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Effect of Olive Mills Wastewater (OMWW) on Soil Thermal Conductivity

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ABSTRACT

Olive Mills Wastewater (OMWW) contains organic matter which can be added as soil amendment and might be highly beneficial to agricultural soils. However, the organic matter in the olive mills wastewater contains oil which might affect soil thermal conductivity, water retention and hence infiltration rate. The effect of adding Olive Mills Wastewater (OMWW) on soil thermal conductivity has been carefully investigated in the laboratory. Three soils were used and classified as sandy clay, silty clay and clay. The thermal conductivity of the soil was determined using a single probe technique. At given moisture content and bulk density, results showed that OMWW concentration had direct effect on soil thermal conductivity. For all soils tested soil thermal conductivity decrease as OMWW applied to soil samples. The decrease in soil thermal conductivity has been noticed at all levels of OMWW concentration but significantly different at 60% or higher. The thermal conductivity values were higher for sandy clay than silty clay and clayey soil at all OMWW concentrations. Thermal conductivity values between 0.89-0.70 W m⁻¹ K⁻¹ were obtained for sandy clay soil, between 0.77-0.63 W m⁻¹ K⁻¹ for silty clay soil and between 0.80-0.57 W m⁻¹ K⁻¹ for clay soil as OMWW concentration increased from 20-100% at water contents of 0.20 cm³ cm⁻³ and bulk density of 1.25 g cm⁻³. Graphical and statistical comparisons of thermal conductivity obtained for the three soils used are presented.

Key words: Soil, thermal conductivity, organic matter, Olive Mills Wastewater, heating

INTRODUCTION

Olive Mill Wastewater (OMWW) is becoming a serious environmental challenge facing the Mediterranean countries, where most of the world olive oil is produced (Wiesman, 2009). Jordan has 22 million olive trees which produced around 200,000 tons of olive fruit annually, 35,000 of oil and 200,000 m³ of olive mills wastewater as by product (MoA., 2012). Most of these evergreen trees are grown in the northern part of the kingdom, mostly under rainfed conditions. Olive trees are drought tolerance, have low cost and can protect high lands from excessive erosion and return good revenue for farmers.

Olive oil is produced by processing olive in mills in addition to pomace and olive mill wastewater as by products. The two by-products are obtained along with the oil (which accounts for 20% of the total), a solid residue (30% of the total) and a black wastewater (50% of the total) called Olive Mill Wastewater (OMWW) in the extraction process. Olive mills dispose their waste

in settlement ponds which are of small capacities leaks to nearby valleys. Olive mills waste is considered as a major source of odor and might be harmful for plants and vegetables growth at high concentration. Because of its organic content, the waste can be used as soil amendments after treatment to improve soil properties which might increase soil productivities.

OMWW is characterized by a high level of organic matter in addition to phenols content as shown in Table 1. The high organic content consists of BOD of 12-63 g L⁻¹ (Cossu *et al.*, 1993) and COD of 80-200 g L⁻¹ (Hayek *et al.*, 1996). These values are 200-400 times higher than a typical municipal wastewater (Tsonis and Grigoropoulos, 1993).

OMWW has also characterized by its high suspended and dissolved solids content and by its brown color related to lignin and humic acids Saez *et al.* (1992). The only pretreatment of OMWW is the sedimentation process in open ponds or lagoons to allow the settlement of solids.

During oil separation from water by centrifugation some oil dissolved in water escaped to OMWW. If the waste is spread in the field, the oil might occupy the macro pores and cover soil particles which might reduce the water films thickness around soil macro aggregates and slow the movement of water through soil aggregates (McGill, 1971).

