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COMPARISON OF DRYING CHARACTERISTIC AND BIODEGRADABILITY OF DAIRY SLUDGE USING MICROWAVE AND INFRARED DRYING

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ABSTRACT: *In our work we focused on the investigation of two intensive drying methods, i.e. infrared (IR) and microwave (MW) drying, for dairy sludge. During the experiments the effects of IR and MW drying with different power intensities on drying characteristic and biodegradability were examined. Our results has revealed that MW drying was more advantageous for dairy sludge, because the drying time need to achieve a certain value of final moisture content was significantly shorter than applying IR drying. Effects of increased specific power intensity could be more manifested during MW process resulted in higher drying rate. At lower power intensity MW process needed more than 30% shorter drying period to achieve the same final moisture content than the IR drying, at higher power intensity the shortening of drying time was about 70%. Considering the change in the degree of biodegradability the MW drying process has also advantages over the IR drying. Microwave dried dairy sludge has 13% higher biodegradability than that of dried by IR method, what provoke advantages for further sludge utilization processes.*
KEYWORDS: *microwave, infrared, drying, biodegradability, sludge*

INTRODUCTION

The amount of purified wastewater and the level of the pollutant removal resulted in the increasing quantity of sludge. On the other hand, the requirements concerning the storage and the expected reduced environmental risk of sludge are growing. The annual municipal sewage sludge production has alone exceeded 25000 t in Hungary. Because of the wide range of pathogenic microorganisms, sewage sludge presents a significant health hazard, as well. In order to reduce the biological risk of sludge handling and disposal various processes are available, for instance composting, anaerobic digestion, chemical disinfection, ozonation and thermal methods (Romdhana et al., 2009). Therefore new solutions regarding sludge handling, treatment and management has been one of the focus areas of research and development activity worldwide.

In drying processes thermal energy is applied to evaporate the water from sludge. Sludge drying processes aim mainly the mass and volume reduction of processed material, moreover the disinfection are also occurred during drying via thermal effects. Sludge pasteurization technologies are designed to provide an operating temperature range of 60-80 ˚C for 30-60 minutes; in combined heat conditioning-dewatering systems the temperature is above 100˚C for a period of 10-40 minutes under pressure (Lawrence et al., 2007). Thermal methods are often used as pre-treatment before drying, in order to enhance the degree of dewatering due to the modification of sludge structure and disruption of cell-walls.

The oldest method for dewatering is the solar drying, but it needs a long drying time (Bennamoun, 2012). There are known several possibilities to accelerate the drying of different materials, such as infrared (IR) or microwave (MW) drying. Contrary to the conventional thermal methods, namely convection and conduction, radiating technology allow immediately and significant energy input to the processed material what is resulted in the shortened process time demand (Glouannec et al., 2002).

Infrared (IR) technique is especially suitable to dehydrate material with large surface exposed to the radiation. Generally, solid materials absorb energy carried by infrared radiation in a thin layer, and the depth of penetration is depended on their transmissivity, which is influenced by the moisture content. Hence, the high water contented wastewater sludge can absorb efficiently the radiated energy in the range of infrared waves. It is known, that the short wavelength infrared radiation can transmit through the high water contented layers of processed materials, but the short wave IR radiation absorbed on the thin surface layer. Since the absorbed radiation converted to heat, the far-IR radiation is more efficiently applicable to dry thin layers, while radiation at near IR wavelength is favorable for thicker layers (Sakai and Hanzawa, 1994).

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Since the heat is generated in a layer under the surface of irradiated material, heat conductivity is occur towards the center of the body and, as well as to the surface. On the other hand, since heat and mass transfer is also take part in the irradiated sample, moisture is migrated from the center to the surface. These effects are manifested in countercurrent heat and mass transfer in deeper layers of materials which decrease the overall efficiency of IR drying (Nowak and Lewicki, 2004). It can be also noticed from energetic aspects, that the air surrounding of processed material is transparent to infrared radiation, hence the heat carried by the air from the surface of drying materials is minimized which is represented in the reduced overall energy loss of process compared it to that of obtained in convective drying.

