

Study Of Factors Affecting The Thermal Conductivity Of Iraqi Bentonite

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Abstract:

Thermal conductivity of compacted bentonite is one of the most important properties where this type of clay is proposed for use as a buffer material. In this study, Lee's disc method was used to measure the thermal conductivity of compacted bentonite specimens. The experimental results have been analyzed to observe the three major factors affecting the thermal conductivity of bentonite buffer material. While the clay density reaches to a target value, the measurement is taken to evaluate the thermal conductivity. By repeating this procedure, a relationship between clay dry density and thermal conductivity has been established in specimens after adjusting the water contents of the bentonite by placing its specimens in a drying oven for different periods. So relationships of thermal conductivity with each of these major factors (clay density, water content, and sand volume fraction) are established in this study. The relevance of these relationships be analyzed together using experimental data on many compacted bentonites.

Key words: bentonite, Montmorillonite, Thermal conductivity, Lee's disc.

Introduction:

Montmorillonite is a member of smectite group clay minerals. Bentonite has a high content of montmorillonite and fewer amounts of other clay minerals. Recently, many different industrial branches such as ceramics, polishing, paper, rubber, clarification of water, wine, soaps and drug industry are using these materials. Also, bentonite is often considered as a possible buffer material for high level radioactive waste disposal, where buffer materials are used as engineered barriers in high nuclear waste depository systems. Bentonite group minerals show a colloidal structure in water due to their internal structure and small particle size [1]. Measured data obtained from studies of Villar [2] on Febex bentonite, Ould-Lahoucine et al.[3] on Kunigel bentonite, Madsen [4] on MX80 bentonite. These measurements show that the thermal

conductivity of compacted bentonite depends on the dry density, water content, and mineralogical composition.

According to Farouki [5], heat conduction is mainly influenced by the composition, structure, density, porosity, grain and pore size as well as binding effect. Many researches reveal that there are three major factors (dry density, water content, volume fraction) that affect the thermal conductivity of bentonite and sand-bentonite specimens. In this study, the analysis of these factors confirmed the observation of Ochsner et al [6] on various soils.

Materials and Methods:

Local Ca-bentonite used in study was obtained from the western region of Iraq which basic clay mineral is calcium montmorillonite (CaM). Ca-

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bentonite produces a mud of high plasticity and is therefore used as a binder in porcelain production [7]. Prior to compaction, the provided bentonite was firstly sieved at 2mm, mixing was carried out through ball milling for 3h to verify the homogeneity. The green specimens were weighted every 2 hrs until no further weight change occurred and then prepared by using one of conventional shape-forming method such as semi-dry pressing method with different water content 0, 3, 6, 9, 12%. Several bentonite specimens designated under different compacted pressure range from 150, 200, 250, 300, 350 kg/cm² till the dry density of the bentonite reached the target values (1.1-1.5 gm/cm³) which agree with ASTM C 133-77 [8]. These specimens had a disc shaped 20mm diameter and 10mm thick for test the thermal conductivity. Thermal conductivity was measured with Lee's disc method which is based on thermal flow into the analyzed specimens, where the simple set up of Lee's disc apparatus is thermometers T_1 and T_2 , steam generator, disk shaped poor conductor (Bentonite), vernier calipers, when these apparatus is in steady state (T_1 and T_2 are constant), the rate of heat conduction into the brass disc must be equal to the rate of heat loss due to cooling (by air convection) from the bottom of the brass disc. The steady state rate of heat transfer (H) by conduction is given by:

$$H = KA (T_2 - T_1) / X$$

Where k is the thermal conductivity of the sample, A is the cross sectional area, $(T_2 - T_1)$ is the temperature difference across the sample thickness and by assuming the heat losses between both sides of the sample are (x) . Then thermal conductivity is measured. With repeating the process, the relationship between thermal

conductivity and clay dry density can be established.

To obtain the bentonite with water content less than nature water content, the bentonite specimen is put into an oven with constant temperature at 100 °C. The change of water content over time is shown in figure 1. After this relationship is established, the bentonite specimen with different water content can be also prepared with putting it in the oven within corresponding time interval.

