Assessment of the impact of various parameters on solar drying process in Aydin region in Turkey

Ersel Yilmaz [1]
[1] Adnan Menderes University, Department of Biosystem Engineering, Aydin, Turkey.
email: eyilmaz@adu.edu.tr

Małgorzata Wzorek[2]
[2] Opole University of Technology, Department of Process Engineering, Opole, Poland.
email: m.wzorek@po.opole.pl

Corresponding author:
Ersel Yilmaz, Department of Biosystem Engineering, Adnan Menderes University, Aydin, Turkey
email: eyilmaz@adu.edu.tr

ABSTRACT

This paper presents the results of the research devoted to the determination of the conditions of solar drying of communal sewage sludge in open area in Mediterranean climate in Aydin region. The testing was undertaken in the summer season.

Drying testes were performed for two types of sludge; residue from two different municipal mechanical-biological wastewater treatment plants.

In order to determine the optimum conditions for the process and undertake an analysis of kinetic drying of sewage sludge, a set of tests were performed under variable parameters, i.e. for various thickness of the dried sludge (5, 10, 15 and 20 cm) and with the application of various mixing intensity (without mixing, 3 and 9 times a day).

The conducted tests let to the determination of the time interval necessary for the drying in the conditions of summer and also the parameters, which are optimal in terms of the time needed for the solar drying process in open area.

Keywords: sewage sludge, solar energy, drying, solar dryers, mixing, open area

INTRODUCTION

The problem associated with the storage and management of sludge resulting from the process of waste treatment concerns a majority of countries. The considerable amounts of generated sludge and the biological hazard associated with it, result in the difficulties of the economically viable utilization.

Recently, thermal methods of sewage sludge disposal become more and more popular. Energy recovery from waste occurs in the combustion processes in incinerators designed strictly for municipal sewage sludge incineration (Fytli & Zabaniotou 2008) or co-combustion with coal in various industrial installations, i.e. in power plants, power and heating plants, waste incineration plants moreover, as high heat processes conductive to thermal waste utilization (Stelmach &Wasilewski 2008, Houdková, et al. 2008).

The fundamental applicability of sewage sludge in the energy generation process is associated with the necessity of fulfillment of requirement of low moisture content. Sewage sludge constitutes the type of waste material for which the boundary value of mechanical dehydration is determined with the content of wastewater solids in the range of 30÷35 percent. The higher degree of dehydration, equal to 90 percent of sewage sludge may only be achieved through thermal drying.

However, the conventional processes of sewage sludge drying are associated with a considerable cost and energy outlay. Depending on the drying methods, the unit evaporation may amount to either 0.78÷0.9 kWh kg_{H2O}^{-1}, or even the expected energy consumption ratio to be of 1.2 kW kg_{H2O}^{-1}.

An alternative to the classical drying processes is drying with the application of solar energy in a solar dryer. The process of drying in this facility applies only the natural drying capability of solar energy and air circulation in order for humidity evaporation.

The drying in solar drier has a number of advantages, which include low outlay associated with investment and operation and noxiousness to the environment.

Solar drying is well know and has long been used in agriculture. The literature presents a wide range of information about the use of solar energy and research works carried out on the drying of wood and agriculture products (Helwa et. al. 2004, Campean & Marinescu, 2011, Koyuncu 2006, Madhlopa & Ngwalo 2004). For this purpose, a number of solutions can be applied including chamber-type dying oven with natural ventilation, grate-platform type and tube drying oven with forced air ventilation equipped with solar panels and solar dryers with greenhouse construction (Ramana 2012).

Those kind of solar dryers with greenhouse construction have been used in municipal sewage sludge drying (Luboschik 1999, Salihoglu et. al. 2007, Socias 2011, Mathioudakis 2013 et. al.). Such method of solar sewage sludge drying is increasingly used. In Europe, a number of solar dryers, mainly in Germany, France, Austria and Switzerland, but also in Poland have been constructed (Wzorek et al 2008, Krawczyk & Badyda 2011, Bennamoun 2012).

Except for the drying of municipal sewage sludge solar energy is also used for the sludge drying from food plants with high protein and fat (Trojanowska 2006) content as well as sediments from pharmaceutical industry (Mehrdadi et. al. 2007).

In countries where climatic conditions are much more favorable than the Central European (less chance of rain in the summer) the drying process can be carried out in the open space. Experience in this area were presented in the papers (Hossam et. al.1990) and (Salihoglu et. al. 2007).

