TAF

Journal of Advances in Technology and Engineering Research

JATER

2018, **4**(6): 236-240

PRIMARY RESEARCH

# Evaluating thermal conductivity of desert sand under different initial physical properties

Hanin Atwany [1] *, Mousa Attom [2], Mohammad O. Hamdan [3], Bassam A. Abu-Nabah [4], Abdul Hai Alami [5]

[1, 2, 3, 4, 5] American University of Sharjah, Sharjah, United Arab Emirates

**Keywords**

Thermal
Conductivity
Physical properties

**Received:** 15 October 2018
**Accepted:** 19 November 2018
**Published:** 19 December 2018

**Abstract**

Analyzing the thermal conductivity of soil as a function of other parameters is necessary to understand the flow of heat around the earth-to-water heat exchanger. Thermal conductivity depends on several parameters, including soil composition, water content, compaction level, and porosity. The effect of the above parameters on thermal conductivity was investigated through laboratory studies. Samples were collected at a depth of 2 meters below ground level from an area located within the American University of Sharjah Campus. The thermal conductivity of the prepared specimens was measured using a C-Therm Technologies analyzer. The results indicate that increasing the water content and dry density increase the thermal conductivity of the soil. However, it was noticed that the initial water has a higher effect on thermal conductivity than the initial dry density. Additionally, it was found that porosity affects the hydraulic conductivity of the sand. The results of this study can be used to investigate the geothermal potential in the GCC region further.



## I. INTRODUCTION

The rapid increase in energy demand and the shift towards clean sources of energy drives the need to investigate alternative sources such as geothermal. Evaluating the geothermal potential requires detailed analysis of soil properties, design, installation procedure, site characterization, and operation of a geo-exchange projects [1, 2]. On the other hand, it was indicated that the heat flow at any depth in the subsoil is proportional to both the temperature gradient and to the soil thermal conductivity [3, 4]. The data available regarding the soil thermal properties for the United Arab Emirates is quite limited and further analysis is required to evaluate the geothermal potential. In general, sand particle size, water content, saturation level, soil compaction and temperature all influence the thermal conductivity of soil. Previous studies concluded that soil thermal conductivity is significantly affected by water content of the soil [5, 6]. Researchers have developed several models to predict the thermal conductivity of the soil that defines the soil ability to conduct heat. However, those models suffer from limitations and are usually valid within a specified range of material properties. [7] experimentally studied the effect of both the porosity and degree of saturation on thermal conductivity of soil using a unidirectional heat flow steady state method and compared lab results to those obtained using models. They concluded that none of the predictive models were valid for all values of porosity and degree of saturation. Nevertheless, the reliability of those models was higher at two-phase state were conduction was dominant. They used experimental results to develop an empirical equation for calculating thermal conductivity based on water content and porosity [7]. [8] examined available thermal conductivity models and categorized them into three groups based on the principles and assumption deployed for each. The three categories included mixing models, empirical models and mathematical mod-

*Corresponding author: Hanin Atwany
†email: mattom@aus.edu

els. They found that the effect of pore structure and interface properties were missing in all the models and they have proposed a conceptual model to overcome this limitation [8]. [9, 10] evaluated thermal characteristics of soils for a range of soil types and saturation levels. They proposed a method for calculating thermal conductivity based on the concept of normalized thermal conductivity that correlates thermal conductivity with thermos-physical parameters [9]. The above results clearly indicate the necessity of testing samples for thermal conductivity given the lack of reliable current models for predicting an accurate value for a wide range of thermos-physical properties. Therefore, in this paper the thermal conductivity was evaluated experimentally using C-Therm TCi thermal conductivity analyzer for all the samples.

