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Evaluation of Jordanian Basalt as a Thermal Insulation Material

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ABSTRACT

Finding a thermal insulation material that is naturally available, cheap, and effective for minimising energy losses is a challenge for geotechnical engineers in Jordan. Previous research suggests the use of mineral wool, polyurethane, or air layers as an insulation material but so far, the basalt has not been used as an insulation material in Jordan. The objective of this study was to measure and compare the thermal conductivity (K), bulk density (ρ_B), porosity (ε) and chemical composition of the basalt from Hashemiah area and Hulial mountain in Jordan in order to evaluate the rock as a thermal insulation material. A total of fourteen samples, seven for each zone, were evaluated. The thermal conductivity was measured using transient plane source technique (TPS) at ambient temperature. Porosity and density were measured by the standards of the American Society of Testing Materials (ASTM). The chemical composition of the samples was analysed by X-Ray diffraction to include the effect of aluminium oxide on thermal conductivity analysis. Experimental values covered the range of ε between 0.008–8.7%; ρ_B between 2.54–2.93 g/cm^3 and K between 1.62–2.98 W/mK. The experimental K values were compared with allometric fit and theoretical prediction models. In general, thermal conductivity tends to decrease with porosity in basalt samples. This study found increasing conductivity values with ε when ferromagnesian-aluminium oxide concentration reached levels above 38% and porosity less than 4% indicating that high percentages of these oxides decrease the insulating effect of the air in the empty spaces of the basalt at reduced porosity levels. Low values of conductivity and percentage of ferromagnesian-aluminium oxides characterise the Jordanian basalt in the Hashemiah area and makes it better for insulation than the Hulial mountain basalt. The experimental values presented in this work are important for predicting the optimum insulation thickness and predicting energy losses in construction buildings where basaltic rocks are used.

Keywords: basalt, Hashemiah area and Hulial mountain Jordan, thermal conductivity, thermal insulation, thermophysical properties.

INTRODUCTION

Thermal properties of rocks have been an interesting topic of uncountable investigations. Due to the advantages, they can be found in different areas of bioclimatic and construction design, such as insulating materials used in stoves, incinerators, ovens, furnaces, composite wall of buildings, etc. Thermal insulation denotes the materials with low thermal conductivity that minimise heat loss and consequently produce considerable economic as well as energy savings. Rocks are considered solids with low thermal conductivity (K) (Canbolat et al., 2013) and this property depends on its atomic structure, water, air content and material porosity (Zhang and Wang 2017). Okonwok et al. (2019) also takes account that anisotropic factors affect thermal conductivity, and consider in greater detail other parameters, such as permeability, crystal size, microstructures, mineral geometry, and internal vesicles (Al Zyoud 2019).

Basalt is one of the most common types of igneous rocks in the world. According to origin, weathering and geological occurrence, the quality properties of basalt vary from place to place. Owing to its abundance in the Jordan kingdom, basalt has a low cost. Basalt is environmentally friendly, non-hazardous, which could serve for multiple industrial applications. This mineral is of dark colour and mineralogically constituted of the following compounds: plagioclase, feldspar, pyroxene and olivine (Sharadqah et al., 2020). Basalt is used as a material for railroad ballast and highway construction (AL-Akhaly 2018). Also, it is widely used in engineering materials, such as aggregates for Portland cement, asphaltic concrete and rock fills for dam and breakwaters.As it was previously mentioned, the coefficient of thermal conductivity or thermal conductivity (K) is one of the most important thermal properties used to evaluate the insulating or conductive performance of a material. This property represents the speed measure at which heat flows through a material (Useche et al., 2021; Popov et al., 2016), by means of heat transport conduction mechanism, where K can be calculated using the Fourier Equation.

$$q = Q/A = -K\, \Delta T/\Delta x \qquad (1)$$

where: q – heat flux (energy/time area), Q – heat flow (energy/time), A – perpendicular area to heat flow (length^2), Δt – temperature gradient, Δx – length gradient, K – thermal conductivity (energy/time length temperature).