Thermal properties control the plant growth by affecting the microclimate conditions, germination and seedling emergence which can be considered as an important factor for plant growth which are all function of soil thermal conductivity. Soil structure affects plant growth through its influence on soil heat, temperature, air, water and mechanical impedance to roots. Thermal conductivity is defined as the heat quantity transferred per unit area of the conducting body in unit time under a unit temperature gradient. There is a lack of information available on the effects of OMWW on soil thermal conductivity either under laboratory or field conditions. The objective of this research was to measure changes in soil thermal conductivity with application of olive mills wastewater on three different soils.

MATERIALS AND METHODS

The study was conducted on three soils types; namely: Sandy clay (55% sand, 5% silt and 40% clay), silty clay (7% sand, 52% silt and 41% clay) and clay (20% sand, 25% silt and 55% clay). For each soil, many tests were conducted at different OMWW concentrations by diluting Olive Mill Effluent (OME) with distilled water.

Olive mill wastewater was taken during olive pressing period of 2012 (October to December) from a local olive mill in Irbid governorate. Samples were stored in tightly sealed plastic containers. The characteristics of the OMWW are shown in Table 1 obtained by following the procedure described by Greenberg *et al.* (1992) for testing of wastewater. The characteristics include: Density, conductivity, pH, total suspended and dissolved solids, phenols, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) as the most widely used parameters of organic pollution applied to both wastewater and surface water.

The Olive Mill Effluent (OME) concentrations used are shown in Table 2; they were obtained by mixing proportion of the OMWW solution with distilled water to produce the desired level.

The thermal conductivity of the soil was measured by using the hot wire method. In this technique, a wire with certain electrical resistance was embedded in the experimental soil sample. A steady current was applied to the wire which caused the wire temperature to increase. The temperature rise of the surrounding soil was measured by a thermocouple connecting to a data logger. Thermal conductivity, K (W m⁻¹ K⁻¹), was calculated by using the equation given by Abu-Hamdeh *et al.* (2000, 2001):

Table 1: Properties of olive mill effluent wastewater*

Properties	Values
Temperature (°C)	25
pH	4.7
Conductivity ($\mu \Omega^{-1}$)	3,500
Phenols ($g L^{-1}$)	2.90
TDS ($g L^{-1}$)	41.50
TSS ($g L^{-1}$)	20.80
BOD ₅ ($g L^{-1}$)	14.50
COD ($g L^{-1}$)	35.50
Density (25°C) ($g L^{-1}$)	0.993

*Results for wastewater samples after 30 days of settling

Table 2: Olive mills effluent concentrations (distilled water)

OME conc. ($\% cm^3/cm^{-3}$)	Distilled water (%)
0	100
20	80
40	60
60	40
80	20
100	0

OME: Olive mill effluent

$$K = 0.0796 I^2 R/S \quad (1)$$

where, I is the current (A), R the wire resistance (Ωm^{-1}) and S is the slope of the straight-line portion of the temperature rise curve against $\ln(t)$ during heating (i.e., $S = \Delta T/\Delta \ln$).

The apparatus set up for this study is shown in Fig. 1. It consists of 8×8 cm base and 20 cm long rectangular box made of galvanized steel with a thickness of 0.20 cm. The electrical wire was embedded at the center of the box in the long direction. The wire was heated by a direct voltage of 10 V provided by a variable power unit for a short time. A thermocouple was embedded in the soil close to the wire to monitor soil temperature variation with time. The soil temperature was recorded by a data logger connected to the thermocouple.

Soil moisture content was determined by drying the sample at a temperature of 105°C in an oven for 24 h. Soils were screened through a 2 mm sieve. The Olive Mill Effluent (OME) concentrations used are shown in Table 2; they were obtained by mixing proportion of the OMWW solution with distilled water to produce the desired level. Soil samples were mixed thoroughly with OME solution in nylon sags and kept overnight at room temperature to equilibrate before placed in the test box.

The soil samples were packed in the box, the power supply was switched on allowing heating of the wire and the current was taken for thermal conductivity estimation. During the heating stage the wire temperature was taken every 5 sec as shown in Fig. 2. The thermocouple temperature was measured as described earlier and slopes of the temperature against time natural logarithm were obtained. The experiment was repeated three times for each treatment (the box emptied, clean and repacked for each replication).