There are several techniques for measuring the soil thermal conductivity as reported in literature. Steady state methods and transient methods were used to report measurements of soil thermal properties. A comparison between results obtained using probe and Guarded Hot Plate (GHP) tests was presented by [11]. He reported that the probe method would generally produce higher values for thermal conductivity in comparison to the GHP method. This difference between the two methods was less evident at high water content levels [11]. [12] made a comparison between two sensing techniques mainly Modified Transient Plane Source (MTPS) and Transient Line Source (TLS) to Evaluate the Thermal conductivity of five soil types. Results of both techniques agreed very well for dry thermal conductivity measurements of fine-grained soils but varied significantly otherwise. The difference was related to several mechanisms such as thermally induced water migration, senor-soil contact resistance and latent heat transfer [12]. For this work, laboratory studies were performed using Modified Transient Plane Source method to determine thermal conductivity.

In summary, this paper is focused on characterizing the soil samples obtained from an area within the UAE and studying the effect of key parameters including water content, density, and level of compaction on soil thermal conductivity. The obtained results may later be used later to develop a theoretical and practical model to predict the thermal conductivity of soil in the UAE or the GCC region in general as a function of the studied parameters.

## II. MATERIALS AND METHODS

For this study, twenty samples were prepared from desert soil that had been collected from a depth of 2 m below ground level and then analyzed. The samples belong to a site within the American University of Sharjah campus, located (25.3097° N, 55.4906° E). Excavation was carried out by removing the surface soil layer to facilitate collecting a sample representative of the proposed operational depth.

The collected samples were then subjected to standard proctor density and sieve analysis tests to investigate the optimum water content, maximum dry density and to characterize the particle size distribution of the soil. Figures 1 and 2 show the compaction curve and the grain size distribution used in this research. From figure 1 it was found that the optimum moisture content is 14% and the maximum dry density is 1.643 g/cm $^3$. However figure 2 indicates that the soil is sandy soil (fine sand) and according to the ASTM standard the soil can be classified as poorly graded sand (SP-type of soil).

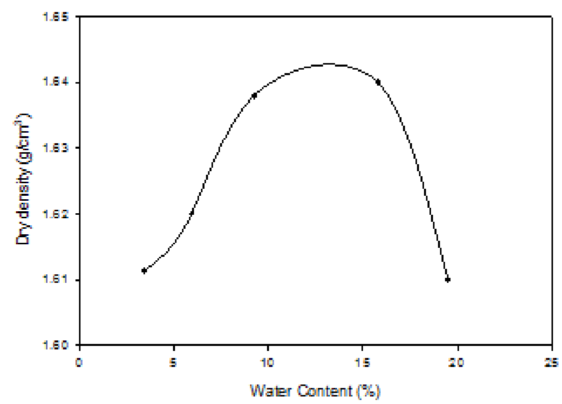


Fig. 1. Comapction curve for the used sand

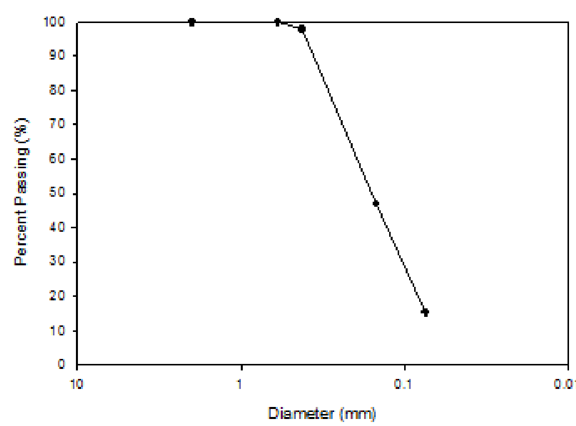


Fig. 2. The grain size distribution of the used sand

### A. *Sample Preparation*

Each of the twenty samples was prepared by casting in a cylindrical mold, 4.2 cm in diameter and 5.1 cm in height. With 84 g of as starting eight of dry sand, water was added to make the weight percentage of sand range from 3% to 12%. The water is added to the dry weight of the sand at 3% increment. All samples were observed to retain the same

ISSN: 2414-4592
DOI: 10.20474/jater-4.6.4

dimensions and thus it was clear that the only varying parameter was water content. The samples are then taken to conduct the thermal conductivity (explained in the following section), after which each of was physically compacted to produce five samples with different initial dry densities ranging from 1.4 to 1.7 g/cm$^3$. The thermal conductivity was then determined for all the compacted samples too.