The rate of drying depends on many factors, including the weather conditions: temperature and relative humidity of air, solar radiation, the speed and flow direction of heat carrier, the size of the exposed surface of a dried product, its content in the deposit and mixing of material.

Shin and others (2000) indicate, that greater influence of drying rate is presented by relative humidity instead of its temperature. Luboschik (1999) has estimated, that as long as the partial pressure of water vapor in the air depends only on the absolute humidity rather than the air temperature, the best results are obtained by drying with the warm sludge and dry air.

According to the information provided by Socias (2011), Luboschik (1999), Hossam and co-authors (1990) as well as El-Arina and Miller (1984) carrying out the research in various climate conditions, it can be concluded that the average daily loss of moisture may range from 2 to 17 kg H_2O m^{-2}. The highest has been achieved by Shannon et al. (2004) of 30 kg m^{-2} drying sludge in Australian conditions of the average temperature of about 65^{o}C.

In a climate of Central Europe, including Germany, evaporation of moisture is attained at 23 (kg m^{-2}) day $^{-1}$ (Luboschik 1999).

Clearly, the solar radiation, which is the main source of thermal energy supplied to the dried substance, is a very important factor in solar drying process.

Turkey has a high potential solar energy, which is the most important renewable sources of energy.

The yearly average solar radiation is 1,311 kWh m^{-2} per year and 3.6 kWh m^{-2} per day. The total yearly insulation period is approximately 2,460 hours per year and 7.2 hours per day (www.eie.gov.tr).

Annual solar energy and annual sunshine hours data for different regions of Turkey are presented in Table 1.

TABLE 1 Solar energy potential in different region of Turkey (www.eie.gov.tr)

Region	Total solar radiation, kWh m^{-2}	Sunshine duration, hours year^{-1}
Southeastern Anatolia	1,460	2,993
Mediterranean	1,390	2,956
East Anatolia	1,365	2,664
Central Anatolia	1,314	2,628
Aegean	1,304	2,738
Marmara	1,168	2,409
Black Sea	1,120	1,971

The next, significant process of solar drying technology used in solar dryers is the mixing, enabling the contact of sludge with drying agent. It should be noted, that from a technical point of view, mixing, turning and aerating the sludge in solar dryers is not at all easy. This is due to the physical properties of the sludge, which are dependent on the composition and technology applied in sewage treatment plant. During drying process they adopt diverse structures of the initial slurry to hard lumps in final stage of drying.

Hereby paper constitutes the determination of the conditions of solar drying of communal sewage sludge in open area in Mediterranean climate in Aydin region. The researches were conducted in order to assess the possibilities for effective drying of sewage sludge providing the lowest investment and operating costs (excluding the construction of solar dryer) during the most favorable time period.

MATERIAL AND METHOD

Solar drying experiments were conducted during the summer time in late July and August and were situated in Aydin, city at the Aegean region in Turkey.

The climate at this region is classified as Mediterranean type, characterized by hot, dry summers and cool, wet winters.

The average annual high temperature is about 24.53 ^{o}C and low temperature is 11.76 ^{o}C. The average annual humidity is 61%. The hottest month is July (the average high temperature is 36.2% and 350.3 of sunshine hours).

The average rainfall is about 651 mm per year and mostly it is recorded from November to April (Annual Report of Turkish State Meteorological Service, 2012).

Drying testes were performed for two types of sludge; residue from two different municipal mechanical-biological wastewater treatment plants.

One of them had come from the wastewater treatment plant in Didim. Sewage sludge was collected after the dehydration process. The other from WWTP in Söke was taken after the fermentation process had been executed in digester. Table 2 presents the physical and chemical characteristics of the sewage sludge.

TABLE 2 The properties of sewage sludge used in the tests

Parameter	Unit	Sewage sludge – Söke	Sewage sludge – Didim
Moisture, W	%	94.21$^{)a}$	86.68$^{)a}$
High Heating Value, HHV	MJ kg^{-1}	11.78	17.33
Organic matter, OM	%$^{)b}$	46.36	68.49
Content of heavy metals:			
Cd	mg kg$^{-1)b}$	0.679	1.240
Pb		48.0	14.9
Cu		231	124
Zn		1351	792
Cr		116	137
Ni		82.9	73.1

^{a} – average test, ^{b} – in dry mass

In order to determine the most favorable low-temperature drying of sewage sludge in the summer, a series of studies was carried out considering varying process parameters such as: different thickness layers of dried sludge with different levels of intensity of mixing.