The conduction mechanism exists in solids, liquids, and gases; it occurs when the heat flow is transferred between "adjacent" molecules. For this reason this mechanism is predominant in solids. In solids, the molecules are closer, forming more compact, fixed crystallographic structures. Also, the conduction mechanism acts on static fluids contained in a closed space (Cengel and Ghajar 2007; Welty et al., 2008). Materials with high thermal conductivity transfer the flow heat to high speed, and these are named "conductors". On the other hand, in materials with low conductivity, the heat transfer rate is lower than conductive materials, and they are named "insulators". Conductive materials exist in nature, such as metals, with K values between 10–400 W/mK; in contrast, insulating materials, such as polymers have K values between 0.1 to 0.5 W/mK, whereas glasses and ceramics from 1 to 200 W/mK (Segovia 2016), etc.

One of the most common methods of measuring thermal conductivity is the trasient plane source (TPS), also named Gustafson probe or Hot disk method. This method is preferred for its short and simultaneous measurements of the parameters: time, temperature, thermal conductivity (K) and thermal diffusivity (α). TPS method has been successfully used to measure these thermal properties in rocks and porous materials (Gruescu et al., 2007). The heat capacity (Cp) is another thermal property determined indirectly by this method, from the experimental values of K, α, and density (ρ), using the following equation:

$$Cp = K/(\rho\alpha) \qquad (2)$$

As regards the prediction of overall thermal conductivity, there are theoretical models and mixed laws, which are used to predict this thermal property in basalt rocks, comparing these results with the experimental values of overall thermal conductivity (K). The overall thermal conductivity predicted by these models is a function of the thermal conductivity of the solid basalt matrix (K_s), the fluid existing in the pores, in this case air (K_f), and porous fraction (ε) of the basaltic rock. Zeb et al. (2020) predicted the thermal conductivity of rocks using Wiener's upper (Eq. 3) and lower bounds models (Eq. 4), also named Parallel models and Series models, respectively.

$$K = \varepsilon K_f + (1\text{-}\varepsilon)\, K_s \text{ Parallel model} \qquad (3)$$

$$K = [(\varepsilon/K_f) + (1\text{-}\ \varepsilon)/K_s)]^{-1} \text{ Series model} \qquad (4)$$

Hashin and Shtrikman (1962) present more models for the prediction of thermal conductivity in a two-phase system, more accuracy than Wiener's model.

$$K = K_s + \{[3K_s\,(K_f\text{-}K_s)\,\varepsilon]/[3K_s + (K_f\text{-}K_s)\,(1\text{-}\varepsilon)]\} \text{ HS} \qquad (5)$$

$$K = K_f + \{[3K_f\,(K_s\text{-}K_f)\,(1\text{-}\varepsilon)]/[3K_f + (K_s\text{-}K_f)\,\varepsilon]\} \text{ HS} \qquad (6)$$

Other common model used is the geometric mean model (GMM) (Eq. 7), very similar to the Assad's model (Eq. 8), considering that the empirical parameter "C" of the Assad's model is one for solid samples with low porosity.

$$K = K_s\,(K_f/K_s)^{\varepsilon} \qquad (7)$$

$$K = K_s\,(K_f/K_s)^{C\varepsilon} \qquad (8)$$

The overall thermal resistance ($R_{overall}$), defined as the sum of the individual constituent resistances (R_i) of a composite structure, can be calculated by the expression:

$$R_{overall} = \Sigma\, R_i \qquad (9)$$

There is more than one way to calculate $R_{overall}$: by the Fourier equation for conduction mechanism (Eq. 10) or through the energy saving ratio for a system composed of multiple insulators (Eq. 11).

$$Q = Q/A = \Delta T/R_{overall} \qquad (10)$$

$$E_{loss} = R_{overall\ without\ insulation}/R_{overall\ with\ insulation} = Q_{with\ insulation}/Q_{without\ insulation} \qquad (11)$$

So, defining:

$$R = \Delta x/K \tag{12}$$

where: R – resistance, Δx – gradient of distance in x direction, K – thermal conductivity, E_{loss} – energy loss (100 – $\%E_{save}$); $R_{overall}$ without insulation – total resistance does not include the isolating material; $R_{overall}$ with insulation – total resistance included the isolating material.