### B. *Thermal Conductivity Test Procedure*

Thermal properties dictate the rate of heat transfer through a material, and thus are of major significance in any thermo-active structure. Soil mainly consists of water, air and solid soil particles, the composite heat transfer properties of each of them collect to makeup the thermal conductivity of soil [13]. To study the thermal conductivity of soil, samples were prepared at different initial water content (different degree of saturation) and with different initial dry densities ranging from 1.4 to 1.7 g/cm$^3$. c-thermal analyzer was used to measure thermal conductivity utilizing Modified Transient Plane Source (MTPS) method [14, 15, 16], which has proved to have many advantages in comparison to other methods such as guarded hot plate and, hot wire or hot probemethods [12]. The MTPS technique employs a one-sided, interfacial heat reflectance sensor that applies a momentary constant heat source to the sample after which the thermal conductivity is measured directly [14]. Thermal grease paste was applied as a contact agent on the surface of the sensor. The mold in the shape of a concentric cylinder was placed over the sensor plate. The rise in temperature between the sensor and the sample induces voltage change in the sensor element, which translates into thermo-physical properties of the sample.

## III. DISCUSSION OF THE RESULTS

### A. *The Effect of Water Content and Initial Density on the Thermal Conductivity of Sand*

Figure 3 shows the effect of the water content on the thermal conductivity of the sand at five different initial densities.

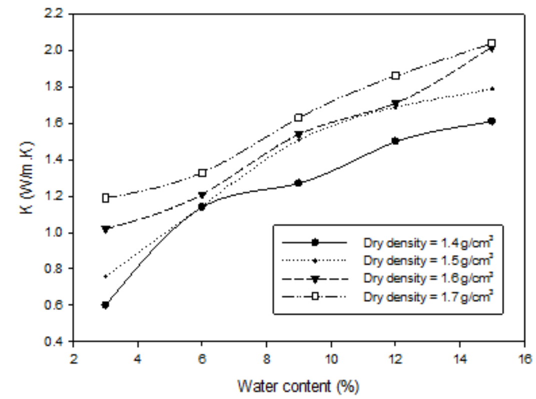


Fig. 3. The effect of water content on the thermal conductivity of sand

It is clear from the Figure 3 that the increase in the initial water content will increase the thermal conductivity of sand. It was noticed that at low compaction level the increase in water content would significantly increase the thermal conductivity of the sand. For example the thermal conductivity increase 63% when the water content increase from 3% to 15% at initial dry density 1.4 g/cm$^3$, while the increase is about 43% in the thermal conductivity for the same increase in the same level of water at initial dry density = 1.7 g/cm$^3$. Figure 4 the percent increase in thermal conductivity at different initial dry density. It is clear from this figure that water content that the water content has less effect as the initial dry density increase.

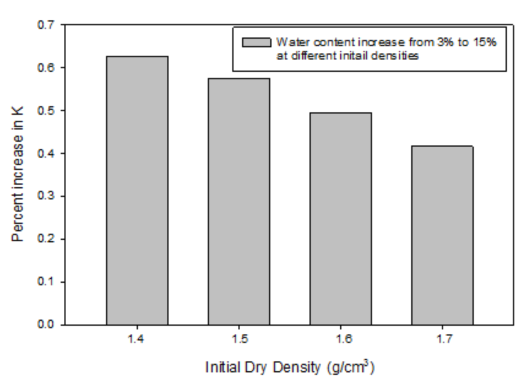


Fig. 4. The percent increase in thermal conductivity at different initial dry density

**ISSN:** 2414-4592
**DOI:** 10.20474/jater-4.6.4

Figure 5 depicts the percent increase in thermal conductivity due the increase in water content at different initial dry densities.

