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Experimental Investigation of the Effect of Adding Bentonite Nano-clay on the Heat Diffusivity Capacity of Kaolinite Clay (α)

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Abstract: *Soil thermal diffusivity capacity (α) is one of the most important soil thermal properties, which is very important in engineering and technology science and sustainable development in the energy sector. The amount of water in the soil is considered as one of the factors affecting the variations (α) in the soil. As adding bentonite nano-clay to clay causes a significant increase in the absorption of surface water and the plasticity properties and the potential of clay swelling, the present study investigates variations (α) under different conditions of moisture in optimum state and by adding different percentages of bentonite nano-clay to clay. For this purpose, after preparing clay soil with low dough range and its mixtures with different percentages of bentonite nano-clay (5%-10% -20%) at four different times (days 1 to 7, 14 and 28), the test samples were placed in contact with the heat source with the capability to set the temperature for 24 hours. The heat source has been inserted under the sample and thermal imaging camera has been inserted on the other side of the samples and above the samples, which generates thermal image given the surface temperature of the samples. The results indicate the desired effects of adding this nano-clay on the thermal diffusivity capacity of soil (α), which prevents thermal heat flux in the soil.*

Keywords: Clay, Nano-Clay, Bentonite Nano-Clay, Soil Thermal Diffusivity Capacity, Thermal Image

INTRODUCTION

The estimation of soil thermal properties in many sciences, including engineering and technology science and sustainable development in the energy and agricultural science sector is very important. Soil thermal properties include thermal capacity (C) and thermal conductivity (K) and thermal diffusivity capacity of soil (α). The thermal diffusivity capacity of the soil is obtained by dividing K by C, indicating the soil ability to transfer the heat from one point to another point. As peripheral soil is combinition of solid, liquid and gas phases and the thermal capacity of these components is significantly different, so any change in the volume ratio of the components of the soil leads to change in value (α). Moisture changes can be considered as the source of the most important changes in (α) (Bachmann et al., 2001; Lipiec et al., 2007). Adding some of the additives to the soil is considered as one of the effective methods to improve some soil behavioral characteristics such as resistance, permeability, optimal moisture content, and plasticity property, and swelling potential. Common additives such as cement, lime, calcium chloride, bitumen, polymer compounds, etc. have been studied in other studies (Bastiaens et al., 2006). Sima and Harsulescu studied the effect of different percentages (0% to 20%) of 7 bentonite models on the permeability coefficient of 5 soil models. The results of this study show that the use of bentonite reduced the permeability coefficient and the transformation of these soils from permeable to relatively permeable to impermeable soils (Sima, Harsulescu, 1979).

The results of the research conducted by Santucci (1998), which evaluated the effect of the percentage of bentonite (0.5%, 1.3%, 2.5% and 5%) on silica sand, showed that adding up to 5% of bentonite powder increased plasticity index and decreased permeability coefficient by 14 to 32% (Santucci de Magistris, 1998). Results of the research conducted by Cho and et al (2002) on the effect of various percentages of calcium bentonite (0%, 5%, 10%, 15% and 20%) on the permeability of weathered granite soil show that with adding bentonite to soil, permeability coefficient decreases due to hydration and its swelling in the empty spaces of the soil (Cho et al., 2002). In a study conducted by Ameta & Wayal in 2008, the effect of different percentages of sodium bentonite on the permeability of wind sands has been investigated. The results show a decrease in permeability with increasing bentonite content (Ameta and A. S. Wayal, 2008). Mishar et al evaluated the effect of the physical and chemical properties of bentonite, including the psychological limit, free expansion, and the percentage of exchangeable sodium ion on the soil consolidation parameters (CV, CC, t50). They concluded that with increasing the psychological limit, free expansion and exchangeable bentonite ion content, density index (CC) and time of 50% consolidation (t50) increase and CV coefficient decreases (Mishar et al., 2010). Other researchers examined the effects of bentonite on parameters such as consolidation coefficient and permeability coefficient in fine-grained wind sands. The results of this research have shown that bentonite reduces the amount of consolidation coefficient and the permeability coefficient of the mixture (Egloffstein, 2001). Gududa et al examined the effects of bentonite on the compaction characteristics and shear strength parameters of soil-bentonite mixtures. The results of the study have shown that the use of bentonite reduces the maximum dry density and the internal friction angle of the mixture and increases the optimum moisture content and cohesion (Gueddouda et al., 2008). The results of the research conducted by Baghbanian et al on the effect of adding bentonite on the characteristics of fine-grained soil showed that adding bentonite increased the plasticity index and it reduced the permeability coefficient and maximum dry density (Baghbanian et al., 2003). De Vries et al (1975) showed that several methods have been proposed to estimate the thermal diffusivity capacity of soils so far.