Microwaves are non-ionizing electromagnetic waves with a frequency range of 300 MHz to 300 GHz. Notwithstanding the numerous advantages of microwave heating over the conventional heating methods, such as volumetric and material-selective heating, it is underutilized in the industrial scale applications. Microwave heating is also considered as non-contacting form of heating (Laktos et al., 2005). Two material selective dielectric parameters influenced the efficiency of the conversion of electromagnetic energy into heat. One of them is the dielectric constant which measures the ability of material to absorb the electromagnetic field; other is the dielectric loss factor which corresponds to the ability of materials to store the irradiated energy. Two mechanisms are playing role in microwave heating: ionic conduction and dipole rotation, therefore the dosed ions in the wastewater treatment technology and the water content are also influential parameters for dielectric heating methods.

Because of intensity of heat generation and accelerated dehydration capability of microwave irradiation application of it solely or combination with other technology for sludge dewatering and treatment has been also investigated. Efficiency of microwave dewatering was reported independent from the quality and quantity of solid fraction of sludge and the process time can be significantly reduced compared it that of experienced in conventional drying process of sludge (Idris et al., 2004).

In our work we focused on the examination of two intensive drying method i.e. IR and MW technology applying them for wastewater sludge dehydration. Our main aim was to compare the drying efficiency of the two methods and to investigate the effects of them on the biodegradability of produced dehydrated sludge.

MATERIALS AND METHODS

Sludge sample was originated from dairy processing from the wastewater treatment plant of a local meat processing factory (Szeged, Hungary). Sludge was stored in closed polyethylene bags at 4°C to avoid the structural and microbial changes. Dry matter content of thickened sludge was 18.2±0.8 w/w%. Initial biochemical oxygen demand (BOD) and soluble chemical oxygen (SCOD) demand of sludge sample was 23.2±1.9 g kg^{-1} and 193.4±2.7 g kg^{-1}, respectively.

Microwave drying experiments were carried out in a Labotron500 (SAIREM, France) microwave-convective drying cabinet equipped with magnetron at an operating frequency of 2450 MHz. The specific power intensity of drying was given by the ratio of magnetron power to the initial mass of sample. Ventilation with ambient temperature air was applied to remove the vapor produced during the drying process. Moisture content of sludge was determined by thermo-gravimetric method at 105°C for 2 hours.

For the IR drying experiments infrared radiator (Philips) was used with a power of 250W. Homogenized sludge samples were placed in Petri dishes formed 25 mm thick layer located 18 cm distance from emitter. The specific power intensity of IR drying was given similar that of described by the microwave method.

To quantify the biodegradable organic matter content of sludge respirometric biochemical oxygen demand tests were run for five days (BOD5) at 20°C according to the APHA5210D standard method using Lovibond BOD Oxidirect measuring system. Total amount of soluble organic matters was given in chemical oxygen demand (SCOD) units. COD was measured by a Lovibond CheckDirect COD photometer according to the standard potassium-dichromate method after 2 hours digestion at 150°C.

RESULTS AND DISCUSSION

Experiments were carried out to examine the drying characteristic of dairy sludge using IR and MW drying. Drying curves show the decreasing of the moisture content plotted against the drying time. Results of IR drying using three different specific power intensities show that the increased intensity has effect mainly on the constant rate period of drying. Rate of dehydration was influenced by the intensity, the higher IR intensity resulted in accelerated dehydration with reduced time demand of the overall process, but in the warm-up period was not significant difference in the moisture removal efficiency of different intensities (Fig.1.).

