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RESEARCH ARTICLE

EFFECT of MICROWAVE and CONVEYOR DRYING on the DRYING CHARACTERISTICS, MODELING, and THERMAL PROPERTIES of MUNICIPAL WASTEWATER SLUDGE

Tuğçe EKİCİ[1], Esra TINMAZ TÖRE[2], Soner ÇELEN[3],*

[1] Tekirdağ Namık Kemal University, Çorlu Faculty of Engineering, Department of Environmental Engineering, Tekirdağ, Turkey, tugcekici@gmail.com, ORCID: 0000-0002-4049-7811
[2] Tekirdağ Namık Kemal University, Çorlu Faculty of Engineering, Department of Environmental Engineering, Tekirdağ, Turkey, etinmaz@nku.edu.tr, ORCID: 0000-0001-9877-305X
[3],* Tekirdağ Namık Kemal University, Çorlu Faculty of Engineering, Department of Mechanical Engineering, Tekirdağ, Turkey, scelen@nku.edu.tr, ORCID: 0000-0001-5254-4411

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ABSTRACT

Wastewater treatment plant sludges are high moisture content sludges that during their storage and transport can cause various different problems. Therefore, a significant process is to dry these sludges. Based on drying times and energy consumption, microwave and conveyor drying methods for drying wastewater treatment plant sludge were examined in this study. Sludge weights of 20 g, 40 g and 60 g were used in the drying experiments carried out using two separate dryers. Microwave drying trials were performed at 360 W, 600 W and 800 W power, conveyor drying trials at temperatures of 60 ± 1 ^{o}C, 70 ± 1 ^{o}C and 90 ± 1 ^{o}C, at a fixed belt speed of 0,2 m/min. Energy consumption increased with the rise in microwave power as a consequence of the experiments. At 800 W and 60 g, the least energy consumption is measured as 0,015 kWh. In conveyor drying, on the other hand, drying time decreased with the rise in drying temperature, and energy consumption decreased. At 90 ^{o}C and 20 g, the least energy consumption was measured as 4,1 kWh. In terms of time and energy, the most appropriate of both drying systems was determined at 800 W. Furthermore, as a result of the statistical analysis, the most suitable model among five drying models was determined according to the $\chi 2$, e_s, and r criteria as Logarithmic and Henderson and Pabis.

Keywords: *Sewage Sludge, Microwave Drying System, Conveyor Drying System, Energy Consumption, Modeling*

1. INTRODUCTION

The number of wastewater treatment facilities is growing increasingly in parallel with population growth, leading to a significant rise in the amount of sewage sludge [1]. In terms of substance, sludge treatment is rich in heavy metals, pathogenic bacteria, viruses and toxic chemicals. In order to remove tons of treatment sludge generated every year in a way that does not affect human and environmental health, various treatment methods are implemented. The need to establish new methods of disposal has emerged in sustainable environmental management in order to allow effective and profitable use of sewage sludge.

Every year in Turkey, around 1.38 million tons of sewage sludge are manufactured [1]. According to TÜİK (Turkish Statistical Institute) 2018 data, there are 16 Metropolitan Municipalities and 1399 Municipalities in our country with a population of 82.003.882. The population rate that provides sewerage service in these settlements is 91 percent. As of 2018, 88.3 percent of 4,795,130 thousand m^3 of waste water discharged from the network to the receiving environment has been treated. Taking into account the 2018 TÜİK results, the ratio of the population served by wastewater treatment facilities to the total population is 79 percent. 1,226,767,920 billion tons of sewage sludge are expected to be generated annually when 3,361,008 tons of domestic / urban sewage sludge is produced per day, assuming 60 g of solid matter per person per day. Most of these treatment sludges are sent to the municipalities' controlled solid waste landfills as they are seen as an simple and inexpensive disposal process. It is a raw material that has beneficial usage alternatives considering the rich content of nutrients, calorific value etc. in domestic sewage sludge [2]. Sending treatment sludge to landfill sites both prevents them from being used as alternative raw materials and causes the capacity of storage sites that already have limited space, to fill up earlier. It is important to give the country's economy maximum benefit by correctly and properly using this substance, which has thermal and nutritional value.

The variety of disposal systems to be applied to reduce the wastewater sludge in volume and mass, and to result in a reduction in costs are of key importance in terms of correct management of waste. In order to treat wastewater sludge in the most efficient way, it is necessary to establish a uniform structure that includes public health and environmental safety elements simultaneously with low-cost alternatives by being evaluated within the management system. While evaluating the use in agriculture, incineration or storage alternatives in the selection of treatment sludge treatment systems or in their final disposal, the issue should be handled as a whole, and choices should be made by evaluating sludge characteristics, country conditions, the country's economy, as well as the conditions specific to the region being talked about [2]. It can be used as fertilizer in agriculture because of its (domestic) dry sludge content. Furthermore, its calorific value increases as the sludge dries, so it can be considered as a strong alternate source of energy.

The treatment sludge must first be stabilized in order to be discharged into the receiving environment; deodorized with reduced pathogen and organic material content must be generated. Principal methods of sludge stabilization; anaerobic digestion, aerobic digestion, lime stabilization, composting and drying [3]. By evaporating the water in the sewage sludge, Both the volumetric/ weight reduction of the sludge is done and the pathogens in it are eliminated. Two different processes take place during drying; first, energy is transferred to evaporate surface moisture from the surrounding atmosphere. Here according to temperature, air moisture flow, and pressure levels, water moves away from the solid surface. Second, after evaporation, the moisture in the sludge is transferred to the surface. The physical structure, temperature and initial humidity are dependent on moisture away from the solid. The drying process is a complex process in which heat and mass transmission occur simultaneously in physico-chemical transformations [4]. Among the applied sludge drying techniques are mechanical drying, solar drying and thermal drying. Moreover, evaporation and filtration are among the methods of natural drying used.

85% of industrial dryers are convection type. However, conduction dryers are more economically efficient and environmentally more advantageous [5]. Due to the increasing energy costs, the legal requirements to be met and the need to create safe working conditions, it is necessary not only to choose the dryer process, but also to design the plant. The chosen method of sludge drying varies according to the size of the plant, the content of the waste processed, and the physical and economic capability of the facility.

Different thermal drying techniques (microwave and conveyor belt dryers) were applied to sludge obtained from the domestic waste water treatment plant in this study.

Since the realization of heating by activating the water molecules in the substances and the evaporation of water in a little while during the processes performed in microwave ovens, many studies have been carried out on microwave drying [6].

The domestic wastewater treatment sludge to be used in the study was taken according to the sampling conditions and the characterization of the treatment sludge was determined in the first stage, the first and last moisture content of the samples was measured with the conveyor belt drying system and microwave methods, which have two different thermal drying methods in the next stages, and the amount of power consumed and thermal changes of the samples were measured by imaging method and the calorific value of the treatment sludge was examined. Furthermore the findings obtained were evaluated according to various models of drying.

2. MATERIAL AND METHOD

The sample of sewage sludge was drawn from the domestic wastewater treatment facility. The sample of sewage sludge, 20 kg, was taken with an industrial type thick black three-layer garbage bag over the belt system where the dried treatment sludge was poured, and it was taken and stored in accordance with the sampling and storage standards so that it would not contact with air. The findings of the research carried out on 2 kg of sewage sludge taken from a sterile plastic bottle are shown in Table 1 below [7].