In some of these methods, thermal conductivity and thermal capacity were firstly estimated separately and, as the result of their division gives the thermal diffusivity of soil (De Vries, 1975). Asrar et al (1983) reported that in homogeneous soils, to estimate the thermal diffusivity potential of soil, it was necessary to solve the one-dimensional equation of heat diffusivity in soil (Asrar, Kanemasu, 1983). Allen et al (2010) reported that the distribution of heat at the surface of the soil relative to the lower layers and an increase in temperature in soil masses was a function of time, which results in the formation of a temperature gradient (temperature variations from the uniform distribution over time (Allen et al., 2010).

Materials used, device, and experiment method

Materials used

The soil materials used in this research are clay materials of kaolinite and bentonite nano-clay. The soil sample was tested according to ASTM D421, D422 and graded and hydrometric tests. To determine the soil properties, according to the ASTM D4318 standard, the Atterberg limits (psychological limit,

LL) and PI (PI), as well as experimental samples to be tested under the same conditions, it is necessary to test them on their optimum moisture content. Therefore, the samples are subjected to a density test according to ASTM D698 standard. The optimum moisture content and density of the maximum specimens are shown in Fig. 2 and (Das, 2008), as well as the gradient diagram in Fig. 1 as well as their physical properties are presented in Table 1 and 2:
Thus, the samples underwent density testing according to the ASTM D698 standard. The optimum moisture content of density of maximum special dry weight of the samples is shown in Figure 2 and (Das, 2008). In addition, the grading diagram is shown in Figure 1 and their physical properties are presented in Table 1 and 2.

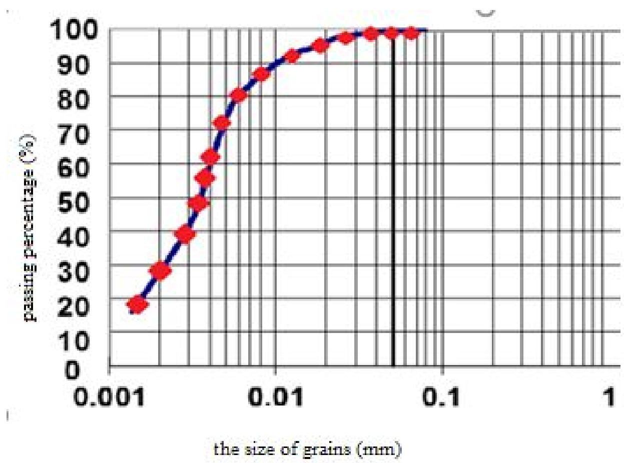


Figure 1: soil grading curve

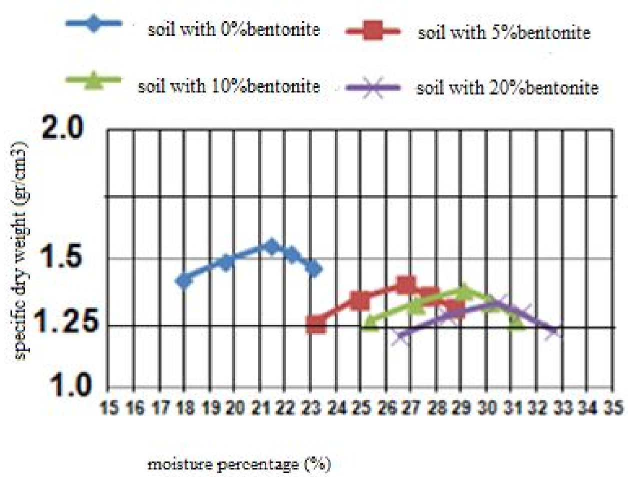


Figure 2: density test results

Table 1: Physical properties of materials

Soil type	Kaolinite
classification	CL
Plasticity limit (%)	33
Psychological limit (%)	47
Plasticity index (%)	14
Maximum specific dry weight (gr/cm3)	1.57

Optimal moisture content(%)	21.6

Bentonite nano-clay used in this research is unmodified montmorillonite nano-clay, manufactured by Pishgaman-e Fannavari Asia Company.