Thus, from the resistances sum of the constituent materials of a composite structure (ΣR_i), and known $R_{overall}$, the individual resistance of the unknown insulator (R_i), can be determined. Then, with R_i and K values of the unknown insulator, using the expression $R = \Delta x/K$, is possible to calculate the optimal thickness of the insulator material of interest (Δx).The objective of this study was to measure and compare the thermal conductivity, bulk density, porosity, and chemical composition of basalt from the Hashemiah area and Hulial mountains of Jordan. Their suitability as thermal insulation material was assessed.

Study area

The locations are presented in Figure 1. The basalt of the Hashemiah area zone covers "around 30 km^2 north of the Zarqah city and are lithologically well differentiated and belong to primary magmatic structures. The Hulial mountain Jordanian basalt samples are in the zone of volcanic eruptions along the arcuate eastern edge of the Graben in Hulial mountain of Jordan.

MATERIALS AND METHODS

To carry out this study, 14 basalt samples were chosen at random, from the Hashemiah area and Hulial mountain areas of the country. From each selected zone, more than 120 kg fresh bulk samples have been collected, selecting, and analysing 7 samples for each zone.

Physical characterisation

The physical properties considered in this study are porosity and bulk density. These properties are related to the mineral composition and physical characteristics of the rock. The bulk density (ρ_{bulk}) is defined as the relationship between the mass (m) and the bulk volume (V_B) of the sample, that is, the total volume of the sample including its pores $\rho_{bulk} = m/V_B$ (Eq. 13). Porosity (ε), expressed as porous fraction, is defined as the proportion of void volume (Vp) divided by the bulk volume of the sample (V_B) $\varepsilon = Vp/V_B$ (Eq. 14). The porous fraction (ε) can also be calculated from the experimental values of the real density (ρ_{real}) and bulk density (ρ_{bulk}) using the equation $\varepsilon = 1 - (\rho_{bulk}/\rho_{real})$ (Eq. 15). These properties were analysed using the ASTM-D6473-15 standards method (ASTM 2015).

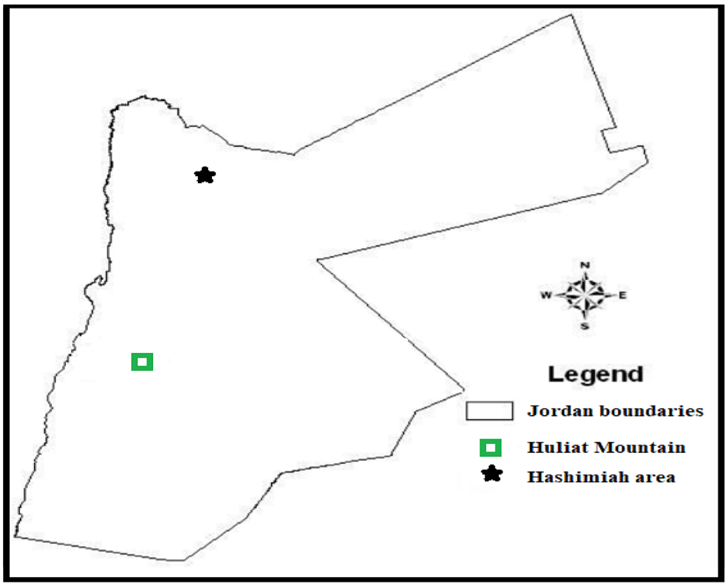

Fig. 1. Location map of the Jordan basaltic tuff

Chemical characterisation

The chemical composition was identified using X-ray fluorescence (XRF) available at the laboratory of Mining Engineering Department of at Al-Hussin Bin Talal University (Jordan), and the results are reported in Table 1.

Thermal characterisation

The thermal conductivity (*K*) was measured using the hot disk method, also called transient plain source (TPS) or Gustafson probe. The advantages of this method are: a) thermal conductivity measurements in a wide range, from 0.005 to 500 W/mK, b) short measurement times (10 s to 10 min), c) high accuracy, reaching maximum 5% standard deviation d) it is applicable for liquids, gels and solids, e) it uses measurement sensors of different sizes adaptable to the sample, f) it is a non-destructive test (Vitiello 2021). The principle consists of placing a sensor between two halves of the sample, sample halves that may be circular or square shape. The TPS sensor is a double nickel spiral supported by two thin sheets of an insulating material, which can be kapton, mica or Teflon, to protect electrical insulation. The preparation of the sample and development of the method continued using the standard method ISO22007-2E, 2008. Temperature and time data are recorded from the sensor, and thermal conductivity and diffusivity values can be measured using this equipment (Fig. 2).