Table 1. Characterization of waste water treatment plant sewage sludge.

Parameter	Unit	Analysis Results	Regular Storage Criteria of Inert Wastes	Regular Storage Criteria of Non-Hazardous Wastes	Hazardous Waste Storage Criteria
Eluat Criteria					
Antimony	mg L^{-1}	<0,001	0,06	0,07	0,5
Arsenic	mg L^{-1}	<0,01	0,05	0,2	2,5
Copper	mg L^{-1}	<0,01	0,2	5	10
Barium	mg L^{-1}	<0,01	2	10	30
Mercury	mg L^{-1}	<0,0001	0,001	0,02	0,2
Zinc	mg L^{-1}	<0,01	0,4	5	20
DOC (Dissolved Organic Carbon)	mg L^{-1}	18,9	50	80	100
Phenol Index	mg L^{-1}	0,092	0,1	-	-
Fluoride	mg L^{-1}	<1	1	15	50
Cadmium	mg L^{-1}	<0,001	0,004	0,1	0,5

Chloride	mg L^{-1}	40,03	80	1500	2500
Bullet	mg L^{-1}	<0,01	0,05	1	5
Molybdenum	mg L^{-1}	<0,01	0,05	1	3
Nickel	mg L^{-1}	<0,01	0,04	1	4
pH	-	7,26	-	≥6	-
Selenium	mg L^{-1}	<0,01	0,01	0,05	0,7
Sulfate	mg L^{-1}	6,7	100	2000	5000
TDS (Total Soluble Solids)	mg L^{-1}	400	400	6000	10000
Total Chrome	mg L^{-1}	<0,01	0,05	1	7
Criteria to Look for in Original Waste					
BTEX (Benzene, Toluene, Ethylbenzene, Xylene)	mg kg^{-1}	0,06	6	-	-
Loss on Glow (LOI)	%	76,6	-	-	10
Mineral Oil	mg kg^{-1}	105,63	500	-	-
Moisture	%	34,88	-	-	-
PCBs	mg kg^{-1}	0,07	1	-	-
Total Organic Carbon (TOC)	mg kg^{-1}	24650	30000	50000	60000
Polychlorinated biphenyls (PCBs)	mg kg^{-1}	0,07			

2.1. Conveyor Drying System

Conveyor drying tests were performed at 1,8 m belt length, at 60 ± 1 ^{o}C, 70 ± 1 ^{o}C and 90 ± 1 ^{o}C temperatures, at a fixed belt speed of 0.2 m / min and at an air speed of 1 m / s. In order to calculate the temperature in the conveyor belt dryer, two thermometers are mounted in the system (as shown Fig.1).

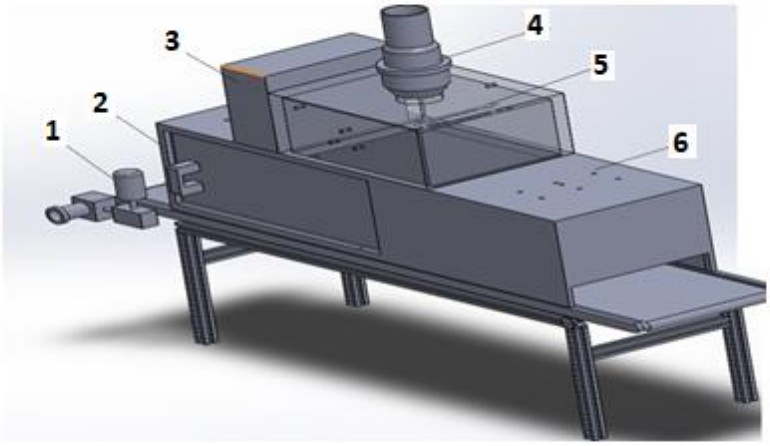

Figure 1. Conveyor drying system (1. Electric Motor, 2. Drying room, 3. Control Panel, 4. Fan, 5. Heater, 6. Ventilation holes) [7].

2.2. Microwave Drying System

Microwave dryer (Arçelik MD554, Turkey) with maximum of 1200 W at 2450 MHz was used for the drying (as shown Fig.2). Furthermore, microwave-resistant 9 cm diameter containers in which the product will be put during drying are suspended in the microwave. Weight losses were measured with a balance with a sensitivity of 0,001 g (Presica XB 620 M, Precisa Instruments AG, Dietikon, Switzerland). In the microwave drying system, the sensitive balance is placed on the microwave oven and the weight loss is recorded by measuring from the bottom.

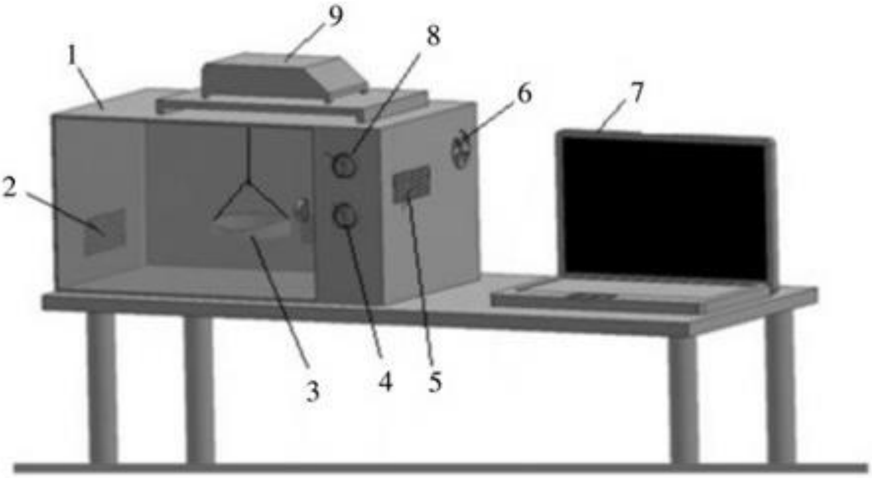

Figure 2. Microwave Drying System (1: Microwave Oven, 2: Ventilation Gap, 3: Glass Container, 4: Timer, 5: Magnetron, 6: Fan, 7: Computer, 8: Power Switch, 9: Precision Balance) [6].

2.3. Energy and thermal analysis

In both the conveyor belt and microwave drying systems, a digital electricity meter was used with an accuracy of 0,01 kW. When the sludge is wet and after cooling, prior to the experiment, temperature changes of the samples were measured and photographs were taken with the imaging device (Flir Ex E6, Estonia). The regions where the sample is heated the most and if the heat is distributed homogeneously are analyzed with thermal imaging. For all power levels and drying temperatures in both drying systems, thermal images of all samples were taken.

2.4. Preparation and Drying of Samples

Sewage sludge was put in glass petri dishes 9 cm in diameter in the form of samples of 20 g, 40 g and 60 g. The initial sludge moisture values used in the dry weight trials were determined at 105 °C for 24 hours in the MINGDA KIT-35A brand oven. The initial moisture content of the productswas estimated to be 97 ± 0.8 percent (wet base) as a consequence of the dry weight determination. As shown in Figure 3, glass containers were taken one by one and treatment sludge was placed so that all surfaces were coated. No external physical compression was applied to the sewage sludge during the preparation of the samples. Before the experiment, the temperatures of each container were measured and imaged while wet with a thermal imager.