At the end of heating stage, the power supply is switched off and cooling process started. Temperature of the wire was taken after every 5 sec until temperature variation ceased with time. Similar steps were repeated for six OMWW concentrations at three different moisture contents of (0.15, 0.20, 0.25 $cm^3 cm^{-3}$) and three soil densities (1.15, 1.25, 1.35 $g cm^{-3}$) for each soil type. Temperature against time natural logarithm graphs were plotted to determine the slopes of the

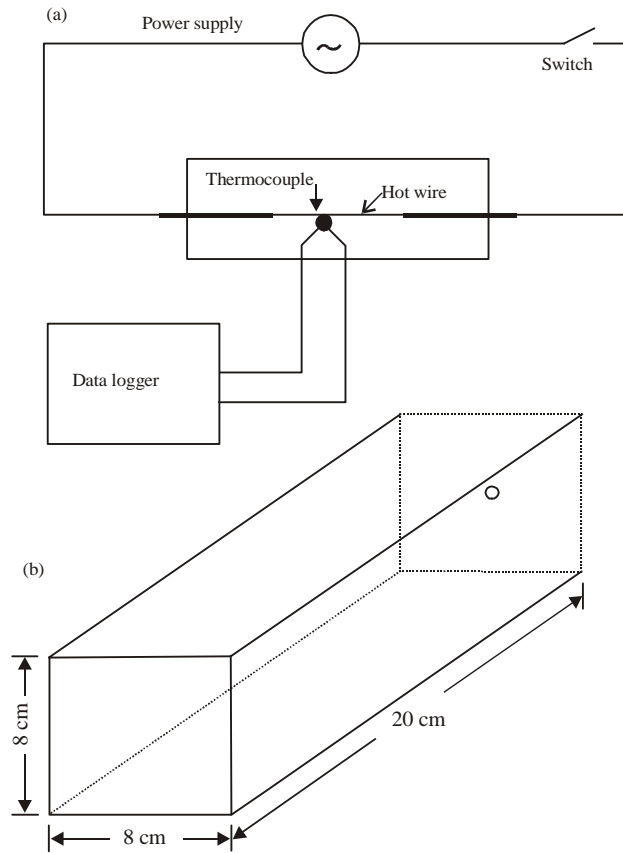


Fig. 1(a-b): Experimental set up, (a) Top view of the apparatus and (b) Rectangular steel box

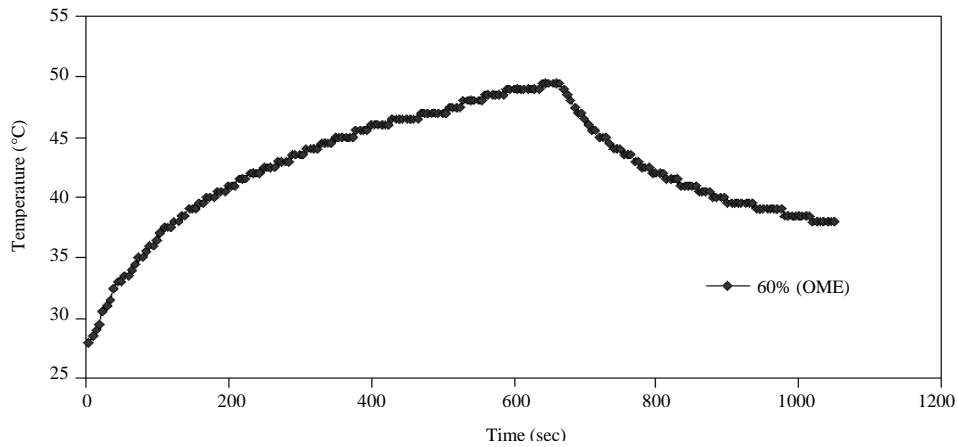


Fig. 2: Soil temperature versus time during heating and cooling processes for sandy clay soil at 20% moisture content and bulk density of 1.25 g cm^{-3}

linear parts of these curves which became linear 300 sec after heat was initiated. The slopes obtained were used to calculate soil thermal conductivity as shown in Fig. 3. Similar steps were repeated for all soils tested at different OMWW concentrations.