DISCUSSION

The thermal conductivity, chemical composition, and some physical properties of basalt, are shown in Table 1, where the samples from 1 to 7 belong to Hashemiah area and 8 to 14 to Hulial mountain zone of Jordan. The high content of silicon oxide (SiO_2), between 42% to 47%, and values less than 5% of Na_2O+K_2O; confirm the presence of natural basalt, in accordance with studies of other authors (Tarawnah 2022). In general, the percentages of silicon oxide were higher for the Hashemiah area basaltic rocks, reporting an average around 46.5% compared with 43% SiO_2 for the samples from the Hulial mountain zone. Low silicon oxide content in the Hulial mountain basaltic rocks is compensated by a higher percentage Al_2O_3, Fe_2O_3 and MgO than Hashemiah area samples. These oxides have relatively higher thermal conductivity (K_{Al2O3} = 32 W/mK, K_{MgO} = 48 W/mK, K_{FeO} = 79.5 W/mK (https://web.mit.edu/8.13/8.13c/references-fall/aip/aip-handbook-section4g.pdf) than the air (K_{air} = 0.026 W/mK) inside the pores or even other mineral rocks, which constitute the basaltic rock sample.

The Hashemiah area samples presented thermal conductivity values (*K*) between 2.23 to 1.62 W/mK, and porosity levels (ε) from 3.22% to 8.7%. Hulial mountain rocks basaltic ranged *K* between 2.98 to 2.47 W/mK and ε between 0.008% to 1.676%. This denotes clearly lower porosity and higher thermal conductivity than the Hashemiah area samples. This difference in porosity (ε), and consequently different distribution of pores (tortuosity T) between basaltic rocks from the Hashemiah area and Hulial mountain, was expected considering ε and T depends on the type of basaltic material and degree of weathering.

In general, the experimental *K* values reveal a decreasing trend as ε increases. Figure 3a, represents ε vs. *K* results of the basalt rock samples,

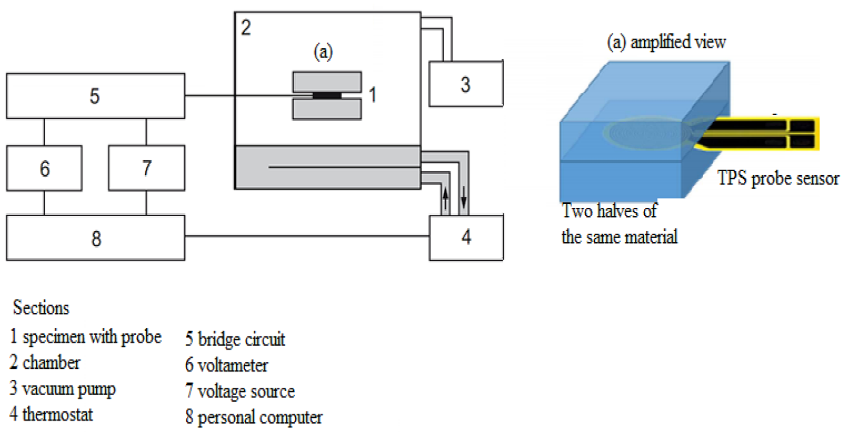

Fig. 2. Schema for Gustafson Probe (TPS). Modified from: ISO 22007-2E (2008), Vitiello, D., 2021.