Table 2: Physical and Chemical Properties of Bentonite Nano-clay

1.8.(gr/cm3)	Density	1*25*1000 nm	Dimensions of layers
Less than 3%	Moisture content	95-98 %	Montmorillonite content
Less than 25 nm	Crystal Film Thickness	1.2 nm	Plates spacing
0.45.(gr/cm3)	Apparent density	Light milky	Color

device and method

In order to prepare the samples, Kaolinite clay was 5, 10, and 20% by weight of bentonite nano-clay. Mixing should continue until it reaches a homogeneous sample, and this requires about 45 minutes. For this purpose, a low-speed electric stirrer was used to remove the additives in the form of dust and manual stirrer was also used. Then, distilled water was added to the optimum moisture content to the samples and stored in a sealed container for 24 hours. The reason for it is that absorbing the moisture of clay particles is a time-consuming process. The samples are completely enclosed in plastic bags after being made so that they are not exposed to the exchange of moisture with surrounding environment. Mixture reached to considered density in ten layers in a box with the same number of beats, according to the hammer designed especially for the box. The chamber provided for the soil sample was made of rectangular plexiglass with dimensions of 60 × 60 × 30 cm, which all parts of it, except the upper and lower surfaces of the soil, were covered with an insulating layer with thickness of 1 cm. This was conducted with the aim of obtaining a one-dimensional flow direction (from soil surface to depths and vice versa), which is one of the fundamental assumptions required for the heat diffusivity equation in the soil). Since the process of substituting a cation instead of cation in bentonite nano-clay, which leads to the absorption of surface water and increasing the swelling ability and plasticity properties, and the process of bentonite nano-clay swelling is time-consuming process, the time of 0, 7, 14 and 28 days after construction of samples was selected for testing and thermal imaging. In order to minimize the evaporation and change in the soil texture, the upper layers of the samples were covered with a layer of plastic removed during the operation of the imaging for each plastic sample.

As distribution of heat at the surface of the soil relative to the underlying layers and the rise in temperature in the soil masses is a function of time, this leads to the formation of a temperature gradient (temperature variations from one place to another place) which variations in temperature from one place to another place is distributed uniformly, so that the test samples are exposed to a heat source for 24 hours with a temperature setting capability, so that the heat source is embedded below the sample (Allen et al., 2010).

As shown in Figure 3-9, on the other side of the samples and above the sample, the thermal imaging camera or the thermal measuring camera or infra-red camera, has been inserted which produces images by the infrared ray measurement (Horton et al., 1993).

Given the issues mentioned and considering the temperature of the laboratory environment, which is about 21 to 25 ° C (within the temperature range of the natural lands), the temperature of the thermal source has been set at 55 ° C, which is outside the temperature range of the natural land. Therefore, it is easily detectable by thermal sensors (Horton et al., 1993; Allen et al., 2010).

Experiments performed

As thermal camera used in this study has the capability to record the temperature of all points on the surface of the samples according to their location, adding bentonite nano-clay to kaolinite clay by 5, 10 and 20 weight percent and preparation of the samples for the experiment, the temperature of three considered points of the samples surface were recorded and the mean temperature of these points were considered for comparing the results obtained from the experiments. The results of these experiments are presented in the next section. Figures 3 to 6 present these results.

Results of experiment in clay by adding different percentages of bentonite nano-clay

- Results of experiment for samples in optimal conditions and without adding bentonite nano-clay are as follows:

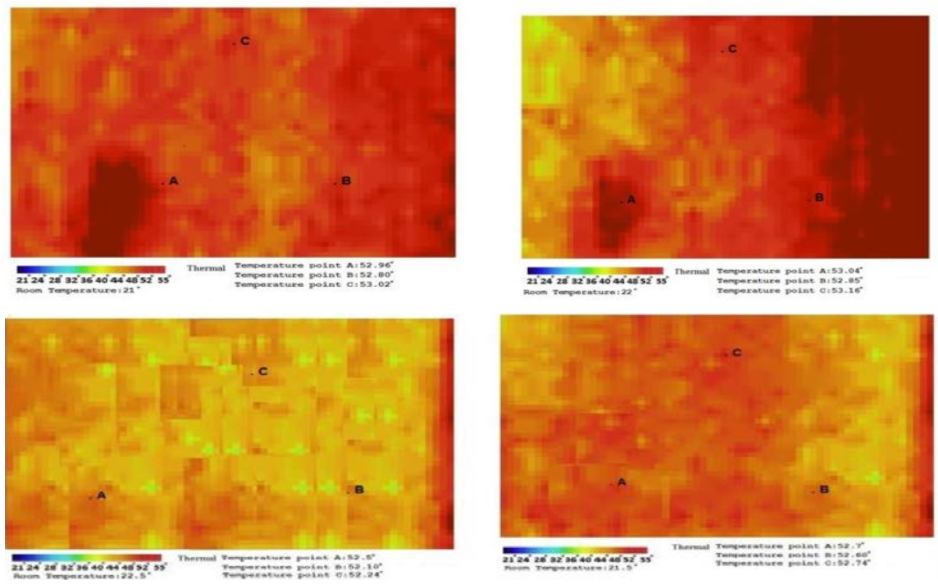
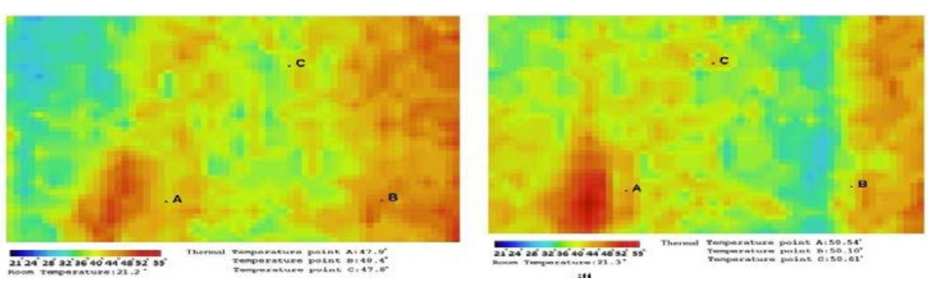


Figure 3. Thermal image related to kaolinite clay without additive (A) first day, (B) seventh day, (C) fourteenth day, (D) twenty-eight days

- the following figures represent the results obtained from experiment on samples in optimum moisture conditions and adding 5% bentonite nano-clay



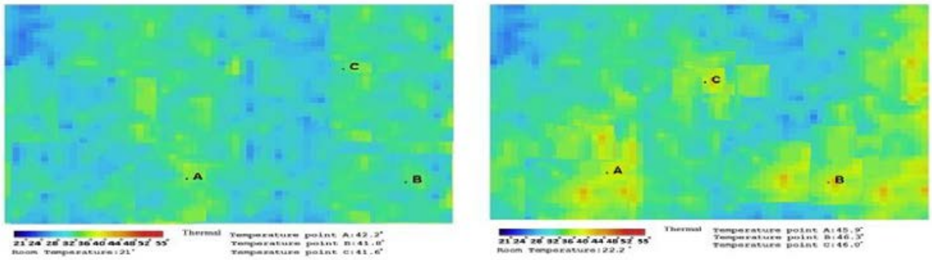


Figure 4: thermal image related to kaolinite with 5% additive (A) first day, (B) seventh day, (C) fourteenth day, (D) twenty-eight day

- results of experiment for samples under optimum moisture conditions and with adding 10% bentonite nano-clay are as follows