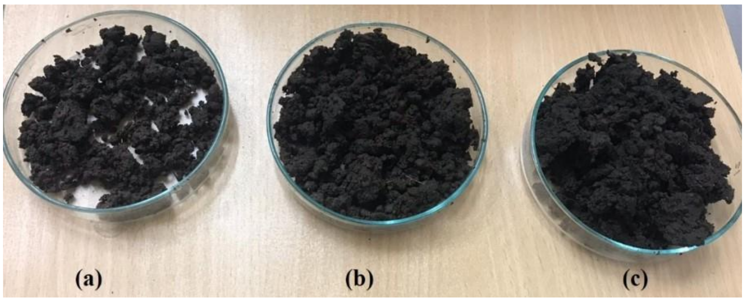

Figure 3. Wet sewage sludge samples (a) 20 g, (b) 40 g and (c) 60 g.

In the microwave drying system, first 360 W, 600 W and 800 W power was applied to the glass container connected to the bottom of the precision scale as 20 g, 40 g, 60 g respectively. The weight data was processed into the device every 10 seconds during the software used on a computer connected to a microwave oven. In the process with conveyor belt dryer, samples were placed one after another on the conveyor belt. The power of the conveyor belt used in the experiment is 2000 W and the dimensions are 2370×50×40 mm. The test system was set to be performed at 0.2 m / min and 1 m / s air speed, and it was studied at 60 ± 1 ^{o}C, 70 ± 1 ^{o}C and 90 ± 1 ^{o}C.

The microwave drying trials were completed when it reached 86 ± 0.5 percent (w.b) and the conveyor trials reached 79 ± 0.5 percent (w.b) with respect to the wet base (w.b). Drying took place in the drying trials until the final moisture value stabilized. The energy consumed during the process was measured by the energy meter.

The temperature changes of the specimens were measured with a thermal imager after each drying phase and their photographs were taken. Trials were repeated three times for each parameter. The means of the data are used.

After the moisture content of the products was calculated according to the wet base as in Equation 1, the dimensionless moisture ratio was calculated using equation 2 in conveyor drying trials and equation 3 in microwave drying trials. It is assumed that the equilibrium moisture content in the microwave oven is zero [8, 9].

$$m_w = \frac{M_w - M_d}{M_w} \tag{1}$$

$$m_R = \frac{m - m_e}{m_o - m_e} \tag{2}$$

In these equations;
M_d: dry mass of the product (g), M_w: wet mass (g) of the product, m_R: dimensionless moisture content, m_w: moisture content of the product at a given time (g.water / g. wet matter), m_e: equilibrium moisture content (g water / g.wet matter), m_o: initial moisture content (g.water / g.wet matter)

2.5. Mathematical Modeling

In the simulation of the drying phase of complex compounds such as sewage sludge, empirical and semi-empirical models are used. Nonlinear regression analysis was used when modeling in this study and the moisture reduction obtained as a result of the experiment was analyzed and modeled. According to the value of the correlation coefficient (r), the suitability of the model in the expression of experimental data was determined. Standard error (e_s) and chi-square (χ2) values were used to measure the fit of the model. These sizes are defined in equation 3-6 [6].

$$r = \sqrt{\frac{S_t - S_r}{S_t}} \tag{3}$$

$$e_s = \sqrt{\frac{\sum_{i=1}^{n_0}(mr_{pre,i} - mr_{exp,i})^2}{n_0}} \tag{4}$$

$$x^2 = \frac{\sum_{i=1}^{n_0}(mr_{pre,i} - mr_{exp,i})^2}{n_0 - n_c} \tag{5}$$

$$S_t = \sum(mr_{exp,i} - mr_{ave})^2 \tag{6}$$

$$S_r = \sum(mr_{exp,i} - mr_{pre,i})^2 \tag{7}$$

where; $mr_{pre,i}$ is the i*th* predicted moisture ratio, $mr_{exp,i}$ is the i*th* experimental moisture ratio, n_o is the number of observations and n_c is the number of coefficients in the drying model. S_t and S_r are the sum of squared error values, which were calculated using average moisture rate (mr_{ave}).

Table 2. Models used to express experimental results.

Model	Model Equation	Referance
Page	$m_R = \exp(-kt^n)$	[10]

Henderson&Pabis	$m_R = a\exp(-kt)$	[11]
Wang&Singh	$m_R = 1 + at + bt^2$	[12]
Logarithmic	$m_R = a\exp(-kt) + b$	[13]
Newton	$m_R = \exp(-kt)$	[14]

2.6. Calorific Value Analysis

The calorific value of a substance is determined by various methods such as analysis based on the composition of the waste, predictive analysis, calorimetry measurement or elemental analysis. It is obtained by making some improvements to the method of measurement used in the method of elemental analysis in the method of analysis based on the composition of the waste. In the estimated method of study, the mass loss suffered by volatile and inert substances at elevated temperatures is measured using volatile and inert waste material detail. One of the most widely used approaches is calorimeter measurement. The bomb is measured with a calorimeter. In elemental analysis, by means of the DuLong equation, the amounts of carbon, hydrogen, oxygen and sulfur are determined in the chemical structure of the sample [15]. The calorific value of the sample was calculated in Leco AC-350 after the crude purified sludge was dried in an oven at 100 ^oC for 2 hours.

3. RESEARCH FINDINGS

3.1. Moisture Change Findings

In the microwave drying system, as seen in Figure 5, the initial and final moisture of 20 g, 40 g and 60 g samples at 360 W power, respectively, according to the wet base, is 0,9629 to 0,8650 in 509 seconds, from 0,9713 to 0,8701 in 200 seconds and dried from 0.9769 to 0.8615 in 180 seconds. Dried from 0.9635 to 0.8656 at 600 W of power in 249 seconds, 110 seconds from 0.9720 to 0.8524 and 120 seconds from 0.9768 to 0.8576. Dried in 190 seconds at 800 W of power from 0.9639 to 0.8650, in 80 seconds from 0.9711 to 0.8629, and in 78 seconds from 0.9773 to 0.8598. With the increase of microwave power, drying time declined [16].