Table 1. Chemical composition and thermo physical properties of basalt rocks

Zone	Sample	%Porosity	K	Density	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	$\sum Al_2O_3+Fe_2O_3+MgO$
North	1	3.220	2.236	2.710	46.19	0.780	14.78	13.54	0.23	7.54	9.86	2.29	0.98	35.86
	2	3.400	2.162	2.540	47.10	3.020	12.68	13.82	0.20	6.66	12.20	2.57	0.87	34.36
	3	2.550	2.190	2.640	46.18	1.930	14.97	13.97	0.21	8.09	10.80	3.08	0.86	38.04
	4	4.560	2.105	2.570	47.29	4.270	13.61	14.84	0.17	7.04	7.57	4.28	0.77	35.48
	5	5.250	2.054	2.920	46.69	4.430	14.10	11.76	0.19	8.14	8.20	4.31	1.78	35.00
	6	5.930	1.880	2.590	46.19	1.500	12.60	10.11	0.12	8.12	15.34	4.32	1.63	31.83
	7	8.770	1.620	2.580	43.63	3.730	13.41	12.12	0.22	7.77	7.42	4.85	1.33	33.30
South	8	0.008	2.980	2.702	44.65	3.650	14.01	10.40	0.15	11.01	12.10	2.33	1.08	35.42
	9	1.180	2.648	2.830	44.25	2.570	14.25	13.36	0.14	8.90	9.95	2.60	2.60	36.51
	10	1.240	2.471	2.664	47.54	4.090	10.76	13.84	0.11	9.54	10.53	2.41	0.98	33.65
	11	1.280	2.558	2.770	42.33	2.400	13.76	15.75	0.14	10.54	10.60	1.85	0.95	40.06
	12	1.480	2.553	2.851	42.80	2.700	14.07	14.76	0.16	9.21	11.54	2.16	0.90	37.94
	13	1.440	2.490	2.842	42.07	2.590	14.15	12.21	0.14	8.90	11.90	3.50	1.05	35.26
	14	1.670	2.772	2.923	45.19	1.200	15.97	13.98	0.12	8.12	12.01	2.02	1.13	38.07

Note: The composition is expressed in percentage, *K* – thermal conductivity at W/mK and density g/cm^3.

which demonstrates the inverse relationship between thermal conductivity and porosity, in accordance with the previous research carried out by Zeb et al., 2020; Usecha et al., 2021.

From the point of view of heat transport, the number of empty spaces in the rocks influences the thermal and electrical properties as result of the interaction of low thermal conductivity of air within the pores, which, being a good insulator (K_{air} = 0.026 W/mK), affects the overall conductivity of the mineral rock. The air molecules being together, static and immobile inside pores, in layers with very small thicknesses (order of millimeters or less), transfer heat by conduction, as it would be solid (Cengel and Ghajar 2007; Welty et al., 2008). This replaces the convective mechanism typical of a fluid in contact with a solid, by a conductive mechanism. Therefore, the high porosity values found in some basalt samples from the Hashemiah area mean a great presence of static air inside pores, which replaces high conductivity thermal of other minerals. Consequently, the overall thermal conductivity of the sample decreases.

The Table 1 also includes the results of the sum of ferromagnesian-aluminium oxides (∑oxid. vs. *K*) for the basalt rocks. From analysis of Table 1, highlight K values for samples 3 and 4 with almost the same porosity (ΔE~0.2%), but different content of ferromagnesian-Al oxides (Sample 3∑ox = 38.04% Sample 4∑ox = 35.48%). The thermal conductivity increases around 3.5% for sample 3 compared to sample 4, deducing from this study that content of metal oxides affects the overall conductive properties of the mineral (Fig. 3b). Al Zyout et al., 2019, only analyses the effect

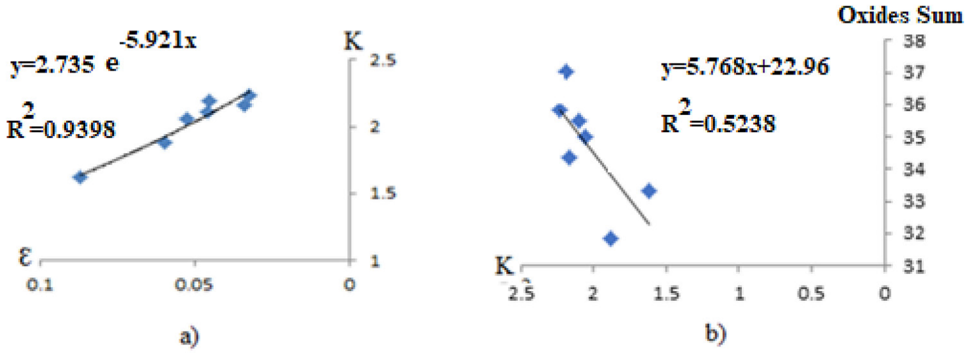

Fig. 3. Hashemiah area basalt rocks: a) change in the thermal conductivity with porosity fraction. b) relation of the sum of ferromagnesian-aluminium oxides with thermal conductivity

of ferromagnesian oxides (Fe_2O_3 + MgO) on thermal conductivity and did not take account the Al_2O_3, probably because they consider that aluminium oxide, being a good corrosion insulator, reduces the thermal conductivity of the mineral.