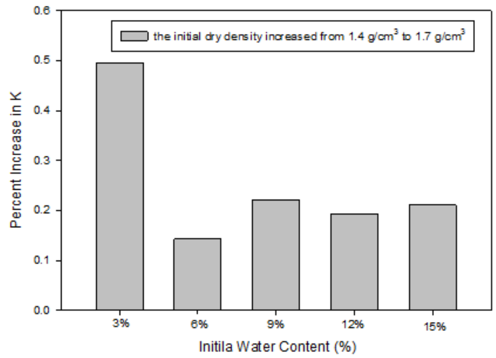


Fig. 5. The percent increase in K at different initial water content

It is clear that the increase in compaction is more effective at low initial water content than at high water content. The increase in K is equal to 49 percent at 3% water content when the initial dry density increased from 1.4 g/cm$^3$ to 1.7 g/cm$^3$. While the increase in K is about 20% at 15% water content when the initial dry density increase for the same level. It is also very clear from Figure 5 that the increase in initial dry density at high water content decrease has less effect the increase of thermal conductivity. Figure 4 and 5 conclude that the increase in water content has a higher effect that increase in compaction level especially at larger initial water content.

### *B. The Effect of Porosity on the Thermal Conductivity of the Sand*

Figure 6 illustrates the effect of porosity on the thermal conductivity of the sand at 5 different initial water content. The figure shows that the increase in porosity will decrease the thermal conductivity of sand. The reduction is consistent with all initial water content.

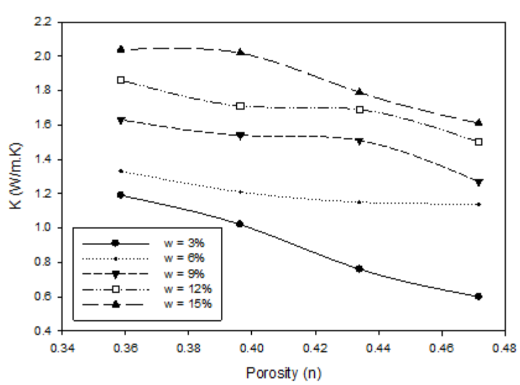


Fig. 6. The effect of porosity on the thermal conductivity of sand at different initial water content

The thermal conductivity decreased from 1.19 to 0.69 W/m.K when the porosity increased from 0.36 to 0.47.
This trend is noticed in all samples. This increase in thermal conductivity can be explained due to fact of increasing the voids in the soil since porosity is equal to volume of voids to the total volume. Increasing the void will reduce the heat transfer through the system and further reduce the thermal conductivity.

## IV. CONCLUSION

Based on the test results to evaluate the thermal conductivity of sandy soil under different physical initial conditions, the following conclusions may be drawn out:

1- The initial physical properties such as initial water content, initial dry density, and porosity have a significant effect on thermal conductivity of sand.

2- The increase in water content and dry density will increase the thermal conductivity while reverse effect was noticed when the porosity increased.

3- It was noticed that the increase in water content has more effect in increasing the thermal conductivity of sand than initial dry density. The thermal conductivity increased between 39% to 63% when the water content increase from 3% to 15% under different compaction levels.

## ACKNOWLEDGEMENT

The authors would like to acknowledge th American University of Sharjah for the providing support for this research. This work was financially supported by the Research Office at American University of Sharjah under research grant contract number EFRG18-SCR-CEN-35 through EFRG for Smart Cities Research 2018-2020.

**REFERENCES**


[1] M. Grobe, R. Richardson, K. Johnston, J. Quibell, H. Schillereff, and B. Tsang, ``Importance of geoscience information in the implementation of closed-loop, ground-source heatpump systems (geoexchange) in Alberta,'' *Energy Resources Conservation Board*, vol. 9, p. 49, 2009.