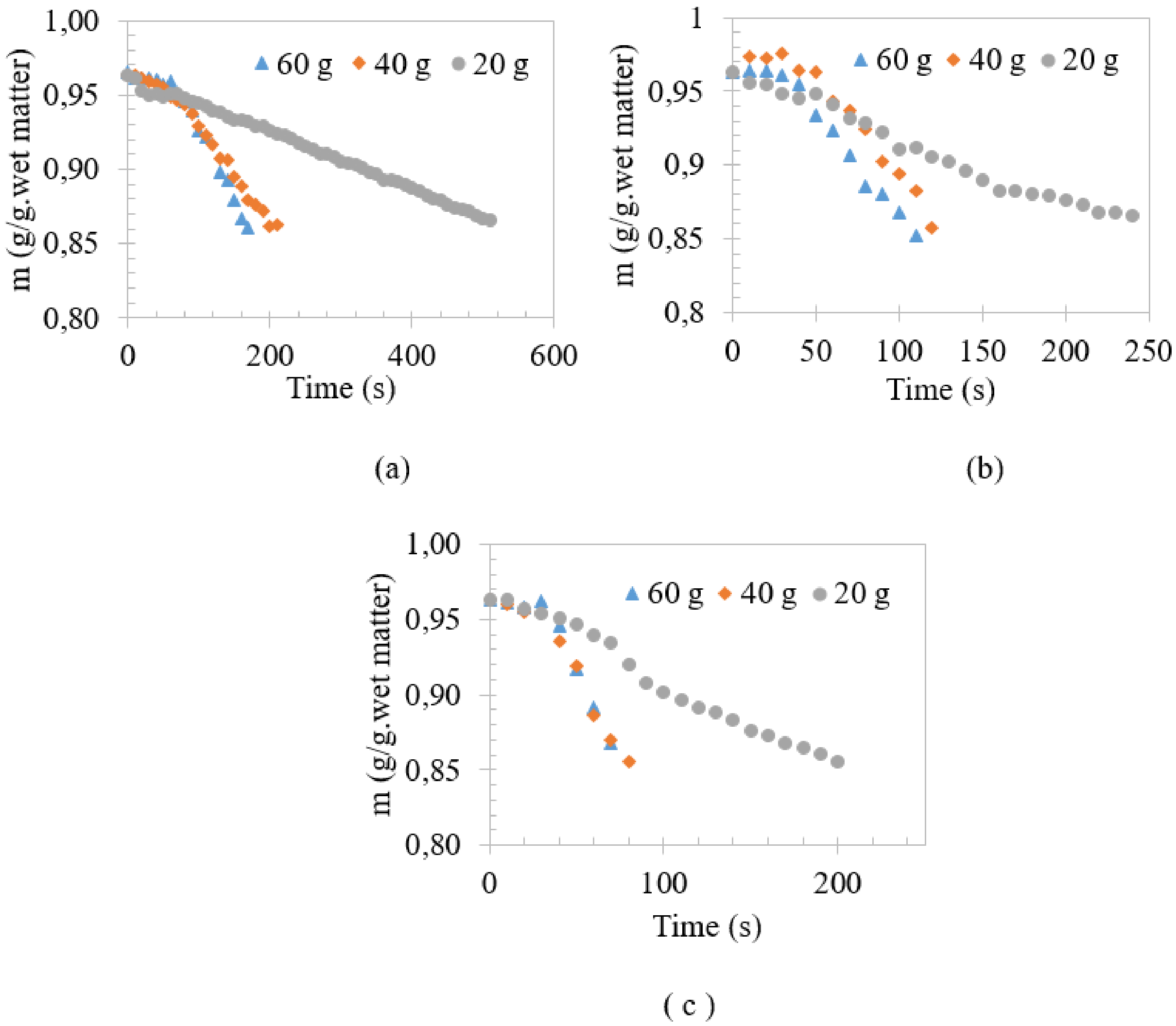

Figure 4. a) Moisture change of sludge dried at 360 W microwave power b) 600 W microwave power c) 800 W microwave power.

In the conveyor drying method, as shown in Figure6, the initial and final moisture of 20 g, 40 g and 60 g samples at 60 ^{o}C, respectively, according to the wet foundation, from 0.9632 to 0.7880 and 255 minutes, from 0.9713 to 0.7896, 300 minutes and It was dried from 0.9770 to 0.7898 for 345 minutes. It was dried at 70 ^{o}C for 225 minutes from 0.9632 to 0.7936, 255 minutes from 0.9714 to 0.7989 and 285 minutes from 0.9770 to 0.7960. Dried at 90 ^{o}C for 165 minutes from 0.9632 to 0.7956, 195 minutes from 0.9714 to 0.7914 and 225 minutes from 0.9770 to 0.7834 The results showed that it is consistent with previous literature [17].

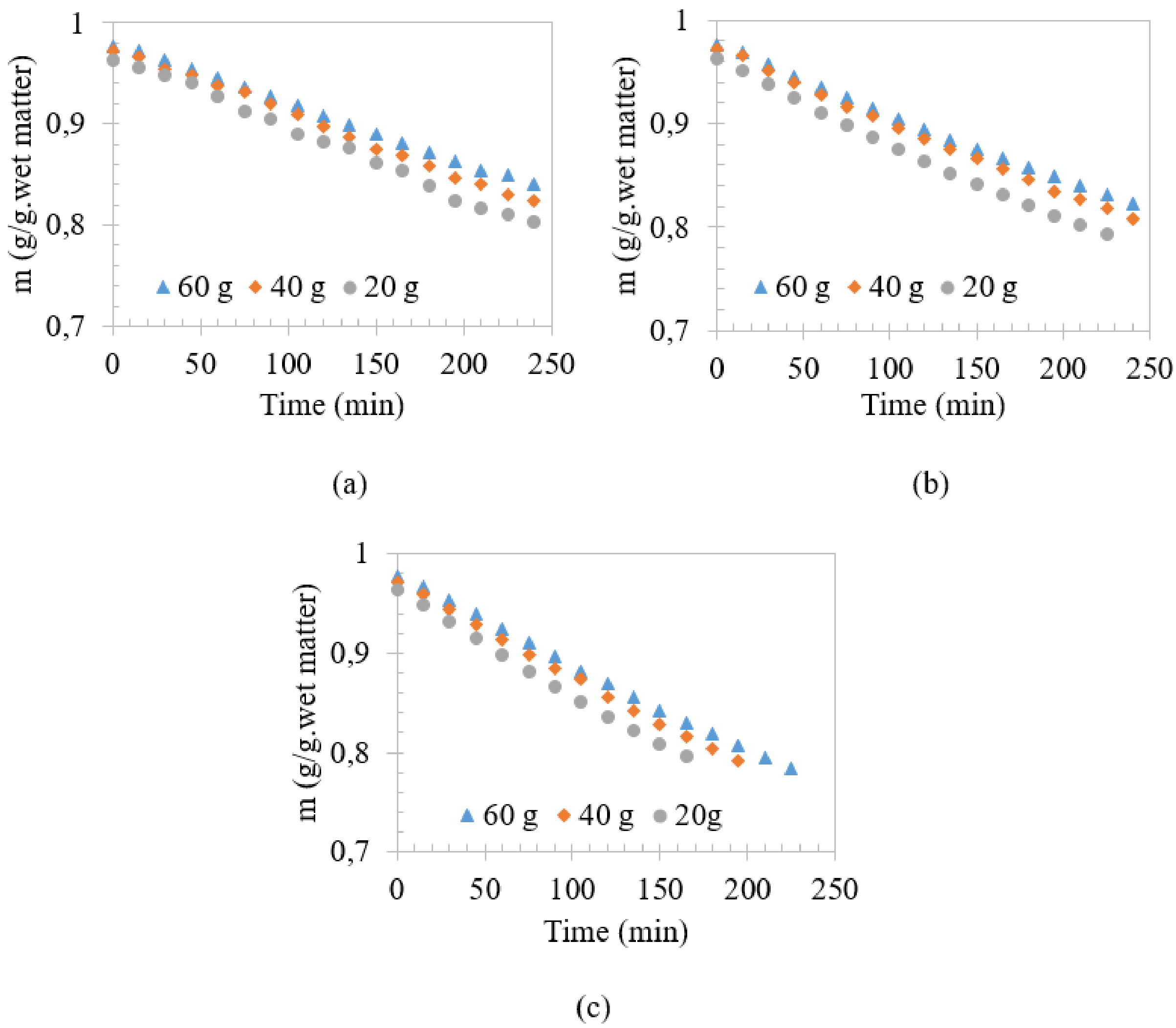

Figure 5. a) Moisture change of sludge dried at 60 °C drying temperature b) 70 °C drying temperature c) 90 °C drying temperature.