Using IR heating the radiation penetrated the processed material and converted into heat, energy is transferred to the product without heating the air surrounding the material. Therefore the moisture removal efficiency of IR drying is higher than that of experienced conventional drying methods (Caglar et al., 2009). In our experiments the drying time to achieve 5 w/w% final moisture *content of sludge can be reduced approximately 35% when 2 W/g IR intensity was applied instead of the lowest 0.5 W/g intensity.*

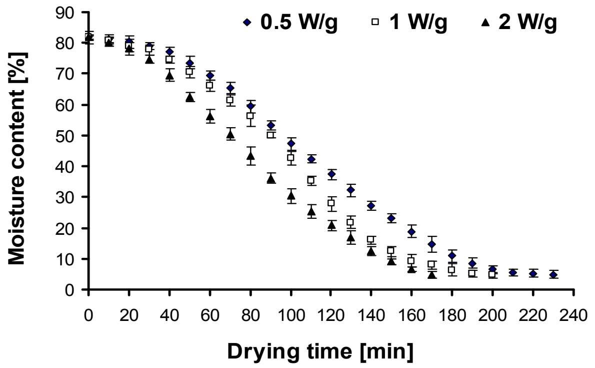

Fig.1. Drying curves of sludge using IR drying

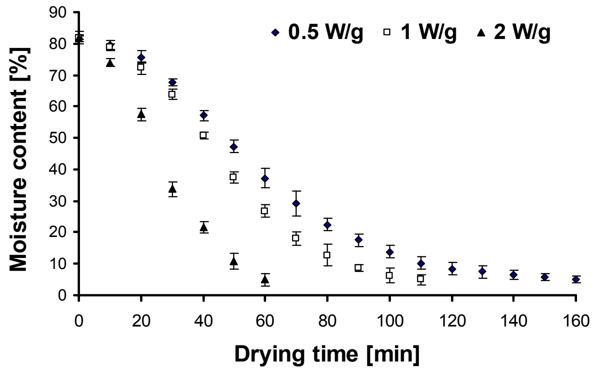

Fig.2. Drying curves of sludge at different MW intensities

For comparison purpose the power intensities of MW drying were set as the same values as in IR drying experiments. Fig. 2. gives the drying curves obtained from MW drying of dairy sludge. Effects of power intensity in MW drying process was stronger that of experienced in IR drying. Increasing the MW power intensity the rate of dehydration was higher, and the time demand for drying has been reduced in a larger extent than observed in under IR drying (Fig. 2).

Taking into consideration the drying time need to reach the final moisture content it can be concluded that using 2 W/g MW intensity the drying time can be reduced with 67% compare it to that of obtained from the lowest, 0.5 W/g power intensity. Advantages of MW process over the IR drying can be explained by the different moisture and thermal diffusion phenomena. Microwave heating involves the conversion of electromagnetic energy into heat which is influenced by the dielectric constant and dielectric loss factor (Géczi et al., 2013). Sludge with high moisture content has a high dielectric loss factor which led to high dissipation of irradiated energy into the material. On the other hand, microwave heating is an intensive and volumetric heating method which resulted in a strong internal pressure gradient in high moisture material such as sludge, it cause an accelerated moisture diffusion to the surface and resulted in an unidirectional temperature gradient and moisture migration (Orsat et al., 2007).

Valuable information about the drying kinetics can be derived from the analysis of drying rate curves. Drying rate curves show the change of drying rate versus the instantaneous moisture content of drying material. Our results show that using MW and also IR drying method the higher power intensity increase the drying rate, as well (Fig 3., 4.).