The test stand was located on concrete floor divided into sectors so that each of two type of sludge was dried in layers with a thickness of: 5, 10, 15 and 20 cm, additionally, each of the layer was mixed in three variants: variant I: no mixing, variant II: mixing 3 times per day, variant III: mixing 9 times per day.

Screw-shaped vertical mixers moving along sectors of the rational frequency in range of 120–360 min^{-1} were used for mixing of the sludge.

In order to determine the loss of water in the sludge, daily in the evening at 6.00 p.m. three samples were taken for each sludge type, to do define the content of moisture in conventional dryer. The amount of water content was performed according to EN 12880:2000.

In the open drying system, sewage sludge was exposed to all of the outdoor environmental conditions. During the process, a meteorological station, which is located near stand test, provided continuous monitoring of ambient temperature (T), relative humidity (RH), wind speed and direction, precipitation, global solar radiation (SR).

In addition, the temperature of the drying sludge was examined. The measurements were carried using thermocouple.

RESULTS AND DISCUSSIONS

A series of tests carried out during summer conditions illustrates the most favorable conditions, considering solar drying point of view. The average distribution of solar radiation and sunshine duration throughout the year (data from years 1970÷2012) for Aydin city is shown in Fig. 1.

The average daily temperature during test period was 28.42 ^{o}C, while the average max temperature 36.14 ^{o}C and min temperature 18.27 ^{o}C. The average value of humidity for this period was 46.44%, global solar radiation 446.77 W m^{-2} and windspeed 0.8 m s^{-1}.

The temperature and relative humidity of air during test is presented in Fig. 2, and the global solar radiation in Fig. 3.

The average daily temperature during test period was 28.42 ^{o}C, while the average max temperature 36.14 ^{o}C and min temperature 18.27 ^{o}C. The average value of humidity for this period was 46.44%, global solar radiation 446.77 W m^{-2} and windspeed 0.8 m s^{-1}.

The temperature and relative humidity of air during test is presented in Fig. 2, and the global solar radiation in Fig. 3.

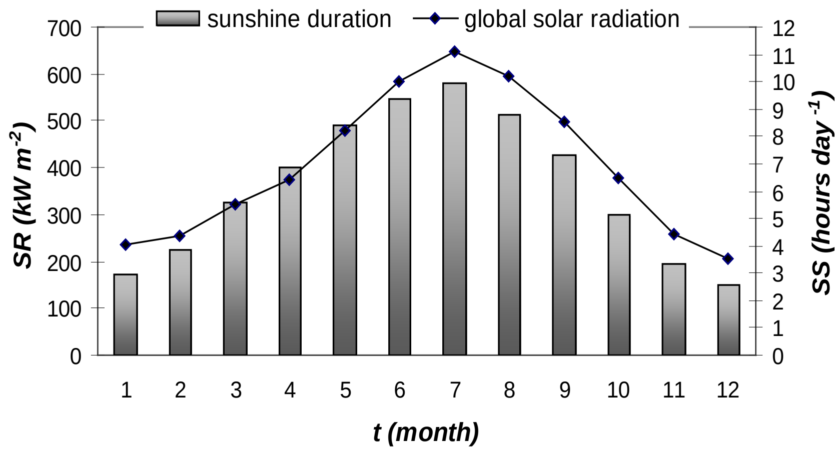

Figure 1. The annual average distribution of solar radiation (SR) and sunshine duration (SS) for Aydin city (Annual Report of Turkish State Meteorological Service, 2012)