Soil moisture content and density have direct effect on soil thermal conductivity for the type of soils studied. As sited in literature, soil thermal conductivity increased as soil density and moisture content increased which is in agreement with the result obtained by Abu-Hamdeh *et al.* (2000, 2001). Therefore, to eliminate the effect of soil density and moisture content on soil thermal conductivity, only the results of the effect of adding OMWW to soil on soil thermal conductivity of tested soils at a moisture content of $0.20 \text{ cm}^3 \text{ cm}^{-3}$ and bulk density of 1.25 g cm^{-3} are presented in this study.

RESULTS AND DISCUSSION

The parameters measured in each test at different OMWW concentration for all soil tested were: temperature, specific time, moisture content and bulk densities. Each test was run in three replicates and their average was used to estimate the soils thermal conductivity.

Figure 2 shows the wire temperature behavior as time elapsed for sandy clay soil at OMWW concentration of 60% during heating and cooling processes. The figure shows that the temperature rapidly increased during the first 5 min of heating, after that temperature variation with time was slow. Cooling process started immediately after power supply was shut off after ten minute of heating. The rate of temperature drop with time during cooling process was slower than the rate of temperature rise during heating process. This might be due to the complicating factors of ions exchange and water migration in response to temperature variations as a result of soil heating.

The characteristic of temperature rise as a function of time logarithm for the clay soil at different OMWW concentration is shown in Fig. 3. On the other hand, the characteristic of temperature fall against time logarithm for the silty clay soil at different OMWW concentration is shown in Fig. 4. Slopes of these curves for all tests were calculated and used in Eq. 1 to evaluate thermal conductivity.

The average thermal conductivity of three sift and restored Jordanian soils as affected by OMWW concentration is shown in Fig. 5 at a moisture content of $0.20 \text{ cm}^3 \text{ cm}^{-3}$ and a bulk density of 1.25 g cm^{-3} . At various OMWW concentrations, sand clay always had a higher thermal conductivity values than other soils. Mineralogical constitutes of the clay soil may have lower thermal conductivity than those in sandy soil.

Thermal conductivity of the three different soils was decreased as OMWW concentration increased. Figure 5 shows that sand clay soil thermal conductivity was reduced from

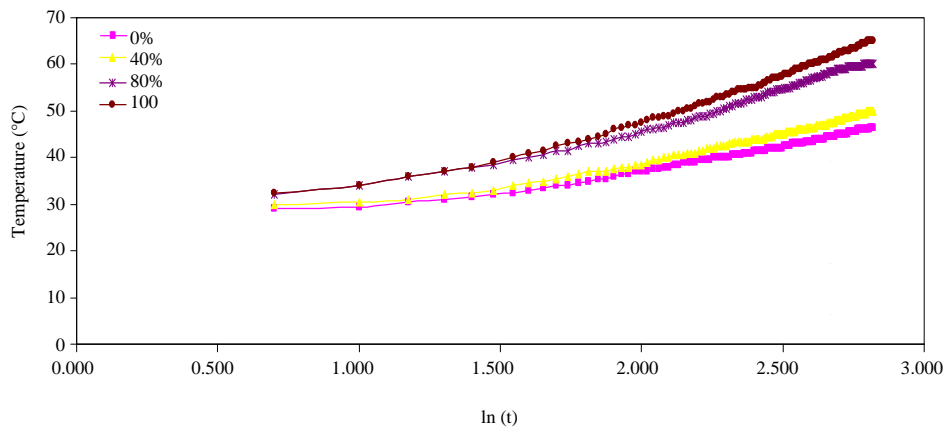


Fig. 3: Wire temperature versus logarithm (t) during heating for clay soil at different olive mill effluent concentration and a moisture content of 20%