However, the contribution of this study is to include the aluminium oxide (Al_2O_3) along with ferromagnesian oxides, because, surprisingly, it was found that overall thermal conductivity measurements of basalt increased with the aluminium oxide content. This led authors to think that the presence Al_2O_3 together with the mixture of ferromagnesian oxides contained in the basalt, carry out to form a new mineral structure with better conductive properties, slowing down the insulating property characteristic of pure aluminium oxide. It is known that thermal conductivity of metal oxides (K_{Al2O3} = 32 W/mK, K_{MgO} = 48 W/mK, K_{FeO} = 79.5 W/mK)) is different from the pure metal from which they originated (K_{Al} = 205 W/mK, K_{Mg} = 156 W/mK K_{Fe} = 80 W/mK) (Perry and Green 2008). However, the new crystallographic structure with new properties, generated by the mixture of oxides together with the other minerals of the basalt rock; It affects the overall thermal conductivity of the basalt, influenced some way by the high conductivity of the pure metal from which the oxide is originated.

Comparing the experimental values of sample pairs 2–3, 10–11, 10–14; nontypical increases of conductivity are observed with increasing porosity (contrary to the general trend initially monitored ε (1/α) K. Maximum increases in gradients ΔK were found around 10%, Δε ≈ 25% and the sum of Ferromagnesia-Al oxides Δ∑ox. Fe-Mg-Al ≈ 16%. Figure 4a showed an unusual direct relationship between ε and K values associated with high content of Fe-Mg-Al oxides present in the basalt rock, reaching highs of 40% at total Fe-Mg-Al oxides content (Table 1). This led authors to think that high percentages of Fe-Mg-Al oxides slow down the insulating effect of air in the pores of basalt. The pairs of samples 2–3, 10–11, 10–14 analysed also presented porosity levels less than 4%, indicating that slowdown is more evident at low levels of porosity.

Figure 4b presents the experimental results of $\%SiO_2$ vs K. The randomly oriented experimental values of SiO_2 and K show that, in general, there is no dependence between the SiO_2 content and the thermal conductivity, in accordance with other previous studies (Al-Zioud 2019). The results of bulk density and porosity showed no dependence in the monitored values between ρ_{bulk} and the porosity values of the study samples, in accordance with research from other authors (Tarawnah 2022; Zeb et al., 2020). The presence of high content of compounds with high molecular weight (titanium oxides, Fe, Al, and others), could lead to thinking about an increase in density, but inaccurate volume values due to the open pores of the rock, and other factors, such as the possible existence of connected pores inside the basalt, lead to randomly oriented values showing no clear correlation between bulk density and porosity.

The experimental results of K are compared with empirical models in Figure 5. The results of the empirical models show that experimental measurements are within the allowed theoretical and empirical limits. The functionality of these empirical models has already been tested in the works previously presented by Zeb et al. (2020), for basaltic rocks in Pakistan and other research (Fuchs et al., 2003). A regression analysis was