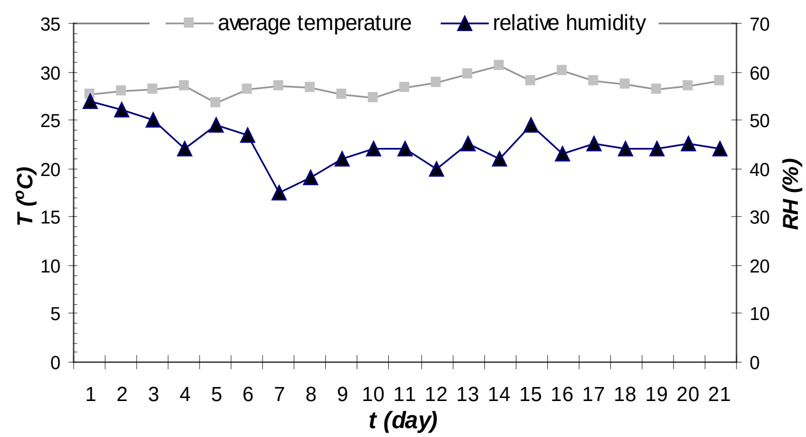

Figure 2. Temperature and relative humidity of air during the tests

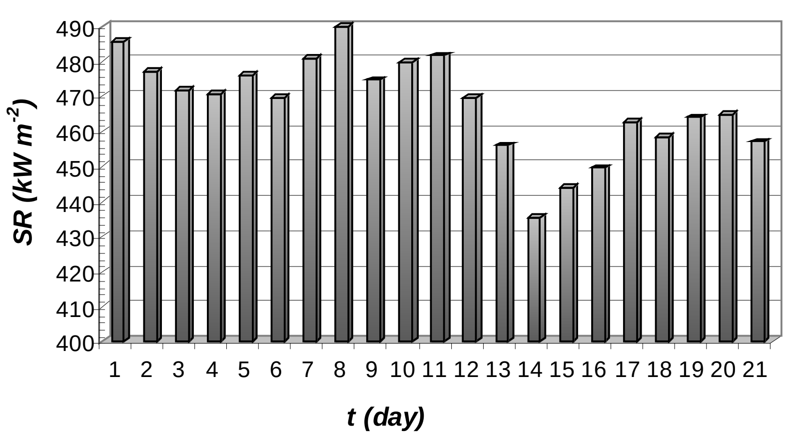

Figure 3. The intensity of global solar radiation during the tests

Achieved changes in moisture W (%) of the sludge during solar drying were approximated by a linear function (y = *a*x + *b*). This feature is characterized by a time course similar to the analyzed data.

The structural parameters *a* and *b* of the regression function were estimated using the least squares method (LSM) and the coefficient of determination R^2 was applied as a measure of fit of the estimated regression function parameters to empirical values. The values of the calculated regression function parameters and the determination coefficients are summarized in Table 3.

TABLE 3. The parameters of regression function and the determination coefficients

Sewage sludge	Layer cm	Variant of mixing	Regression function parameters		Determination coefficient
			a	*b*	R^2
Söke	5	no mixing	-11.04	116.9	0.97
		3 times	-14.09	114.3	0.81
		9 times	-13.36	110.8	0.85
	10	no mixing	-4.40	102.6	0.97
		3 times	-4.95	97.11	0.96
		9 times	-4.06	97.70	0.81
	15	no mixing	-2.44	101.2	0.99
		3 times	-4.46	102.9	0.93
		9 times	-5.84	103.6	0.98
Didim	5	no mixing	-15.80	110.4	0.81
		3 times	-15.80	110.4	0.81
		9 times	-13.01	105.1	0.94
	10	no mixing	-8.10	102.9	0.95
		3 times	-8.53	102.6	0.91
		9 times	-8.23	99.63	0.93
	15	no mixing	-6.07	102.6	0.93
		3 times	-6.52	102.0	0.92
		9 times	-5.80	103.0	0.96

Fig. 4 illustrates the drying curves of sewage sludge derived from WWTP in Söke while Fig. 5 the sewage sludge from WWTP in Didim.

Analyzing the drying curves it can be concluded that mixing shows a major impact on the rate of drying process. For each of the dried sludge in a layer thickness of 5 cm, using mixing, 15% content of moisture was obtained after 5 days.