In addition to increasing drying power, drying time is influenced by microwave power, moisture loss accelerates, and drying time decreases. Owing to the reduction of the sample mass, there are variations in drying time as well. The reason for this phenomenon is that the moisture in the sample is not homogeneous, the heat energy is formed in the interiors and the interaction of microwave energy with the product due to the band speed causes variation in drying times. Since both drying processes are different from each other, different drying times have occurred. Drying occurred more rapidly than conveyor drying due to volumetric heating in microwave drying [5].

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3.2. Mathematical Modeling Findings

Among the models given in Table 2, correlation coefficient calculated for 60 g for microwave drying (0,902-0,986), standard error (0,014-0,05) and χ2 (2 x10^{-5}-2,1×10^{-4}) for 40 g calculated correlation coefficient (0.937-0.978), standard error (0.012-0.005) and χ2 (3×10^{-5}-1.2×10^{-4}) and the correlation coefficient calculated for 20 g (0.985-0.996), standard error (0.002-0.004) and It is concluded that the logarithmic model is suitable for the values of 3,2 (3,1×10^{-6}-1,6×10^{-5}). As shown in Figure 7, an appropriate correspondence is between model results and experimental data. The best compatibility between microwave powers is at 800 W, where the fastest drying takes place.

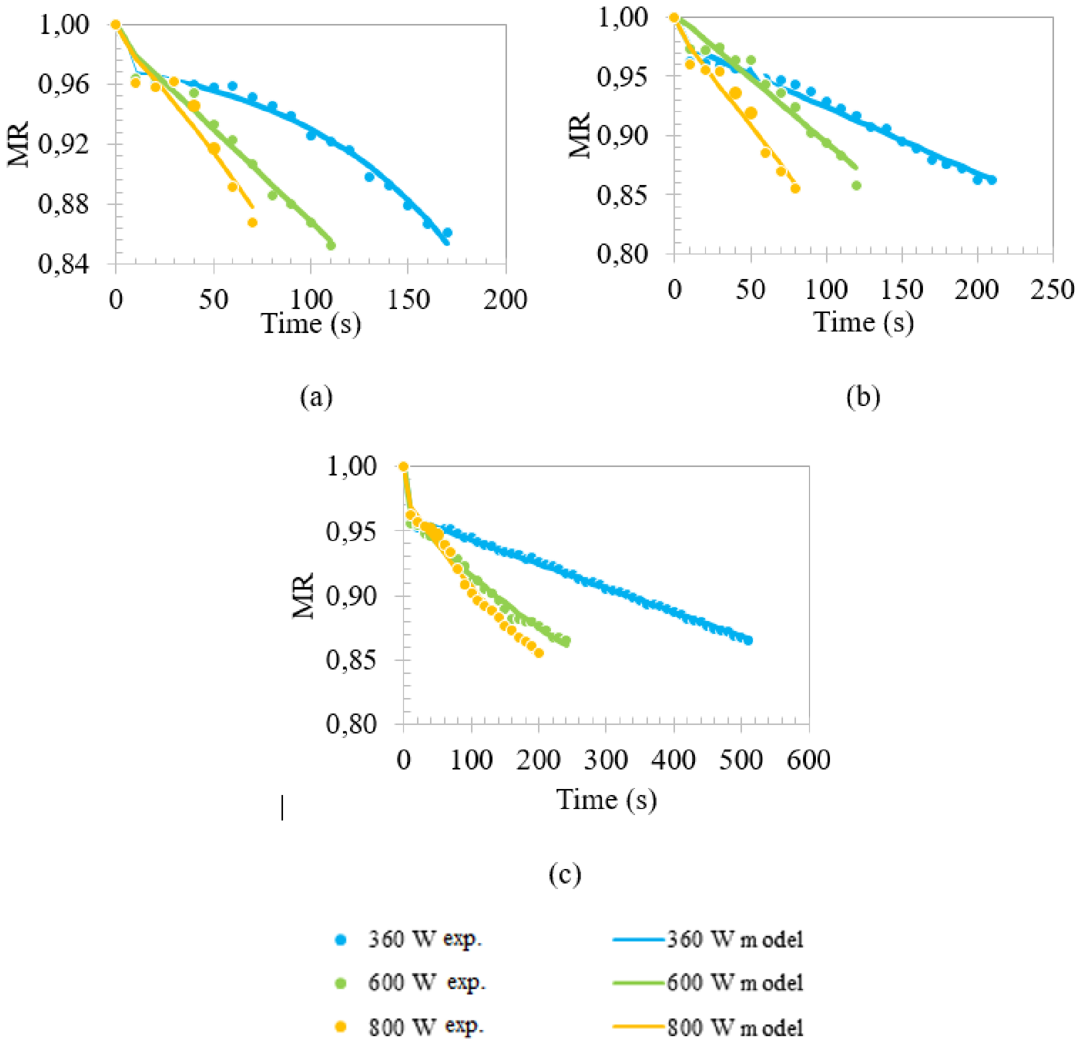

Figure 6. Compliance of a) 60 g, b) 40 g and c) 20 g samples in microwave drying to the logarithmic model.

Correlation calculated for 60 g (0.999-1), standard error (0.002-0.001) and $\chi2$ (6.1×10^{-7}; 2.7×10^{-6}) for conveyor drying, correlation coefficient calculated for 40 g (0.998-1), the standard error (0.003-0.001) and the correlation coefficient calculated for $\chi2$ (6.38×10^{-6}-1.63×10^{-6}) and 20 g (0.997-1), standard error (0.003-0.001) and It was concluded that the Henderson and Pabis model was suitable for 2 (4.63×10^{-6}- 8.68×10^{-6}) values. As shown in Figure 8, an acceptable correspondence is between model outcomes and experimental results. The greatest compatibility between the drying conditions of the conveyor is at 90 ^{o}C, where the quickest drying occurs.