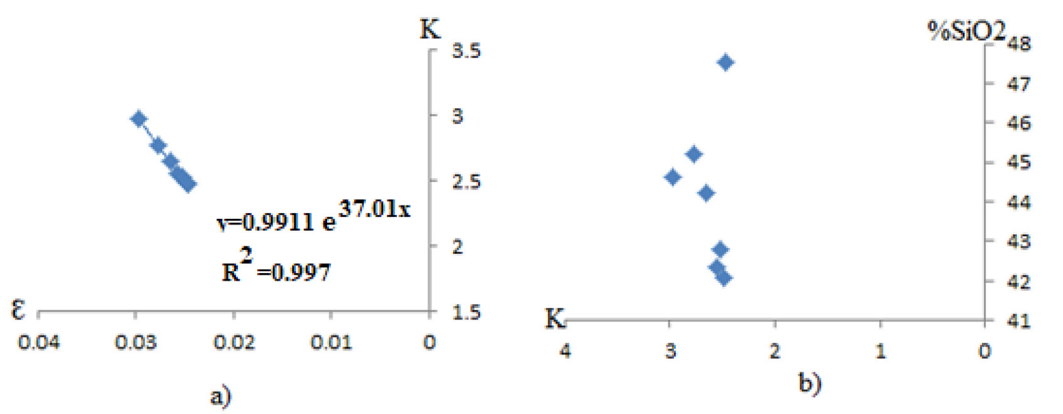

Fig. 4. Hulial mountain basalt rocks: a) atypical performance of thermal conductivity versus porosity for some samples of Hulial mountain zone, b) change in thermal conductivity with the silica contents

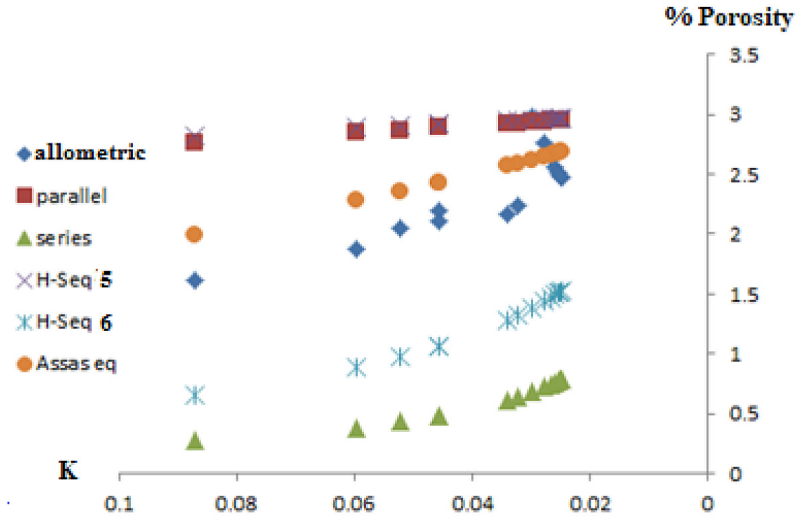

Fig. 5. Values of thermal conductivity experimental vs porosity (ε) for basalt rocks from Hashemiah area and Hulial mountain, adjusted by allometric model compared with values of predicted models

used to obtain an allometric fitting equation using the experimental values of thermal conductivity (*K*), porosity ε, thermal conductivity of the basalt solid matrix (Ks) and thermal conductivity of air (Ka). The best allometric fit corresponded to the exponential model as given by $K = 2.7359\ e^{-5.921\varepsilon}$ (Eq. 13) from Figure 3a, where the constant 2.7359 represents the value of the thermal conductivity of the basalt when the porosity is equal to 1. The same type of allometric adjustment, but with different parameters, it is in accordance with that applied by Zeb et al., 2010; for estimating the thermal conductivity of minerals and rocks.

The experimental values of *K* were compared with the parallel, HS (Eq. 5) and Assa's model (Eq. 8), obtaining minimum and maximum deviation percentages between -20% to 12% (Table 2); whis is remarkably different compared with previous the investigations presented by Zeb et al., (2020), where the percentage of deviation ranged between 0.40% to 33%.

However, due to the crystallographic structure, porosity and thermal behaviour of mixture basaltic, the best models should be obtained experimentally within the porosity range of study interest. The low thermal conductivity values monitored for the basaltic rocks of the Hashemiah zone reveal that would be better thermal insulation material than basalt of the Hulial mountain. If basaltic rocks would exist with the chemical composition similar to the Hashemiah area basalt rocks (low ferromagnesium-Al oxides content), but with highest porosity (considering the insulating effect of air in the pores), this basalt would have better insulating properties. It is known that at same Hashemiah area, there is volcanic material with high porosity, also called volcanic scoria, that in principle would have the same composition as the basalt of this area (Okonkwo et al., 2019). Geotechnical analysis sources of the volcanic scoria from this place reveal that there are samples of scoria that could achieve porosity up 80% (Sharadqah et al., 2020). Deducing from

Table 2. Thermal conductivity: comparison of the experimental values with some theoretical models

Samples	K experimental	K parallel	%dev	KHS-eq.5	%dev	K Assas's	%dev
8	2.980	2.934	1.52	2.956	0.79	2.624	11.93
9	2.648	2.944	-11.21	2.964	-11.93	2.667	-0.72
10	2.471	2.949	-19.38	2.968	-20.11	2.888	-8.81
11	2.558	2.946	-15.19	2.965	-15.93	2.674	-4.56
12	2.522	2.948	-16.87	2.967	-17.60	2.682	-8.32
13	2.490	2.949	-18.44	2.968	-19.18	2.686	-7.88
14	2.770	2.941	-6.17	2.961	-6.90	2.650	4.30

the analysis of this study, scoria could become the objective of future research in the field of potential natural thermal insulators.