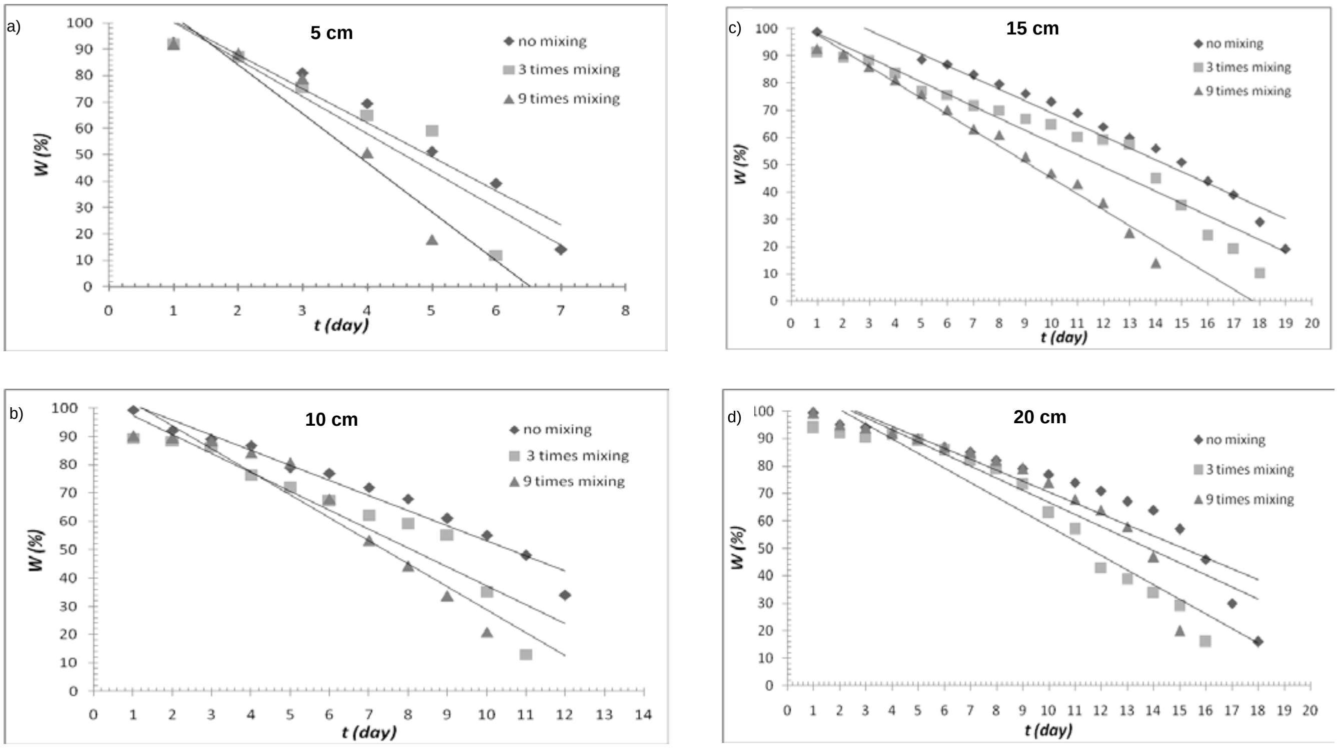

Figure 4. The drying curves of sewage sludge from Söke dried in various conditions

