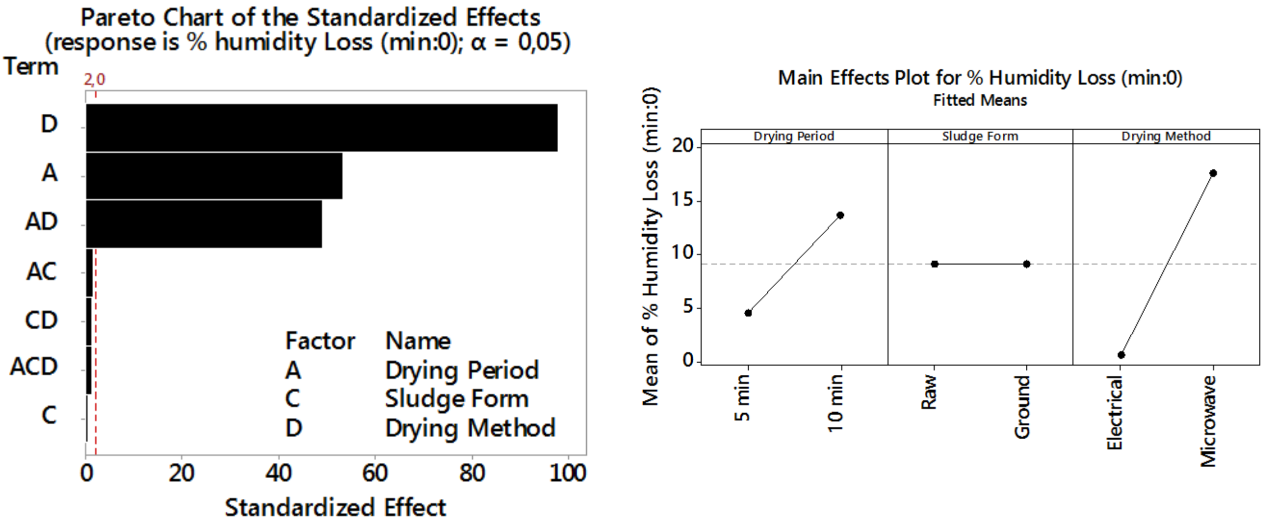
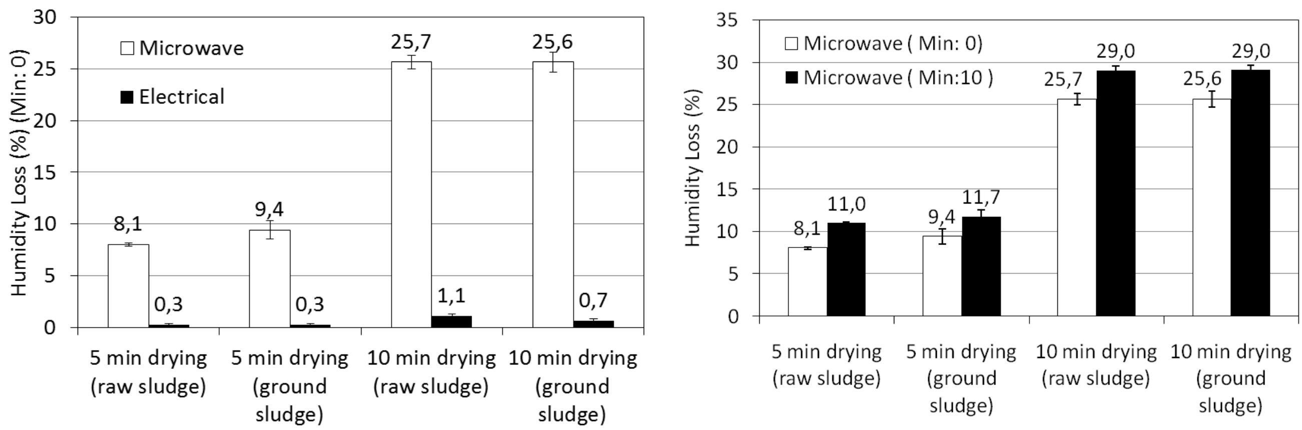


Fig. 1 a) Pareto chart of the standardized effects on humidity loss, b) Main effects plots for humidity loss immediately after microwave or electrical drying (min:0)