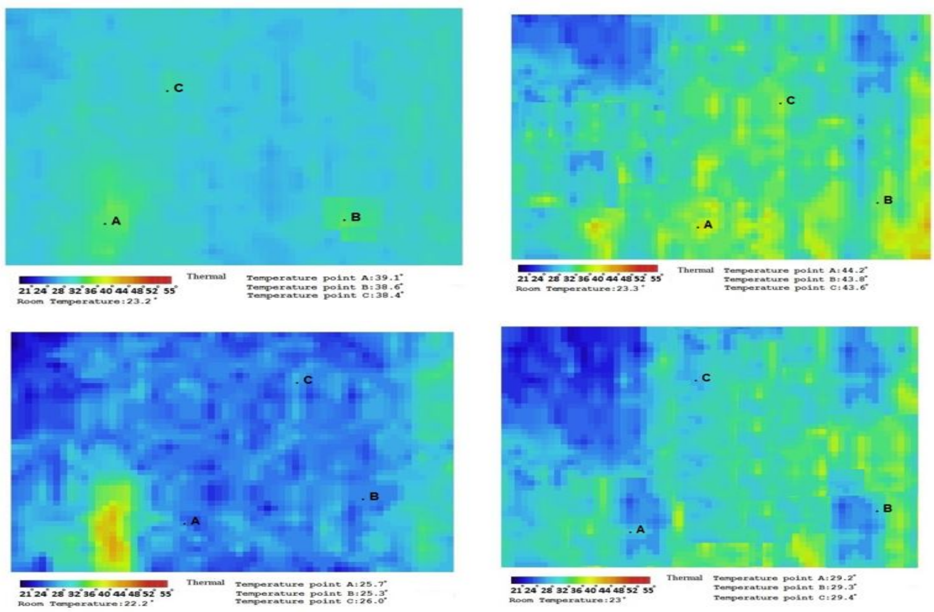
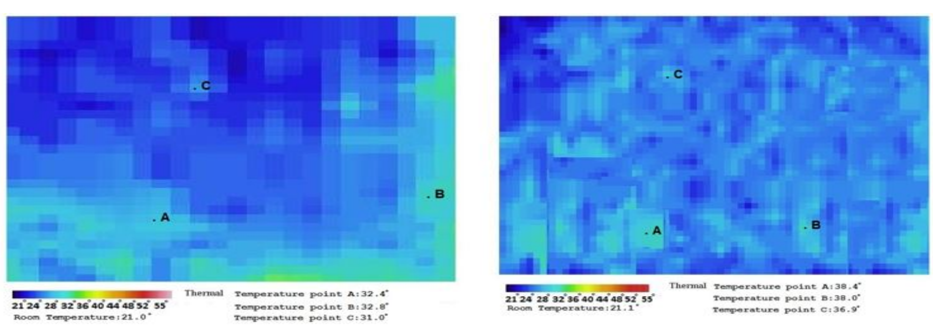


Figure 5: thermal image related to kaolinite with 10% additive (A) first, (B) seventh (C), fourteenth, (D) twenty-eight days

- results of experiment for samples in optimum moisture conditions and adding 20% bentonite nano-clay are as follows



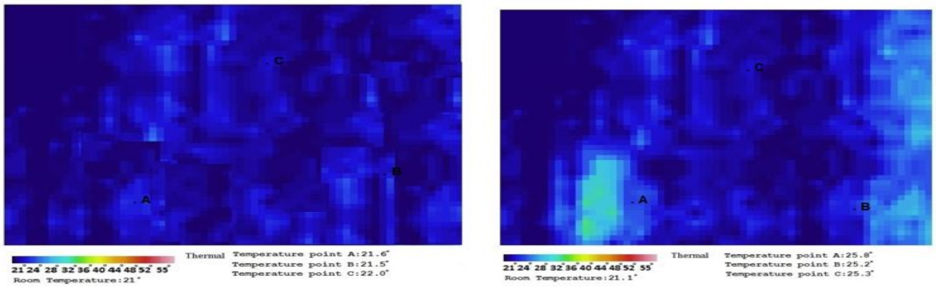


Figure 6: The thermal image of kaolinite clay with 20% additive (a) first one, (b) seventh day (c) fourteenth day, (d) twenty-eighth day

Comparison of the results of experiments in clay with different percentages of additive separately for experiment times

Comparison of the results of the experiment in tested clay for samples in optimum moisture conditions and adding different percentages of bentonite nano-clay in the first, seventh, and fourteenth and twenty-eighth days are as follows.

- Comparison of mean recorded temperatures at the surface of samples

In Figure 7, the comparison of the mean temperatures recorded at the surface of the samples with different percentages of bentonite nano-clay on days 1, 7, 14, and 28 is shown.

As shown in Figure 7, adding 5 and 10 and 20% bentonite nano-clay to kaolinite clay reduced the level of temperatures recorded at the sample surface compared to state without bentonite nano-clay.

Table 3: mean temperatures recorded at the sample surface with different percentages of bentonite nano-clay at different times

bentonite percentage / time (day)	Mean temperature of points A, B, C (° C)			
	1	7	14	28
0	53/1	52/9	52/7	52/6
5	50/4	48/0	46/1	41/9
10	43/8	38/7	29/4	25/7
20	38/1	32/4	25/4	21/7