The sand we used obtained from crushed granite from Ramadi. From the viewpoint of micromechanics, the bentonite-sand mixture can be regarded as a kind of composite materials. Bentonite can be treated as a matrix and the sand can be treated as an additive. Since bentonite/sand proportion (sand volume fraction) is one of the three major factors affecting the thermal conductivity. So this factor was investigated by establishing a relationship between it and thermal conductivity of bentonite-sand products following the same previous sequences which mentioned above with same specimens dimension, dry density and water content values.

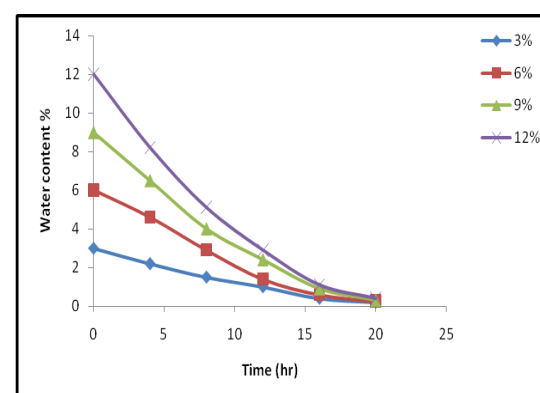


Fig.1: The change of water content of bentonite over time in an oven(at 100 °c).

Results and Discussion:

The measured heat conductivities of the oven dry bentonite samples with various water contents shows as expected the lower values (lie between 0.2 and 0.78 W/Mk). These values show the influence of the water content on the heat capacity of the bentonite. The anisotropy is very weak. The thermal conductivity (k) was proportional to the dry density: the higher the dry density the higher the thermal conductivity. On the other hand, the effect of water content was evident: at the same dry density, the higher the water content the higher the thermal conductivity. Figure 2 and figure 3 confirm the behavior of thermal conductivity with each of different dry density and different water content. From these both figures, thermal conductivity not only rise with water content, but also rises with dry density, these behaviors comply with the prediction curve of the modified DeVries and Campbell model for Black Hill Bentonite [6]. Also from figure 2, the beginning rise of thermal conductivity occurs at the water content range of 9%- 12%. This confirmed that water content not only contributes it high thermal conductivity to the bulk thermal conductivity, but also interacts with particles in clay to form a water bridge for smaller contact thermal resistance. In fact, figure 3 show that the thermal conductivity-dry density plot of water content 12% was in a higher position than that of 0,3,6,9%. Thus, it is clear that the thermal conductivity increased with dry density or water content increase.

From the viewpoint of micromechanics, the bentonite-sand mixture can be regarded as a kind of composite materials. Bentonite can be treated as a matrix and the sand as a inclusion. As the thermal conductivity of the sand (7.7W/mk) is much higher

than that of other minerals, the proportion of sand will affect the thermal conductivity. This effect was discussed by Farouki [5] and taken account in the model of johansen[9]. So with higher water content in bentonite, the difference of thermal conductivity between bentonite and sand become smaller, therefore, the increasing of volumetric fraction of sand is not that effective [6]. Therefore the difference in the mineralogical compositions of these bentonite specimens studied in this study to explain the difference in the thermal conductivity. Figure 4 (a-e) show the thermal conductivity behavior of bentonite with different volume fractions of sand 0, 6, 12.5, 20.5, 30.4 % at specified clay dry density and water content. These values of sand volume fraction obtained from transforming the weight fraction of sand into volume fraction for different bentonite dry densities. So relationship between thermal conductivity and volume fraction of bentonite-sand mixture for different water content (0, 3, 6, 9, 12 %) was established. As expected from this figure the thermal conductivity of bentonite increases with increasing volume fraction of sand especially at lower values of volume fraction (< 20%), but tends to be insensitive to volume fraction greater than 20%. For all volume fractions, the sand-bentonite specimens show significant water content dependence and this agree with other researches which mentioned above.