Actually, there are no experimental values of thermal conductivity and its relationship with other thermophysical properties for scoria from the Hashemiah area of the Jordan Kingdom. However, from the analysis of this study, a prediction of scoria thermal conductivity could be made using the allometric adjustment (*K* vs ε), Eq. 13 from Figure 3a, obtained for the basalt of the Hashemiah area, considering that both basalt and its scoria have a very similar chemical composition (Taha & Mohammad, 2013). Thus, a good estimate of the thermal conductivity of scoria would probably be obtained. Another way to predict a K_{scoria} value would be through the application of the most precise empirical models, which present low percentage of deviation respect to the experimental allotropic model, such as Assads's and Maxwell's models (Aurangzeb and Maqsood 2007).

Under this premise, for the scoria from the Hashemiah area with average porosity 80%, using the exponential allometric adjustment, Eq. 13 from Figure 3a, and Assad's and Mean model (Eq. 7 and Eq. 8), K values around 0.024 W/mK and 0.067 W/mK, for each model respectively, were obtained. The optimal thickness of the scoria insulation was calculated, using the equations 11 and 12. An insulating layer of scoria that is located inside a wall composed of brick and gypsum was taken as design to achieve an energy saving of 80%. Using the calculated values K_{scoria} allometric = 0.024 W/mK; K_{scoria} Assad's model = 0.067 W/mK and data of K_{brick} = 0.7 W/mK and gypsum K_{gypsum} = 0.48 W/mK; the optimal thickness were calculated. The results of thickness for scoria were 2.1 cm and 6.01 cm, for the allometric and Assad's model, respectively. From the results, it is observed that the optimal thicknesses of the scoria, although different, they are, applicable and manageable, for either of two thermal conductivity prediction models used (Assads, Mean or allometric). Additionally, other advantages are the energy savings resulting from thermal insulation, and the low price of "volcanic scoria" due to its natural abundance. Therefore, the basalt scoria from the Hashemiah area Jordan could become a potential competitor for the prefabricated and synthetic resin insulators currently used. An interesting line of research is opening up for the use of basalt, its scoria, in natural or slightly processed state, from the perspective of heat transport.

CONCLUSIONS

From the point of view of heat transfer, the way in which the thin and static layer of air inside the basaltic pores affect overall K, corroborates the predominant conductive effect over the convective mechanism, in static fluid films, treating them as if they were solid, obeying Fourier's law of conduction. In general, thermal conductivity tends to decrease with increasing porosity for basalt samples. The air content in the rock increases with the porosity, the insulating effect of which reduces the overall coefficient of thermal conductivity of the basalt rock. However, this study revealed that certain increases in *K* with porosity occurred when high contents of ferromagnesian-Al oxides were reached, upper 38% ∑ox. Fe-Mg-Al, and low levels of porosity, %ε lower than 4%. The contribution of aluminium oxides affected the overall *K* values, considering that the previous research did not take account the effect of this parameter on the overall conductivity of the basalt rock.

The basaltic rock of the Hashemiah area would have better performance as a thermal insulator, due to its lowest thermal conductivity and Fe-Mg-Al total oxides content. The *K* prediction models, and thickness calculation equations presented in this study, applied to samples with greater porosity and similar chemical composition to the Hashemiah area basalt, such as the volcanic scoria from this same area, revealed optimal results of thickness for this material. This leads the authors to conclude that Hashemiah area volcanic scoria would be a good alternative as a low-cost insulation material. The Hulial mountain basaltic rock, due to its low porosity, would be a potential acoustic insulation material. All these proposals and results presented may be subject to improvements and require further future research before their handling and application.

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