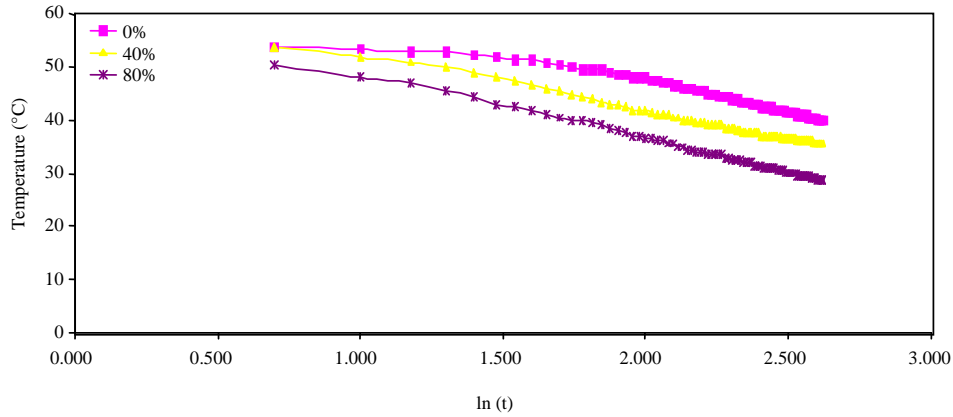


Fig. 4: Wire temperature versus logarithm (t) during cooling for silty clay at moisture content of 20% at different olive mill effluent concentration

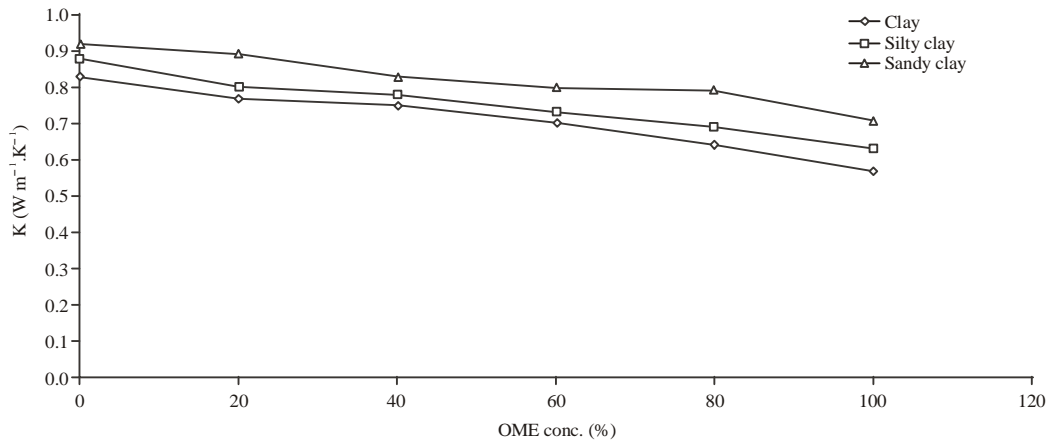


Fig. 5: Thermal conductivity versus olive mill effluent concentrations for sandy clay, silty clay and clay soil at a moisture content of 20%