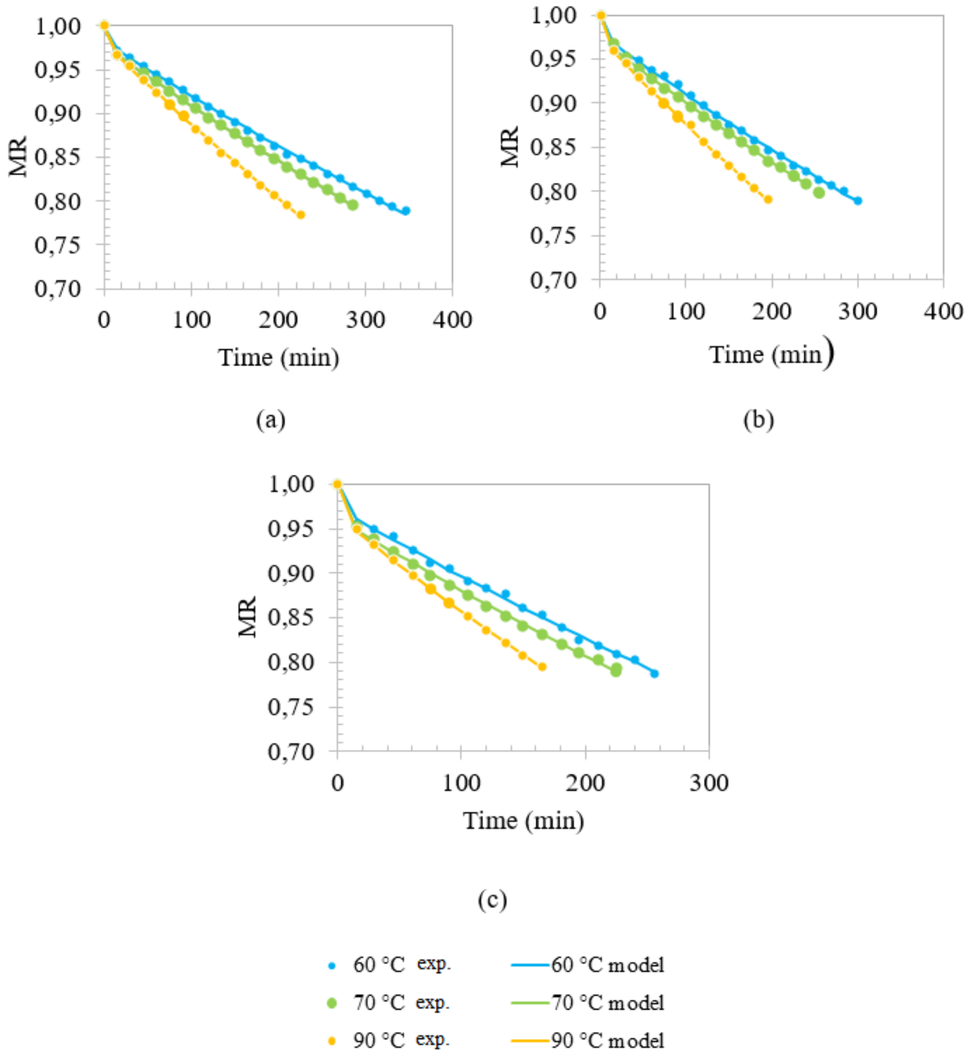

Figure 7. Conformity of samples a) 60 g, b) 40 g and c) 20 g in conveyor drying for Henderson and Pabis models.

3.3. Thermal Analysis Findings

For all the drying conditions, Figure 9-14 shows the lowest and highest temperatures of the thermal images. Temperatures for microwave drying system; measured between 23,8 ^{o}C - 130 ^{o}C / 22,9 ^{o}C - 128 ^{o}C / 23,6 ^{o}C - 145 ^{o}C. Local overheating is caused by high energy absorption and drying rates. Excessive localization is triggered by overheating and becomes difficult to manage. The temperature of the end product grew as the microwave power increased. In certain areas, the color is shown as yellow; these points are where the substance begins to heat. Microwave energy acts on water molecules and by vibrating water molecules, allows heat to be emitted. As a result, increasing temperature was detected, especially in the middle of the sample. The red color on the sides shows that the slurry's liquid component is discharged sideways and this is due to unnecessary loading of energy. According to the thermal images taken in the microwave drying system, the drying process is homogeneous. Temperatures for the conveyor belt dryer system have been measured between 22,4 ^{o}C – 51,5 ^{o}C / 19,7 ^{o}C - 53 ^{o}C / 21,7 ^{o}C – 65,5 ^{o}C. The temperature stays on the surface in the conveyor belt drying system, so it does not go far, so the temperature is not homogeneous, as shown in Figure 12-14. The inhomogeneity of the treatment sludge is related to the differences found in temperatures. In order to obtain a homogeneous composition, the sample has to be mixed.

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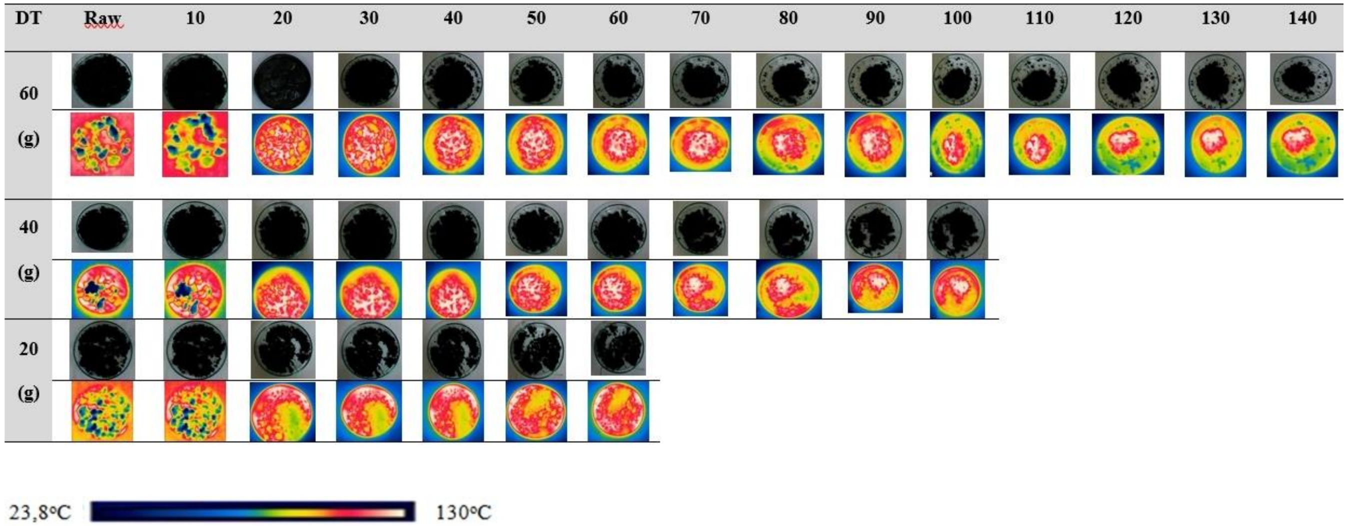

Figure 8. Thermal images of raw and dried treatment sludge under 360 W in microwave drying system (DT: Drying Time, minute.).