Fig. 2a shows the drying performances of microwave oven and classical electrical oven. After 10 minutes of drying with microwave irradiation, the humidity loss obtained was 25.7% while that of electrical drying was only 1.1%. Fig. 2a also shows that grinding of the sludge did not have a significant effect on drying. Fig. 2b gives a comparison of humidity losses obtained immediately after drying and after 10 minutes of air cure following drying. It would be seen that air cure of a certain period after drying increases humidity loss since volatilization continues.



a) b)

Fig. 2 a) Humidity losses recorded after drying by using microwave irradiation and electrical heating **b)** Comparison of the humidity losses obtained immediately after drying (Min:0), and after 10 minutes of air cure following drying (Min:10)

Microwave Modeling

The multimode domestic microwave oven was used for experimental purposes in this study. The excitation port of the oven was a rectangular waveguide and fundamental mode was TE_{10}. Microwave drying of the ground sludge was modelled by simulation with commercial software Comsol Multiphysics. Sludge was placed into the microwave oven with a tray as shown in

Fig. 3. The electric field distribution and power dissipated density were analyzed by simulation.

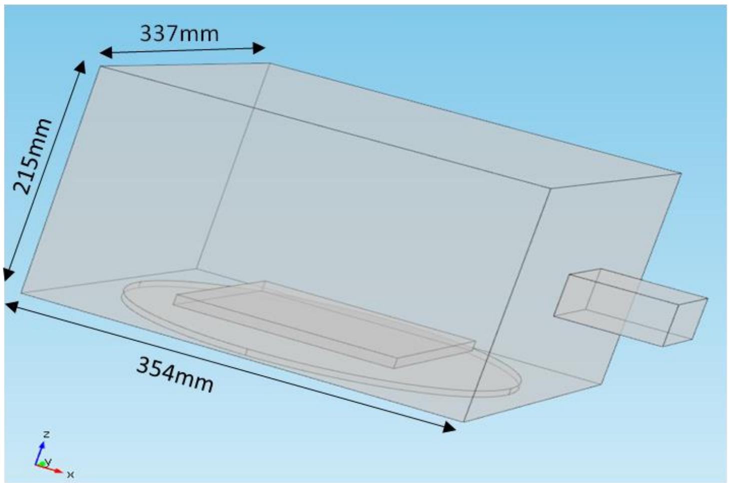


Fig. 3 Three dimensional view of the microwave oven and the sludge tray used

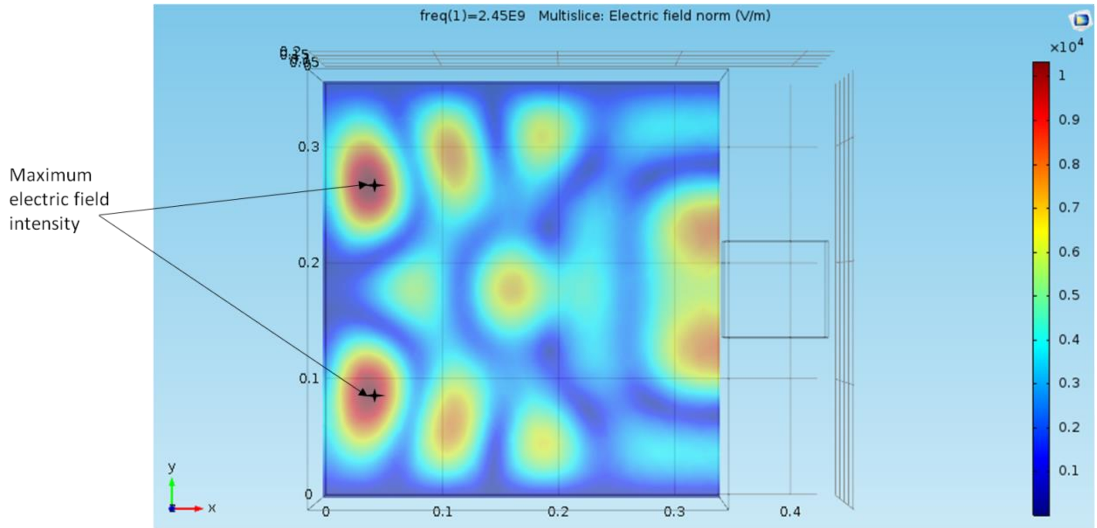
Dielectric characteristics of the sludge sample are given in Table 2. ε' is the relative permittivity, which is a measure of the electrical energy stored in the material. $\varepsilon''$is the relative dielectric loss factor, which determines the microwave power that dissipated on the material, and is the source of the heat energy generated on the material.