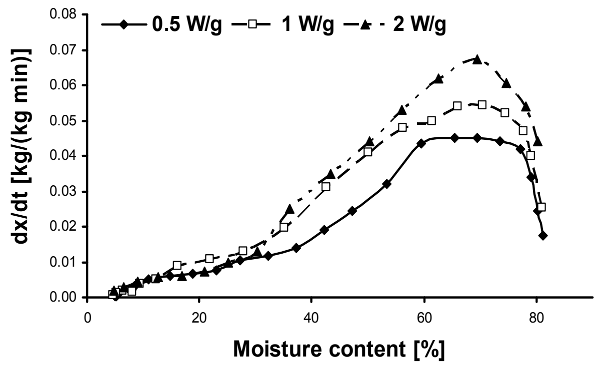

Fig.3. Drying rates of IR dried sludge

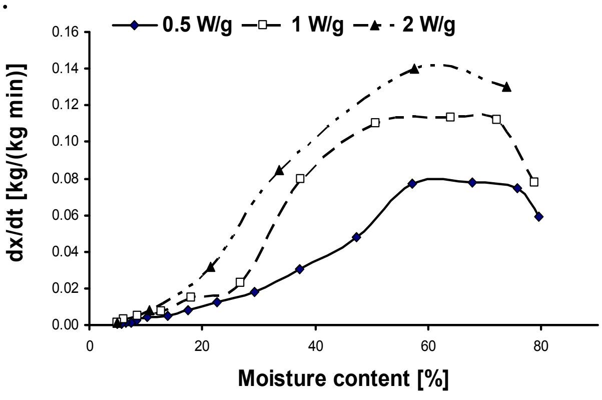

Fig.4. Drying rates of MW dried sludge at different intensities

Similarly to the results of the analysis of drying curves, the change of power intensity is considered more influential parameter for MW drying than for IR drying method (Fig 4). Maximum average drying rate was achieved as 0.141 kg/(kg min) with 2 W/g MW drying and 0.067 kg/(kg min) with using 2 W/g IR drying, respectively. In the falling rate period of drying, in the region of low moisture content, the advantage of higher power intensity was reduced by both the MW and IR drying. Drying time needed to achieve lower than 5 w/w% was derived from drying curves to compare the overall rate of dehydration process produce dried sludge with minimum microbial risk. Using the same power intensity during IR and MW drying, the time demand was significantly shorter for MW than that of for IR method in all experiments.

The other aim of our work was to examine the change in the biodegradable organic matter fraction of dairy sludge after drying. Applying drying process prior to sludge utilization based on biotransformation, such as anaerobic digestion, composting or agricultural use, beside the drying *characteristics the ability for biodegradation is a key parameter to analyze the efficiency of pre-treatments. Results of our experiments are summarized in Table 1.*

Table 1. Summary of drying kinetic data and biodegradability of IR and MW method

Drying method	Specific power [Wg^{-1}]	$t_{w<5\%}$ [min]	Maximum drying rate [$kg\ kg^{-1}min^{-1}$]	BOD_5 [$g\ kg^{-1}$]	$BOD_5/BOD_{5initial}$ [-]	$BOD_5/SCOD$ [-]
IR	0.5	228.1±2.2	0.045	25.3±1.8	1.09±0.08	0.18±0.02
MW	0.5	158.3±1.1	0.059	31.5±2.1	1.35±0.13	0.23±0.02
IR	1	193.6±1.3	0.054	29.7±2.3	1.28±0.07	0.22±0.03
MW	1	106.3±1.2	0.113	38.2±1.7	1.64±0.11	0.38±0.01
IR	2	164.4±1.9	0.067	29.6±1.8	1.27±0.06	0.35±0.02
MW	2	58.2±0.9	0.141	33.1±2.2	1.43±0.03	0.36±0.03

Increasing the power intensity of IR drying from 0.5 to 1 W/g the BOD values of dried sample increased by 17%, but the further increasing was not resulted in enhanced concentration of biodegradable organic matters. Different trends was observed applying MW dryin method, because the enhanced power intensity from 0.5 to 1 W/g cause an increment of 21% in BOD, but the sludge after dried with 2 W/g power intensity has lower BOD. Considering the change of soluble organic matter content during the drying process, the ratio of biodegradable fraction to the total soluble organic matter content was calculated, given as the ratio of BOD_5 to SCOD. Our experimental results have revealed that MW drying produced sludge with higher biodegradability which can be advantageous in further utilization processes.

CONCLUSIONS

In our work we investigate the infrared (IR) and microwave (MW) drying methods for dairy sludge. Results shown, that MW has higher moisture removal efficiency than IR drying, which has manifested in higher drying rate and shortened process time demand. Comparing the drying mechanisms it was concluded that the increase of specific power intensity has more effective in MW operation than in IR drying. Other main goal of our work was to examine the effect of IR and MW drying method on the biodegradability of processed sludge. It can be concluded, that MW and IR drying increased the biodegradability as well, but using the same power intensity the MW method was more effective with shorter exposure time demand. It can be noticed, that MW treatments at a certain value of power intensity cause a slightly decrease in the amount biodegradable organic matter content.

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