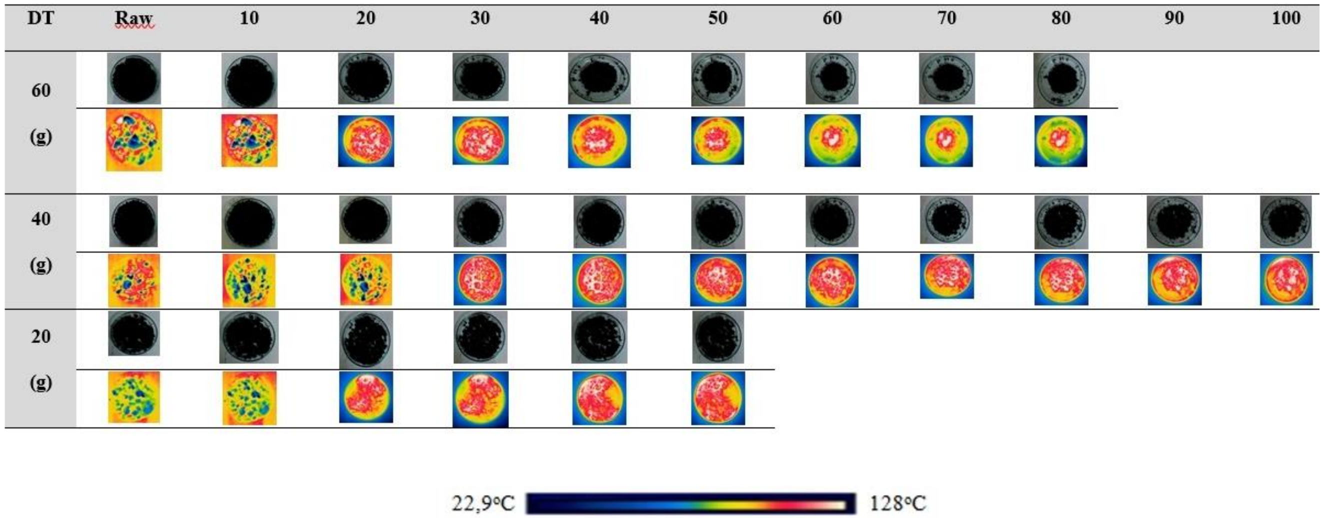

Figure 9. Thermal images of raw and dried sewage sludge under 600 W in microwave drying system.

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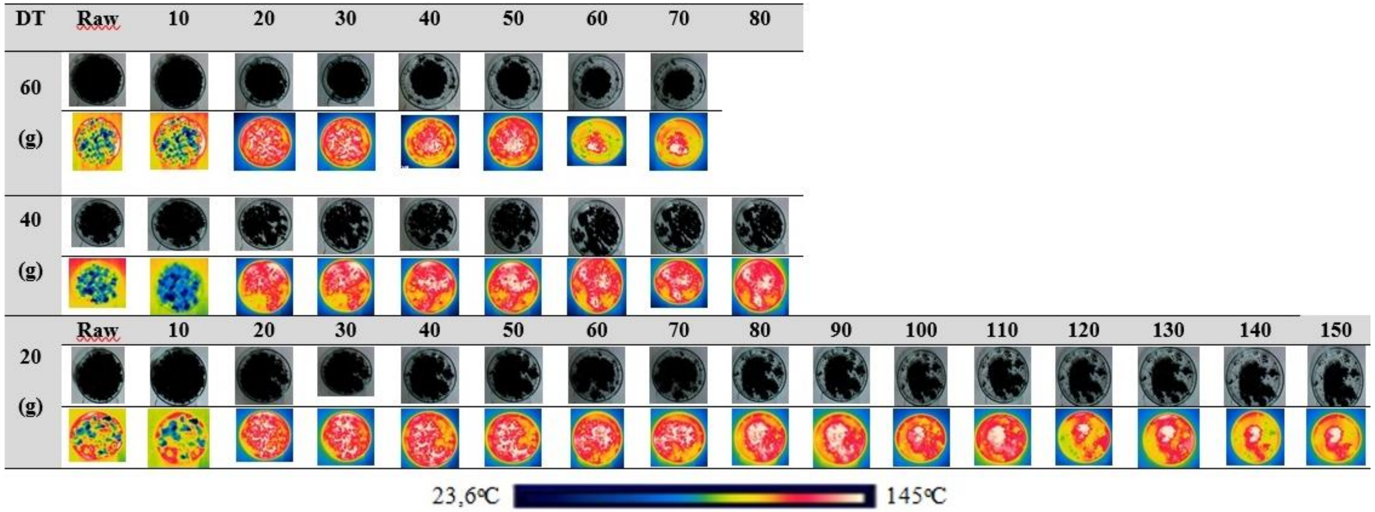

Figure 10. Thermal images of raw and dried sewage sludge under 800 W in microwave drying system.

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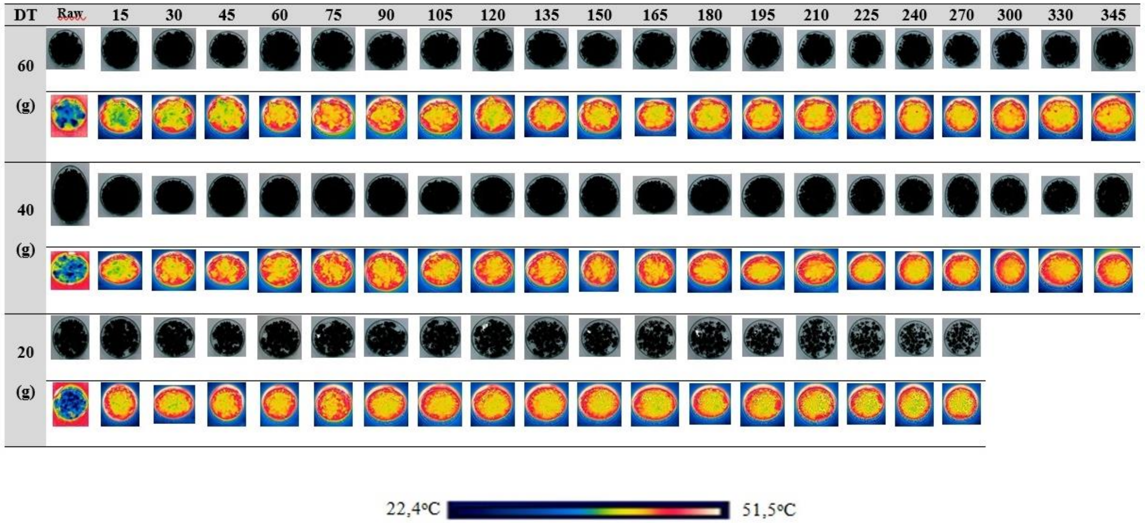

Figure 11. Thermal images of raw and dried sewage sludge below 60 °C in conveyor belt drying system.