Table 2 Dielectric characteristics of the sludge studied ($\boldsymbol{T_0 = 9}$°C)

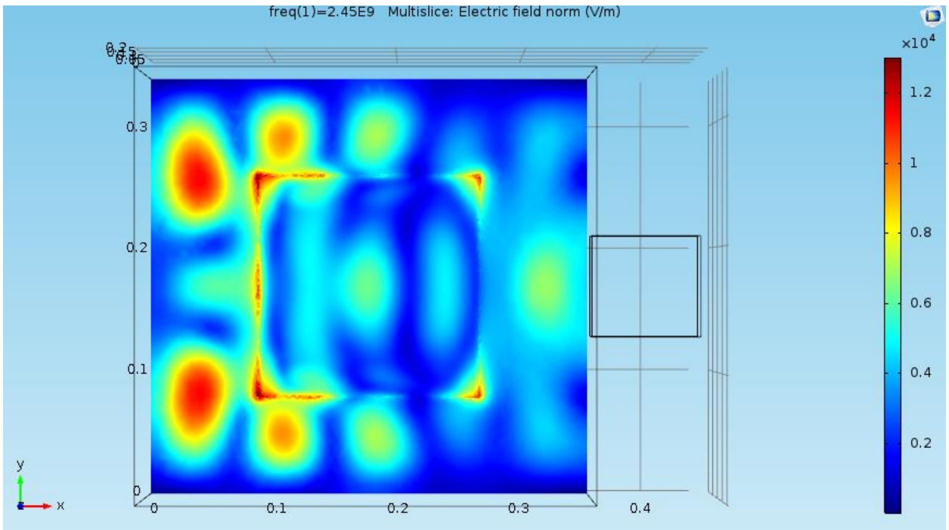
Analysis number	$\boldsymbol{\varepsilon'}$	$\boldsymbol{\varepsilon''}$	$\varepsilon''/\varepsilon'$ (×10^{-3})
1	52.60	12.59	239.45
2	52.65	12.60	239.26

Figure 4a shows the electric field distribution on z=24 mm plane in the empty microwave oven. Maximum values are marked on the figure. It was found that the electric field is stronger near the walls of the microwave oven. Due to the reflection of the electromagnetic waves from the walls, the distribution is symmetrically relative to the XZ plane.

Figure 4b shows the electric field distribution on z=24mm plane when sewage sludge sample was placed into the microwave oven. When the sample was placed in a microwave cavity, the electromagnetic wave was reflected from the oven wall and the sample surface. Thus the original electromagnetic field distribution changed. The influence of uniformity of the electromagnetic field distribution mainly depends on the oven design and the sample position. The electric field distribution in the oven changed due to the placement of the sample. The electric field was dense on the corner points of the tray where sludge was placed.



a)



b)

Fig. 4 The electric field distribution a) when the oven is empty, b) when the sewage sludge sample was inside (z=24 mm from the bottom)

A thermal fax paper was placed at the top of the sludge tray before microwave drying; the stain obtained during drying was examined. Fig. 5 shows the stain made by the sludge sample during microwave drying. The stain obtained on the paper agrees with the hot and cold points generated during microwave drying. This figure also shows how the thermal energy has been transferred from the hotter spots throughout the sample during the heating. It can be inferred from Fig. 5 that the electric field was high at the corner points and scattering occurred because of material interactions.

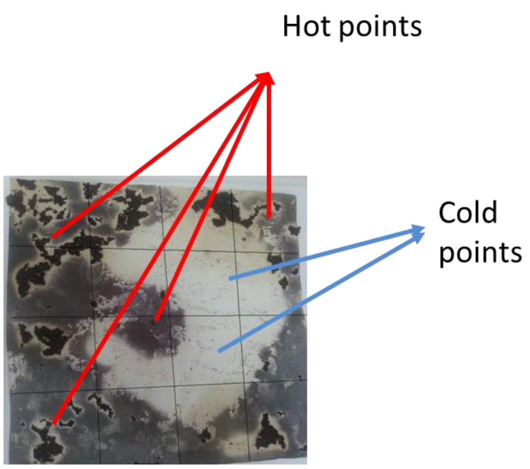


Fig. 5 Thermal fax paper stain of the sludge during microwave drying

When the material is exposed to a microwave field, different parts of the field are transmitted, absorbed and reflected. The absorbed electromagnetic field generates resistive heat or energy loss to the material. The power dissipation density represents a rate of energy loss from the electromagnetic system to the thermal system. Fig. 6 shows the power dissipation density as a slice plot through the middle of the sludge sample in the microwave oven after 5 minutes drying of the sludge.