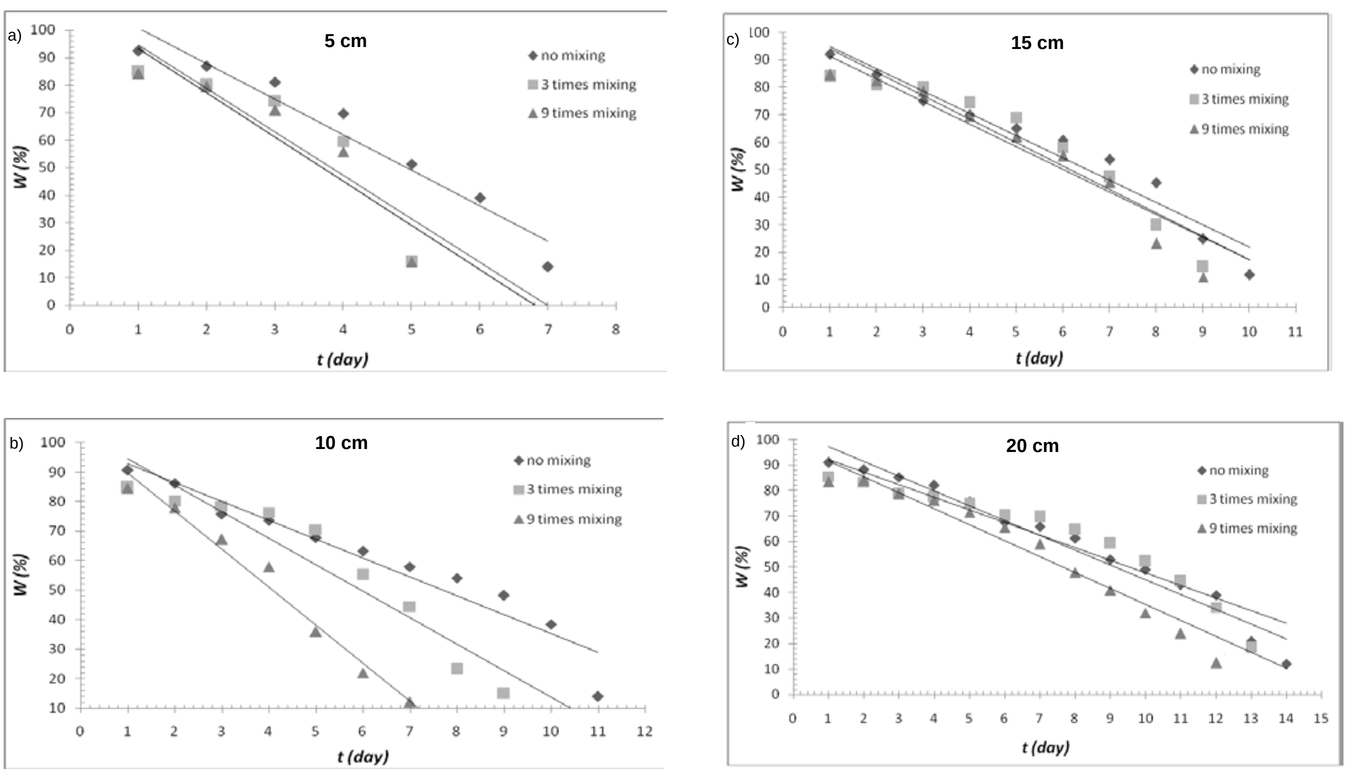

Figure 5. The drying curves of sewage sludge from Didim dried in various conditions

The process required 7 days to achieve the same level of moisture without mixing.

During drying, the thickest layer – 20 cm, noted differences in the rate of drying sludge. For example, the time to reach 15% of moisture content by the sludge from the treatment plant in Didim with mixing – variant II was 13 days, while for the sludge from Söke 16 days.

It can be determined that the use of mixing reduced the drying time respectively in the layer of 20 centimeter by three days on average. The thickness of the sludge layer in the solar drying application, as the author states (Trojanowska 2006) may be, depending on the technology 10÷15 cm, and in the case of drying in the prism 30÷40 cm.

Undoubtedly, the thickness of the layer, wherein the sludge is being dried has a significant effect on the drying rate. Comparing the results for the sludge from WWTP in Didim (variant III) drying time to reach less than 15% content of moisture was in 5 cm layer – 5 days, 10 cm – 7 days and 20 cm – 12 days.

Literature data show, that the period of sewage sludge drying using solar energy can range from a few to several days. For example, drying of sludge in Polish conditions in the solar dryer, as the authors (Trojanowska 2006, Wzorek et al. 2008) state, can be executed in 10 cm layer during 10 days in good conditions in summer, whereas in spring and autumn, may reach up to 40 days and more.

Similar results were obtained during biological sludge drying, for what Velis et al. (2009) prove 20% of moisture content in the sludge is obtained within 7÷15 days.

It was noted that the thickness of the layer which can be effectively dried by the sun radiation, without further treatment, i.e. mixing, regardless of the sludge layer thickness is about 10 cm.

A phenomenon, known and described in the literature, inter alia by Léonard et al. (2003), and Ruiz et al. (2007) that is the creation of two phenomena i.e. shrinkage and cracks that take place inside the sludge during drying process, thus are the result of moisture loss from a dried material, were also observed.

For the drying of sewage sludge in the variant without mixing, the evaporation of moisture from the surface of the dried material, after a few days of drying, slower loss of moisture is observed when compare to the one reported for variants with mixing. This is due to the fact that the transport of moisture occurred from the interior of the layer of the dried material. However, mixing led to the elevation of deposits from the interior to the surface layer, thus, the contact with the drying medium was facilitated. At the same time mixing resulted in the formation of small agglomerates (granules) from the sludge, which increased the contact area with air.

Temperature measurement results of the sewage sludge showed that their temperature during drying in hours 12.00÷3.00 p.m. reached up to 46 °C and on average, was from 5 to 10 °C higher than the air temperature.

The main purpose of drying sewage sludge for its energy application is to increase the energy values. It is well-known that moisture is a ballast and decreases the fuel energy utility. Between the moisture content in fuel there is a linear inverse relationship.

The heating value in the operational state – Low Heating Value (LHV) can be calculated from the relation (PN-ISO 1928:2002):

$$LHV=HHV(1-W) - r_w(W+9h)$$

where:

HHV – High Heating Value, kJ kg^{-1}

W – content of moisture, %,

h – content of hydrogen, %

r_w – enthalpy of water vaporization at ambient temperature, kJ kg^{-1}.

Using the linear relations shown in Figs 4 and 5, defining changes of moisture content in time, and for their specific function coefficients in Table 3 one can determined the time required to reach a specific calorific value of sludge. For reference, Fig. 6 shows the change in calorific value in time of the dried sludge in a layer of 15 cm in variant III.