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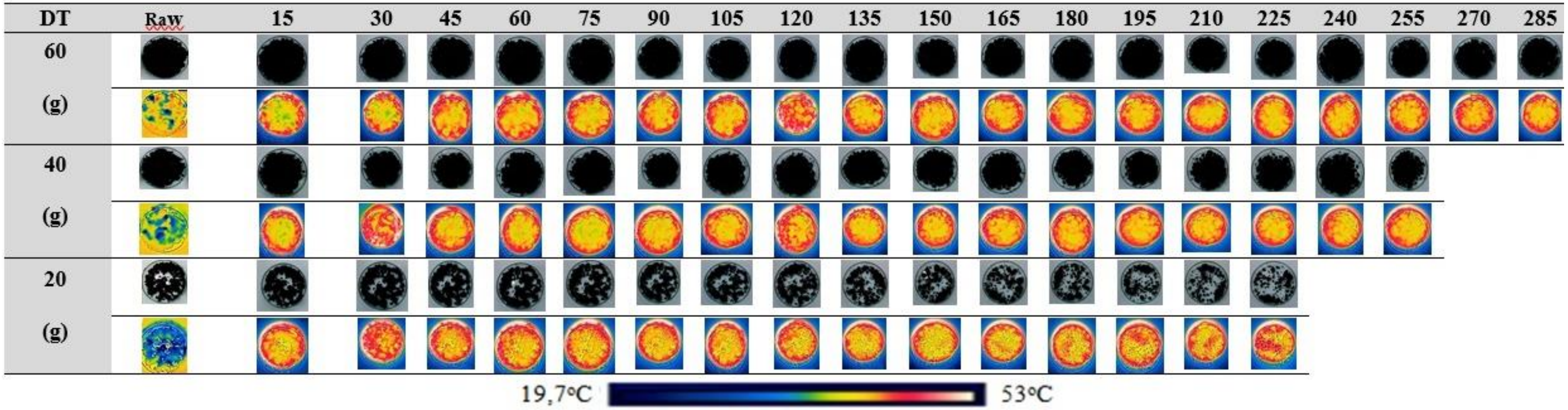

Figure 12. Thermal images of raw and dried sewage sludge below 70 °C in conveyor belt drying system.

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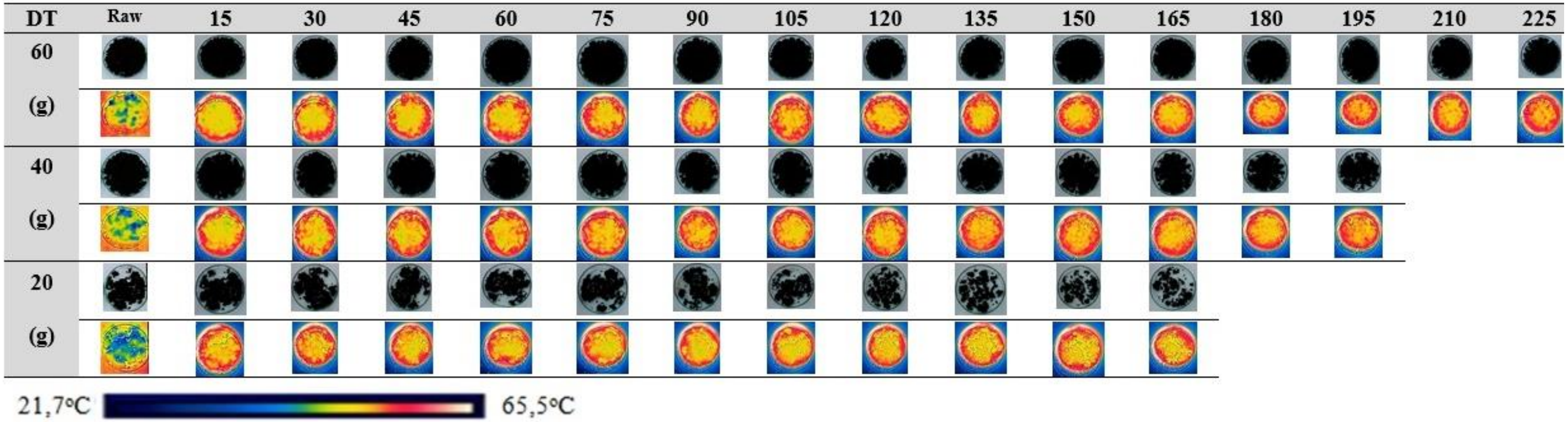

Figure 13. Thermal images of raw and dried sewage sludge below 90 °C in conveyor belt drying system.

3.4. Energy Analysis Findings

In the study of the analysis, the electrical energy consumption values of the microwave sludge system were between 0,03-0,15 kWh by weight for microwave power of 360 W, 0,02-0,06 kWh for microwave power of 600 W and 0,015-0,07 kWh for microwave power of 800 W. As the drying power enhanced the drying time, energy values increased. With the rise in microwave capacity, energy consumption has increased. At 800 W and 60 g, the least energy consumption is calculated as 0,015 kWh.

In conveyor drying, it was between 4,75-6,32 kWh for 60 ^{o}C drying temperature, 4,55-5,78 kWh for 70 ^{o}C drying temperature and 4,1-5,46 kWh for 90 ^{o}C drying temperature, respectively. As the drying time increased, energy consumption increased as the drying temperature decreased. Drying time decreased and the consumption of energy decreased as the drying temperature increased [17]. At 90 ^{o}C and 20 g, the least energy consumption is calculated as 4.1 kWh.

Since the heat generated at low microwave power is lower, the transfer of heat within the material and the transfer of heat from the product to the environment takes longer. Thus the time needed to achieve the evaporation temperature for the water in the product extends and the energy used for evaporation is decreased. In this situation, efficient drying is prevented.

4. CONCLUSIONS

For the drying of sewage sludge, the microwave drying system and the conveyor belt drying system were contrasted. It has been found that compared to the microwave drying system, the conveyor belt drying system has a longer drying time. It has been found that the microwave drying system is more favorable than the conveyor belt drying system when it comes to energy consumption. In terms of time and energy, the most appropriate of both drying systems was calculated at 800 W level. When the product is placed in a larger plate, more drying can be done. When the results of the study were evaluated, it was revealed that different drying times were observed because the drying mechanisms of both dryers were different, and microwave drying was faster than conveyor belt drying. It has been found that the higher the output power of the microwave and the smaller the mass of dried material, the quicker the drying takes place.

According to the thermal analysis performed on the sewage sludge, the drying process in the microwave drying system is more homogeneous, the drying process in the conveyor belt drying system is not homogeneous. In the calorific value analysis, it was shown that drying could increase the calorific value of the sewage sludge. With the calorific value of the waste, 3503.8 cal / g was concluded.

For predicting separable humidity rate (mr), Logarithmic and Henderson and Pabis model was chosen as the most predictive drying kinetics model with the comparisons made depending on the coefficients of the examined drying models with the highest r value based on microwave power, drying temperature and sludge weights in all experiment conditions.

Drying of treatment sludges due to their high moisture content and increasing amount each day; It is an effective method for reducing transportation and management costs, storing and recycling these wastes. When selecting the right drying process, drying time and energy consumption are a restricting factor.

As the drying process is carried out in the microwave drying system at high temperatures, it is assumed that pathogenic microorganisms in the sewage sludge can be more effectively eliminated.

It was observed that the samples dried in the conveyor belt drying system could not be dried homogeneously and some regions in the sample had different temperatures, and it was seen that the drying process was more homogeneous, which was not seen in the microwave drying system. If a uniform distribution of heat is required, it is assessed that the sample should be mixed.

While a very effective method for drying thin layer materials is microwave drying, it is not ideal for drying high volume and bulk materials. A conveyor belt drying scheme should be used if mass drying is needed. It is concluded, because of these differences, that an integrated structure should be developed in which the two systems can operate together.

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