0.89-0.71 $W m^{-1} K^{-1}$ at OMWW concentration of 20 and 100%, respectively. This might be a result of increasing the amount of organic matter and minerals as the OMWW concentrations increased. Organic matter and mineral solids in OMWW were estimated at 4-16 and 2%, respectively. The results give some insight on the relation between the percentage of organic matter content in soil and thermal conductivity. Although, it is expected that thermal conductivity will decrease with an increase in organic matter content, this figure gives an indication of the amount of reduction in thermal conductivity for a given increase in organic matter. For example, thermal conductivity decreased from 0.92 $W m^{-1} K^{-1}$ at 0% OME (pure distilled water) to 0.71 $W m^{-1} K^{-1}$ at 100% OMWW concentration which means a reduction of 23% in the soil's thermal conductivity was observed for an increase of 100% in OMWW concentration for sandy clay soil. A constant incremental increase of 20% (from 20-100%) in OMWW concentration did not yield the same amount of reduction in thermal conductivity. Thermal conductivity decreased in the range of 10% to 30% each time the percentage of OMWW increased by 20% for sandy clay soil as shown in Table 3.

Table 3: Mean thermal conductivity of three Jordanian soils at different olive mill effluent concentrations, each value represent the average of three replicates*

OME conc. (%)	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)					
	Heating			Cooling		
	Sandy clay	Silty clay	Clay	Sandy clay	Silty clay	Clay
0	0.92 ^a	0.88 ^a	0.83 ^a	0.76 ^a	0.67 ^a	0.63 ^a
20	0.89 ^a	0.80 ^b	0.77 ^b	0.67 ^b	0.62 ^b	0.60 ^b
40	0.81 ^b	0.78 ^b	0.75 ^{b,c}	0.64 ^b	0.61 ^b	0.57 ^{b,c}
60	0.80 ^b	0.73 ^{b,c}	0.70 ^{b,c}	0.61 ^{b,c}	0.58 ^b	0.53 ^{b,c,d}
80	0.79 ^b	0.69 ^{b,c}	0.64 ^{b,c,d}	0.56 ^{b,c}	0.54 ^{b,c}	0.49 ^{b,c,d}
100	0.71 ^{b,c}	0.63 ^{b,c,d}	0.57 ^{b,c,d}	0.57 ^{b,c}	0.52 ^{b,c}	0.43 ^{b,c,d,e}

* Means with the same letter indicate insignificant difference at a 10% level, OME: Olive Mill Effluent

Table 4: Comparison of mean thermal conductivity of three Jordanian soils at different olive mill effluent concentrations obtained by heating and cooling methods, each value represent the average of three replicates*

OME concentration (%)	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)					
	Sandy clay		Silty clay		Clay	
	K-Heating	K-Cooling	K-Heating	K-Cooling	K-Heating	K-Cooling
0	0.92 ^a	0.76 ^b	0.88 ^a	0.67 ^b	0.83 ^a	0.63 ^b
20	0.89 ^a	0.67 ^b	0.77 ^a	0.62 ^b	0.80 ^a	0.60 ^b
40	0.81 ^a	0.64 ^b	0.75 ^a	0.61 ^b	0.78 ^a	0.57 ^b
60	0.80 ^a	0.61 ^b	0.73 ^a	0.58 ^b	0.73 ^a	0.53 ^b
80	0.79 ^a	0.56 ^b	0.64 ^a	0.54 ^b	0.69 ^a	0.49 ^b
100	0.71 ^a	0.57 ^b	0.63 ^a	0.52 ^b	0.57 ^a	0.43 ^b

* Same letter indicate insignificant difference at a 10% level, OME: Olive Mill Effluent

The maximum thermal conductivity of ($0.92\ W\ m^{-1}\ K^{-1}$) was noticed in sandy clay soil. The thermal conductivity of clayey soil was less than sandy clay and silty clay at all OME concentrations. Thermal conductivity values obtained were between $0.38-1.71\ W\ m^{-1}\ K^{-1}$ for sandy clay and in the range $0.39-0.70\ W\ m^{-1}\ K^{-1}$ for clay soil at volumetric moisture contents of 10 and 20%, respectively as reported by Ghuman and Lal (1985). For the clayey soil, thermal conductivity decrease uniformly with increasing OME concentration as shown in Fig. 5. The low thermal conductivity of the clayey soils is due to the lower bulk density, compared with other soils and to the lower conductivity of minerals constituting the clay particles (De Vries, 1963). Also, the decrease of thermal conductivity may be attributed to increase in air porosity as the grain size decrease which resulted in increased of thermal resistance between soil aggregates. This implies that clayey soil would face larger surface temperature variations relative to sandy clay and silty clay under the same heat intensity which might risk the growing of temperature dependent crops on the clayey soils.