[2] M. Yucel and M. Halis, ``Iso 50001 based integrated energy management system and organization performance,'' *Journal of Advances in Technology and Engineering Research*, vol. 2, no. 2, pp. 52-58, 2016. doi: https://doi.org/10.20474/jater-2.2.5

[3] S. Shiozawa and G. Campbell, ``Soil thermal conductivity,'' *Remote Sensing Reviews*, vol. 5, no. 1, pp. 301-310, 1990. doi: https://doi.org/10.1080/02757259009532137

[4] M. Attom, M. Kou, and N. Al-Akhras, ``Geo environmental utilization of iron-filing with cement in soil stabilization,'' *International Journal of Technology and Engineering Studies*, vol. 2, no. 2, pp. 32-37, 2016. doi: https://doi.org/10.20469/ijtes.2.40001-2

[5] N. H. Abu-Hamdeh and R. C. Reeder, ``Soil thermal conductivity effects of density, moisture, salt concentration, and organic matter,'' *Soil Science Society of America Journal*, vol. 64, no. 4, pp. 1285-1290, 2000. doi: https://doi.org/10.2136/sssaj2000.6441285x

[6] G. Turkoglu Demirkol, M. S. Ozcoban, and N. Tufekci, ``Removal rate of compacted clay soil in the batch and continuous reactors and its permeability,'' *Journal of Advances in Technology and Engineering Research*, vol. 3, no. 5, pp. 176-183, 2017. doi: https://doi.org/10.5004/dwt.2017.21014

[7] A. Alrtimi, M. Rouainia, and S. Haigh, ``Thermal conductivity of a sandy soil,'' *Applied Thermal Engineering*, vol. 106, pp. 551-560, 2016. doi:

[8] Y. Dong, J. S. McCartney, and N. Lu, ``Critical review of thermal conductivity models for unsaturated soils,'' *Geotechnical and Geological Engineering*, vol. 33, no. 2, pp. 207-221, 2015. doi: https://doi.org/10.1007/s10706-015-9843-2

[9] T. Zhang, G. Cai, S. Liu, and A. J. Puppala, ``Investigation on thermal characteristics and prediction models of soils,'' *International Journal of Heat and Mass Transfer*, vol. 106, pp. 1074-1086, 2017. doi: https://doi.org/10.1016/j.ijheatmasstransfer.2016.10.084

[10] A. Hussien, ``Nanoheater underwater robotic welding for marine construction and manufacturing,'' *International Journal of Technology and Engineering Studies*, vol. 3, no. 5, pp. 184-196,, 2017. doi: https://doi.org/10.20469/ijtes.3.40002-5

[11] O. T. Farouki, ``Thermal properties of soils,'' 1981. [Online]. Available: https://urlzs.com/GkYqZ

[12] J. Yao and W. J. Likos, ``Transient plane and line source methods for soil thermal conductivity,'' *Geotechnical Testing Journal*, vol. 40, no. 5, pp. 858-870, 2017. doi: https://doi.org/10.1520/gtj20160333

[13] A. Mickley, ``The thermal conductivity of moist soil,'' *Transactions of the American Institute of Electrical Engineers*, vol. 70, no. 2, pp. 1789-1797, 1951. doi: https://doi.org/10.1109/t-aiee.1951.5060631

[14] S. E. Gustafsson, ``Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials,'' *Review of Scientific Instruments*, vol. 62, no. 3, pp. 797-804, 1991. doi: https://doi.org/10.1063/1.1142087

[15] N. Mathis, ``Comparison of destructive and non-destructive thermal conductivity results with filled epoxy,'' *Thermophysical Properties*, vol. 20, no. 6, p. 464–467, 1999.

[16] N. Mathis, ``Transient thermal conductivity measurements: Comparison of destructive and nondestructive techniques,'' *High Temperatures High Pressures*, vol. 32, no. 3, pp. 321-327, 2000. doi: https://doi.org/10.1068/htwu289


**ISSN:** 2414-4592
**DOI:** 10.20474/jater-4.6.4