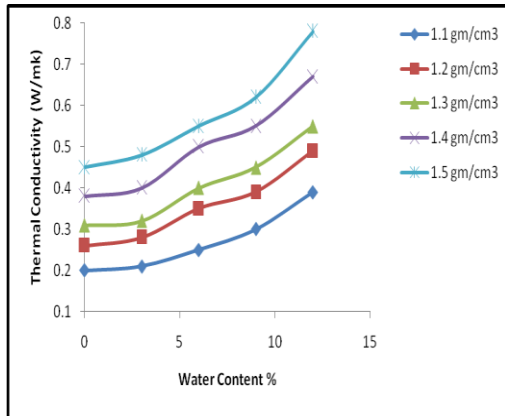


Fig.2: Thermal conductivity-water content relationship for different dry density of bentonite.

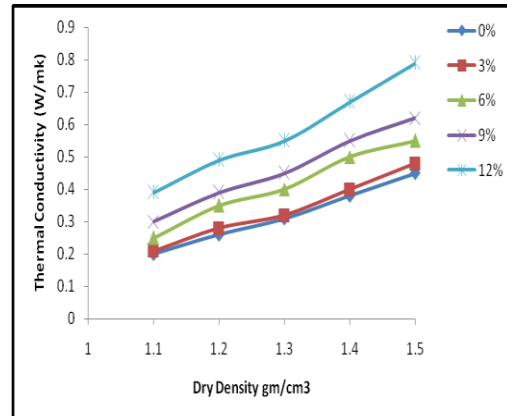


Fig.3: Thermal conductivity-dry density relationship of bentonite for different water content.