Minitab was used to analyze the data at a significance level of 10%. The null hypothesis was that the mean of the thermal conductivity values were the same for each soil type at different OME concentrations. Also, a pair t-test was performed to test the null hypothesis that thermal conductivities obtained were similar during heating and cooling stages. The p-value (one tail) test was 0.05 which indicate that the two methods yield different values of thermal conductivity. Table 4 shows comparisons of the mean thermal conductivity values during heating and cooling stages at different OME concentrations for sandy clay, silty clay and clay soils.

As shown in Table 4, there is significant difference among the mean values of thermal conductivity obtained during heating and cooling stages at every OME concentrations for all soil

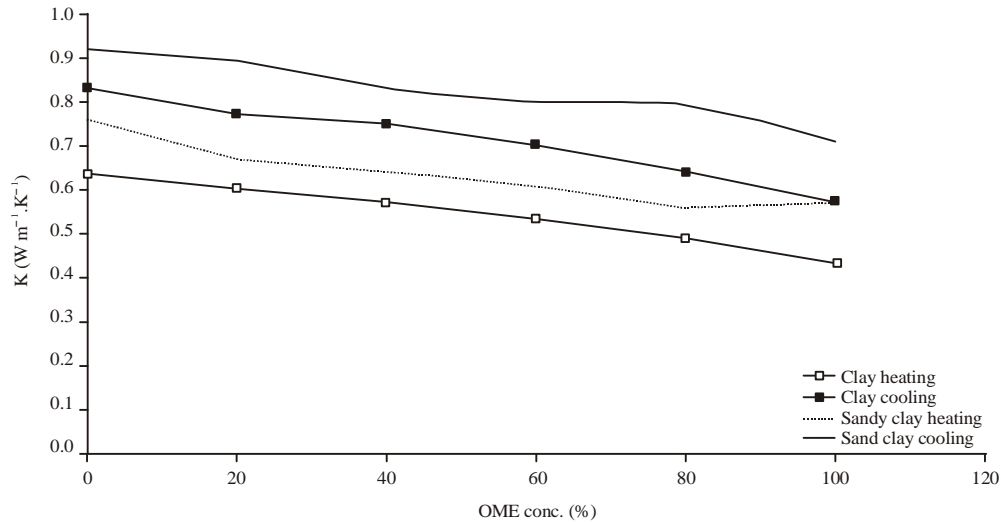


Fig. 6: Thermal conductivity versus olive mill effluent concentrations during heating and cooling processes of sandy clay and clay soil at a moisture content of 20% and bulk density of 1.25 g cm^{-3}

types studied. The thermal conductivities obtained during cooling stage were less than those obtained during heating stage as shown in Fig. 6. This might be as a result of water spread in response to temperature changes during a complicated heating process.

CONCLUSION

Thermal conductivities were investigated for three sieved and repacked Jordanian soils at a constant water content and bulk density at different OMWW concentrations. Thermal conductivities values varied with soil type and OMWW concentration. Generally thermal conductivity increased as bulk density and moisture content increased for all soils studied. The heating data yield higher thermal conductivities than those obtained from the cooling one. At given moisture content thermal conductivity values of all soils decreased with increasing OME concentration. Sandy clay soil had the higher thermal conductivity at any OMWW concentration. Sandy clay exhibited slight decreases in thermal conductivity values after certain OME concentration. Thermal conductivities were lower for clayey soil than sandy clay and silty clay soil which might affect the growing of temperature dependent crops on this type of soil.

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