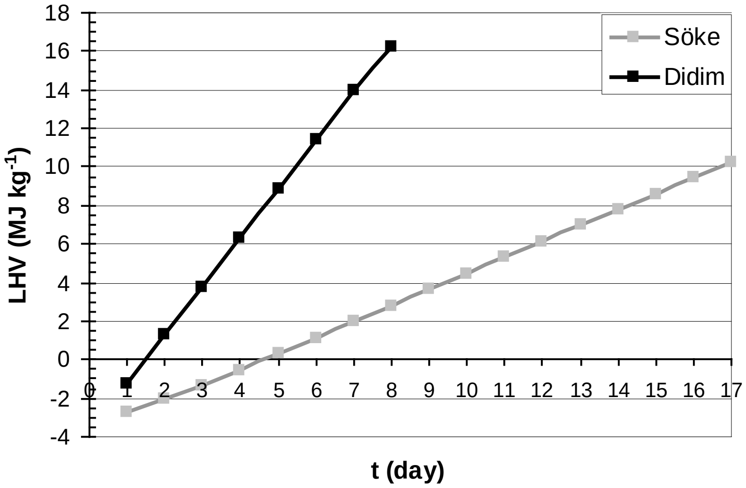

Figure 6. Change in the calorific value of the sewage sludge (dried in 15 cm layer) as a function of drying time

Certainly, the sludge from WWTP in Didim present better energy properties. Not only are characterized by a lower initial moisture content, but also have a higher content of organic parts, which causes high heat value (HHV) for municipal sewage sludge. In addition, they require a shorter drying time to achieve moisture content of 10%, at which LHV is 14.47 MJ kg^{-1}. This level allows them to be used in the energy practices for example in process of clinker burning in cement plant.

Heating value of the sludge from the WWTP in Söke is characterized as for typical digested sludge, which as mentioned in the subject literature (Khan 1995, Tchobanoglous et al. 2002, Wzorek & Król 2009) varies from od 10÷15 MJ kg^{-1} d.m. (dry mass), with well-run fermentation process up to 6.3÷10.5 MJ kg^{-1} d.m.

CONCLUSIONS

Drying of solar energy allows, at rather low costs, to reduce the weight and volume of the sludge by three times, which considerably facilitates and reduces the costs of transport. But it is the drying process that prepares the sewage sludge into their energy use in the process of combustion or co-combustion with coal.

Research on solar drying of municipal sewage sludge in open area revealed, that municipal sewage sludge may be periodically dried using "free" energy without significant capital investment in the construction of solar dryers.

As a result of the experiments, the time of drying of sludge in summer conditions in the region of Aydin was determined and the conditions under which the drying process, namely the thickness of the layer, as well as the intensity of mixing, which have a positive influence on the process were identified. It was recognized that the speed rate of solar drying process, except for the weather conditions, is dependent on the mixing of sewage during the drying process.

The results showed that in industrial conditions the drying of sludge is much preferred in a layer thickness of 15 cm. Conducted studies have enabled the design of the mixing device, which will be able to run periodically.

In conclusion it could be said, that solar drying of sludge has become an economically feasible technique of sludge drying in the regions, where warm and drought weather conditions are naturally available.

REFERENCES

Annual Report of Turkish State Meteorological Service (2012) State Meteorological Service Publishing, Ankara, Turkey

Bennamoun, L. (2012) Solar drying of wastewater sludge: A review. Renewable and Sustainable Energy Reviews, 16, 1061-1073

Campean, M., & Marinescu, I. (2011) Solar systems for wood drying. Environmental Engineering and Management Journal, 10, 1069-1076

El-Ariny, A.S., & Miller, H.I. (1984) Utilization of solar energy for sludge drying beds. Journal of Solar Energy Engineering, 106, 351-357

EN 12880:2000: Characterization of sludges – Determination of dry residue and water content

Fytli, D., & Zabaniotou, A. (2008) Utilization of sewage sludge in EU application of old and new methods – a review. Renewable & Sustainable Energy Reviews, 12, 116–140

Helwa, N.H., Khater, H.A., Enayet, M.N., & Hashish, M.I. (2004) Experimental evaluation of solar kiln for drying wood. Drying Technology, 22, 703-717

Hossam, A.A., Saad, S.G., Mitwally, H.H., Saad, L.M., & Noufal, L. (1990) Solar energy for sludge drying in Alexandria Metropolitan Area: Case Study in Egypt. Water Science Technology, 22, 193-204