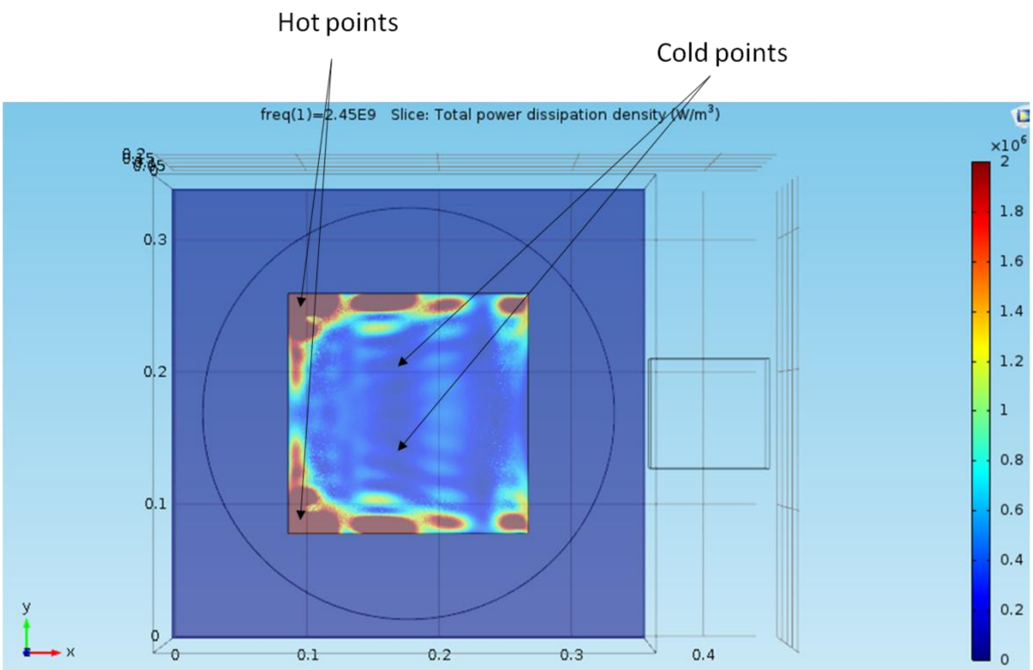


Fig. 6 Power dissipation distribution of the sludge sample on z=24 mm plane after 5 minutes microwave drying

It can be seen from the figure that a higher power dissipation density was obtained at the edges of the sludge sample, similar to the electric field distribution in Fig. 4. Middle of the sludge sample showed lower values. Power dissipated distribution concentrated on the corners, as would be expected. It was seen that, the larger the electric field value, the greater the loss power density. The power absorbed in the sample was found to be approximately 59% of the input microwave power. Most of the remaining power was reflected back to the source.

Conclusion

Mechanically dewatered sewage sludge of 78% dry solids content was dried by using microwave and electric oven. Microwave drying had a superior impact on the sludge than classical drying using electrical oven, in terms of humidity loss. Grinding of the sludge had not a significant effect on the drying performance, whereas longer duration of drying was effective. After 10 minutes of drying with microwave irradiation, the humidity loss obtained was 25.7% and increased to 29% after 10 minutes of air cure following drying.

Modelling study showed that the electric field was stronger near the walls of the microwave oven when it is empty. When the sample was placed into the oven, the electromagnetic wave was reflected not only from the oven walls and but the sample surface as well. The electric field was high at the corner points. A higher power dissipation density was obtained at the edges of the sludge sample, similar to the electric field distribution. The power absorbed in the sample was found to be approximately 59% of the input microwave power.

Microwave power is the source of heat energy that is formed on the material. The higher values of power dissipated density value on the edges yielded higher temperature levels on the sludge. High temperature results in higher loss of humidity. It can be concluded that if the placement of the sludge is undertaken according to the distribution of electric field and power dissipation density, higher humidity loss levels can be obtained.

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