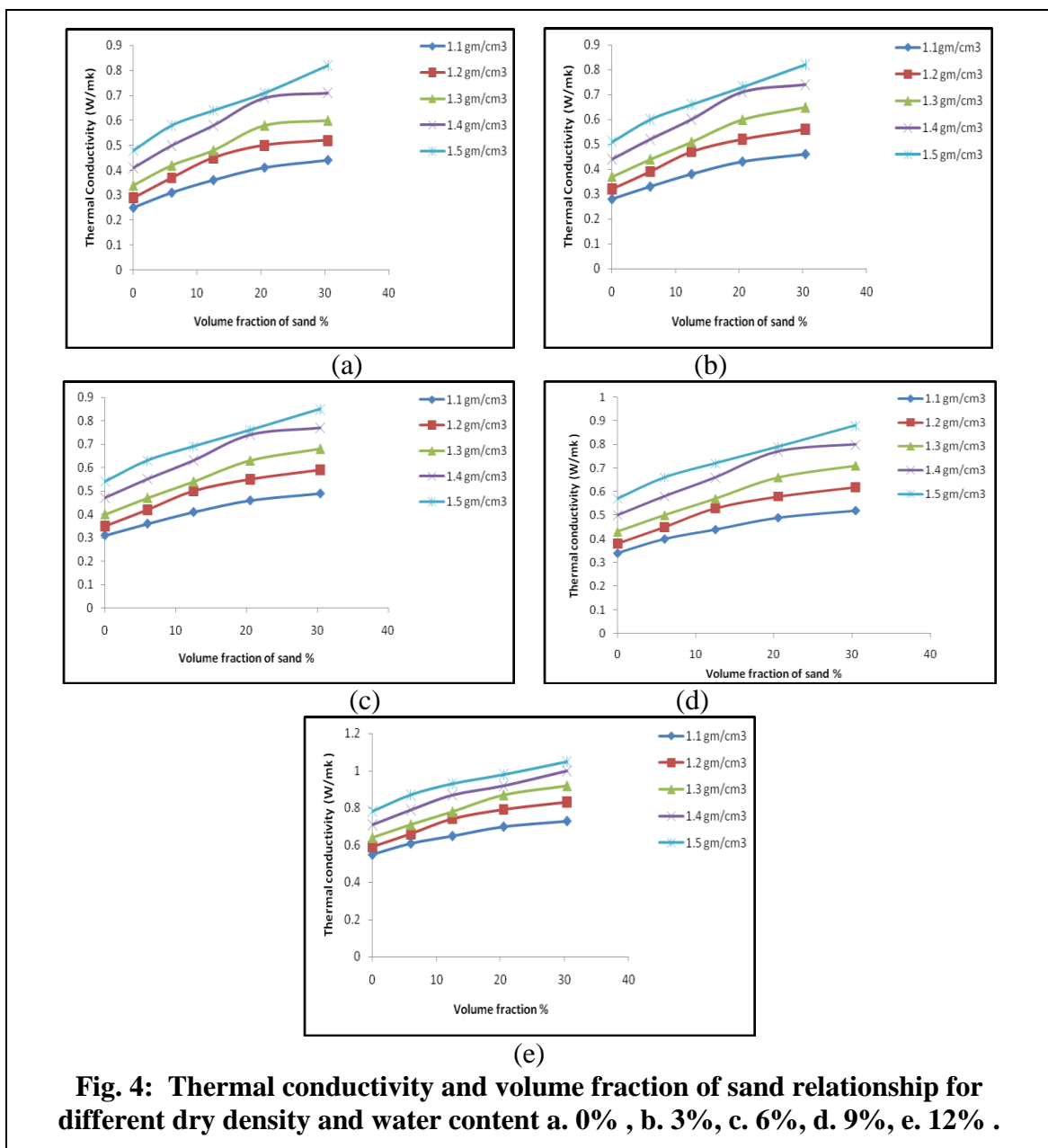


Fig. 4: Thermal conductivity and volume fraction of sand relationship for different dry density and water content a. 0% , b. 3%, c. 6%, d. 9%, e. 12% .

Conclusion:

1. The results show that the thermal conductivity of compacted bentonite with different density, water content and volume fraction of sand increase with increasing these three major factors. So these three major factors dry density, water content and volume fraction which are in general easily measurable, have been often used in order to improve and investigate the thermal conductivity of any powdery material and soil.
2. The results confirm that three major factors water content, dry density, volume fraction of sand have a significant effect on the thermal conductivity of bentonite. So this type of clay have a wide range of industrial and infrastructure applications, mainly due to the very peculiar properties of its clay minerals such as high cationic exchange capacity, thixotropy, swelling and plasticity.
3. The heat transport is a result of different mechanisms, in minerals themselves by a phonon mechanism and factors of influence are part from the composition in the clay sample besides the clay dry density as well as the water content during the measurement.

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دراسة العوامل المؤثرة على الموصلية الحرارية لآطيان البنتونايت العراقية

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الخلاصة:

تمت دراسة مدى تأثير الموصلية الحرارية لاطيان البنتونايت والتي تستخدم كمادة عازلة للماء والسوائل الاخرى فضلا عن استخاماتها في تيطين جداول السقي وفي الصناعات وبالاخص الطبية بأهم ثلاث عوامل رئيسية هي الكثافة الجافة لمضغوطة البنتونايت , المحتوى المائي فضلا عن النسبة الحجمية لمزيج بنتونايت – رمل والذي غالبا مايتواجدان معا في التربة . وبنسب مختلفة من موقع الى آخر، حيث تم في هذا البحث قياس الموصلية الحرارية لهذه الاطيان بأستخدام طريقة قرص ليزر. ووفق تحليلنا للنتائج المستحصلة من خلال أيجاد علاقة للموصلية الحرارية مع كل عامل من هذه العوامل الثلاث كل على حدة , حيث أظهرت هذه العلاقات مدى تأثير الموصلية الحرارية لهذا النوع من الاطيان بتلك العوامل الثلاث حيث تزداد قيمة الموصلية للطين بزيادة تلك العوامل الثلاث والتي أكدت عليها الكثير من البحوث والدراسات المنشورة في الدوريات العالمية، مما يمكننا من تطبيق وتأسيس نفس تلك العلاقات على انواع اخرى من الاطيان التي تزخر بها تربة العراق لتكون قيد الدراسة ولتحسين خواصها الحرارية.