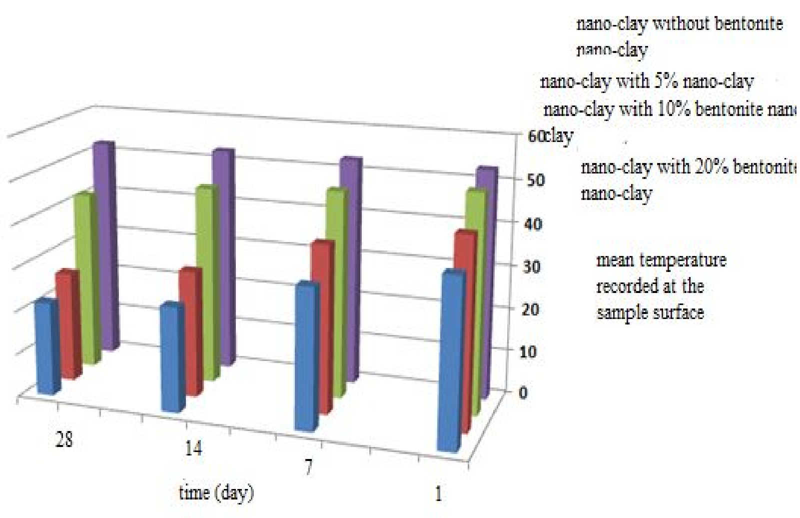


Figure 7: Comparison of mean temperatures recorded at the surface of samples with different percentages of bentonite nano-clay on days 1 to 7, 14 and 28

Analysis of results

Soil thermal properties include thermal capacity (C) and thermal conductivity (K) and thermal diffusivity capability (α). The thermal diffusivity capability of soil, obtained by dividing K by C, is the most important heat property of soil, which indicates the ability of soil to transfer heat from one point to another point. Therefore, adding bentonite nano-clay to clay increases the absorption of surface water and the plasticity properties of clay given the inherent nature of bentonite nano-clay and as type of the clay is montmorillonite.

Increasing surface water absorption also increases the thermal capacity of the soil, since by increasing the soil moisture, water is gradually replaced by air, and as the thermal capacity of the water is significantly higher than the thermal capacity of the air, so due to adding moisture to the soil, the soil heat capacity (C) also increases significantly, which this relationship is a nonlinear relationship.

In addition, adding bentonite nano-clay to clay an increase in swelling capability of the soil masses, which this increase in swelling in the soil masses causes blocked the pores in the soil particles, which is an important and influential factor in the process of heat transfer from soil masses. Given the above points, a suitable combination of clay and bentonite nano-clay is a type of thermal insulation, which prevents thermal heat flux in the soil or causes a sharp drop in the thermal flux in the soil, so that the possibility of energy loss in many cases is removed or minimized.

Conclusion

The results of the experiments indicate that the ability of heat transfer in kaolinite clay is reduced by adding bentonite nano-clay. Bentonite generally improves the performance of kaolinite clay in terms of resistance to heat transfer. The results of the experiment are as follows:

1. By adding bentonite nano-clay to kaolinite clay, the optimum moisture content of density increases and specific dry weight decreases
2. By adding bentonite nano-clay, the resistance of clay to heat transfer increases. Thermal diffusivity of soil, which is obtained by dividing K by C, is the most important thermal property of the soil, indicating the ability of the soil to transfer heat from one point to another point. Therefore, adding bentonite nano-clay to clay increases the absorption of surface water and the plasticity properties of clay given the inherent nature of bentonite nano-clay and as type of the clay is montmorillonite.
3. Based on the results obtained, samples in which nanotube bentonite was not used in experiments, the highest and closest temperatures to heat source were recorded in them.
4. The greatest effect of bentonite nano-clay on the increase of surface water absorption also increases the thermal capacity of the soil since by increasing the soil moisture, water is gradually replaced by air and as thermal capacity of the water is significantly higher than the thermal capacity of the air, soil heat capacity (C) also increases significantly due to increased moisture content.
5. According to the results, the addition of 20% bentonite nano-clay to kaolinite clay and spending 28-day time causes a drop of approximately 60% in temperature recorded by the thermal sensors at the surface of the samples, the ratio of the temperature of the heat source, which this drop is significant.
6. In the non-additive samples, no significant change has occurred in the recorded thermal images; this means that increasing the amount of bentonite nano-clay contributes significantly

to the resistance of the clay to the heat.

7. According to the results obtained from the experiments and the points mentioned in section 14-2, the process of substituting a cation with cation in bentonite nano-clay, which leads to the absorption of surface water and increased ability of swelling and plasticity properties, and the process of swelling is time consuming, as much time is spent on the construction of the samples, the temperature recorded at the surface of the samples would decrease and the obtained thermal images showed this issue. This means that time is an important factor in this process.

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