Houdková, L., Borán, J., Ucekaj, V., Elsäßer, T., & Stehlík P. (2008) Thermal processing of sewage sludge – II. Applied Thermal Engineering, 28, 2083-2088

http://www.eie.gov.tr/eieweb/english/solar/solarTurkey_e.html

Khan, M., Mcmahon, S., & Decanio, S.J. (1995) Estimating the heating value of sewage sludge. Clean Energy from Waste and Coal, 515, 144–156

Koyuncu, T. (2006) An investigation on the performance improvement of greenhouse type agricultural dryers. Renewable Energy, 2006, 31, 1055-1071

Krawczyk, P. and Badyda, K. (2011) Modeling of thermal and flow processes in a solar wastewater sludge dryer with supplementary heat supply from external sources. Journal of Power Technologies, 91, 37-40

Léonard, A., Blacher, S., Pirard, R., Marchot, P., Pirard, J.P., & Crine, M. (2003) Multiscale texture characterization of wastewater sludges dried in a convective rig. Drying Technology, 21, 1507- 1526

Luboschik, U. (1999) Solar sludge drying-based on the IST process. Renewable Energy, 16, 785-788

Madhlopa, A., & Ngwalo, G. (2007) Solar dryer with thermal storage and biomass-backup heater. Solar Energy, 81, 449-462

Mathioudakis, V.L., Kapagiannidis, A.G, Athanasoulia, E., Paltzoglou, A.D, Melidis, P., & Aivasidis A. (2013) Sewage sludge solar drying: experiences from the first pilot-scale application in Greece. Drying Technology: An International Journal, 31, 519-526

Mehrdadi, N., Joshi, S.G., Nasrabadi, T., & Hoveidi, H. (2007) Application of solar energy for drying of sludge from pharmaceutical industrial wastewater and probable reuse. International Journal of Environmental Research, 1, 42-48

PN-ISO 1928:2002: Solid fuels: Determination of calorific value by combustion in a bomb calorimeter and calculation of low calorific value of solid fuels

Ramana, M.V. (2012) A review of new technologies, models and experimental investigations of solar driers. Renewable and Sustainable Energy Reviews, 16, 835–844

Ruiz, T., Wisniewski, C., Kaosol, T., & Persin, F. (2007) Influence of organic content in dewatering and shrinkage of urban residual sludge under controlled atmospheric drying. Process Safety and Environmental Protection, 85, 104–110

Salihoglu, N.K., Pinarli, V., & Salihoglu, G. (2007) Solar drying in sludge management in Turkey. Renewable Energy, 32, 1661-1675

Shannon, R., Nathan, S., & Luboschik, V. (2004) Solar sludge drying, Water Works, December, 38-43
Shin, Y., Kim, H., & Chun, H. (2000) Drying of water treatment process sludge in a fluidised bed dryer. Korean Journal of Chemical Engineering, 17, 22-26
Socias, I. (2011) The solar drying plant in Mallorca: the drying process in waste management. Proceedings of the III European Drying Conference – EuroDrying'2011, 26-28 October, pp. 1- 3. Palma de Mallorca, Spain
Stelmach, S., & Wasilewski, R. (2008) Co-combustion of dried sewage sludge and coal in a pulverized coal boiler. Journal of Material Cycles and Waste Management, 10, 110-115
Tchobanoglous, G., Burton, F.L., & Stensel, H.D. (2003) Wastewater Engineering: Treatment and Reuse. Metcalf&Eddy Inc. McGraw-Hill, New York, NY USA
Trojanowska, K. (2006) Technologie solarne w utylizacji osadów komunalnych [Solar Technologies in Municipal Sludge Disposal]. Forum eksploatatora, 6, 58-61
Velis, C.A., Longhurst, P.J., Drew, G.H., Smith, R., & Pollard, S.J.T. (2009) Biodrying for mechanical-biological treatment of wastes: a review of process science and engineering. Bioresource Technology, 100, 2747-2761
Wzorek, M., & Król, A. (2009) Analysis of selected properties of sewage sludge within the consideration of its energetic application in forming alternative fuels. Polish Journal of Environmental Studies, 6, 132-136
Wzorek, M., Głowacki, T., & Troniewski, L. (2008) Determination of circumstances of drying waste sludge with solar energy. Proceedings of the 18th International Congress of Chemical and Process Engineering, 24-28 August, pp. 895. Praha, Chech Republic