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Experimental Investigation on the Effect of Sawdust Particles Size on Its Thermal Conductivity

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ABSTRACT

The measurement of the thermal conductivity of the sawdust is one of the most difficult techniques due to its uniformed shape, by using this instrument, it gives the ability of measuring the thermal conductivity of the sawdust, without changing its physical properties, during the experiment, as well as, there are no necessity to use the additional materials in form of adhesive materials, that gives an identified shape of the specimen. In this study, wood sawdust is classified into three groups depending on the size of the wood pellets, namely; wo1≥1.18mm, 1.18>wo2>0.6mm and wo3≤0.6mm. To keep out the thermal properties of the sawdust as it is, no mechanical or chemical processes were carried out on sawdust specimens, such as compressing or bonding. The effect of moisture content on the thermal properties of sawdust is eliminated by drying the specimens, the procedure is carried out by heating it up to 100℃ for a 30 min. During this study, it can be seen that the thermal conductivity of all samples is inversely proportional to the working temperature. At a relatively low temperature less than 45℃, it can be said that the first model (wo1) has the lowest thermal conductivity while the differences in the thermal conductivity of the samples are insignificant when the temperature exceed 50℃, therefore; the first model (wo1) represents a good choice for flat plate solar collector insulation because it has the same activity as well as it is light and cheap.

1. INTRODUCTION

The thermal conductivity of any material refers to the thermal behavior of that material. The ability of any material to conduct or transfer heat from one side to another, is by measuring its thermal conductivity [1]. Thus, when the material has a low thermal conductivity, it is considered as a good insulator. This term is very famous in classifying the materials into thermal conductors and insulators.

The thermal conductivity of the material, is greatly affected by the arrangement of particles, crystals and impurities, as well as, the gaps between the fragments forming the body, therefore, the body that formed from the pure material, and have a homogeneous particles and crystals arrangements, is able to conduct heat better than a body with the same dimensions and is made from the same material used in the first object, but it has impurities or gas bubbles which increases its thermal resistance [2-4]. Grain size also affects thermal conductivity, because the space between big fragments is more than that in case of small particles, and that gaps may be filled with different impurities. Different methods are used to measure that coefficient. The basic idea of all methods is to supply the heat from one side and dissipate it from the other side. The same methodology is used to measure the thermal conductivity of the sawdust. The instruments that are used for that purpose were made by Engineering Technical College of Mosul which holds the Iraqi patent (5278).

The high costs of some insulating materials oblige the researchers to find new and cheaper insulators [5, 6].

Sawdust is a material that has low thermal conductivity [7, 8]. Many researchers have studied the physical properties of sawdust. The thermal conductivity of insulating materials is affected by many factors such as; temperature, density, diameter or shape, cell size, amount and type of additives and binders [9]. Studies conducted many experiments to estimate the sawdust packed bed thermal conductivity by measuring the sawdust bed temperature [10]. Other studies used transient plane source technique and the heat flow meter to measure the thermal conductivity of five species of hardwoods and softwoods types [11]. Furthermore, other studies formed discs of clay and sawdust mixture with different sawdust ratio and measured its thermal conductivity, by using Lees' disc apparatus. It concludes that mixing the sawdust with clay reduced the sawdust conductivity, when the tested sample was dry [12]. Studies shows that mixing recycled polyethylene terephthalate with different percentage of sawdust gave a low thermal conductivity [13]. On the other hand, the effect of three different kinds of sawdust with different particles size on the properties of composites reinforced materials using Ritz apparatus [14]. Studies on Lees' Conductivity apparatus, to evaluate the conductivity of some biomass materials, modeled the sawdust into a thin disc and determined its thermal conductivity at different particle size and temperature. The results showed that sawdust can be used as alternative to the existing industrial insulators due to its good insulation capability [15, 16]. The conductivities of three different particle sizes namely; 300 µm, 600 µm and 850 µm of some wood materials from the forest in Nigeria were investigated [17], it is found that any type of disc shape wood with 600 µm particle size, has low thermal conductivity with a range of 0.045 – 0.067 W/m. K. As a result, they considered these types of wood as good insulators compared with industrial solar collector's insulators, also can be used as a lagging of cooler, incubator, refrigerator, food flask, etc.

After measuring and comparing between bulky and small particle sizes of three different wood types, it is established that the thermal conductivity of sawdust was lower than that of uniform solid wood [18].

2. METHODS OF RESEARCH

In this study, thermal conductivity of dry sawdust is measured using the apparatus that is made by the Engineering Technical College of Mosul which holds the Iraqi patent (5278) [19]. The effect of different particle sizes on the sawdust thermal conductivity is studied. After calculating the thermal conductivity of the sawdust, the results were compared with that of the PV solar panel insulators as well as that used in heat pumps [16], for the possibility of using sawdust as insulation for PV panels and heat pumps. To achieve those goals, it is necessary to use specific instrument, that it is able to measure the thermal conductivity of semi-solid materials like sawdust, sand, and powder. The sawdust samples were prepared using sieves of three different sizes, (wo1) group, refers to the sample in which the particle size is equal or greater than 1.18 mm., while the particle size in group (wo2) is between 0.6 to 1.18mm and group (wo3) is the sample in which the grains size was equal or less than 0.6 mm. To eliminate the effect of water content by the sawdust, the sawdust was dried by using an electrical heater. Each sample was dried for 30 minutes with continuous stirring under drying temperature of 100°C. The density was calculated by dividing the specimen mass to the volume of the specimen, while the specimen volume was selected to fit the apparatus requirements.

The apparatus in the laboratories of the Engineering Technical College of Mosul offers that ability [19]. Technical descriptions and facilities of the appliance are shown in the following part of this paper.

2.1 Apparatus

The apparatus that is used for measuring the thermal conductivity of solid materials and fluidized bed is shown in Figure 1. This instrument was manufactured in the Engineering Technical College of Mosul [19]. It consists of two main parts. The first one is a heat source, which is subdivided into two parts; heat generator and heat transition lines. The heat generator consists of a stainless steel tank that holds 1.7 litters, electrical heater 650W, a passive heat pump, that is used to transfer energy from the lower to the upper portion of the reservoir, by thermal siphon. Two copper tubes with different diameters are provided to carry out working material (water) from the heat source (electrical heater) to the lower reservoir positioned below the specimen. It is clear that different diameter of copper tubes means the difference in side surface area of each tube [8, 20], so that; the water inside the bigger diameter tube is relatively colder than that is inside the smaller tube, this connection lines forces the water to move up through the narrow tube and fall through the other one due to the difference in densities of water inside each tube. This mechanism leads to carry heat to the upper portion or, to the second main component which called the core of the apparatus. The apparatus core consists of two parts; the lower which is an aluminum tank with an outer diameter of 100 mm, representing the continuity of the heat handling loop, and the heat sink which is the upper part of the core of the apparatus, which consists of a simple water vessel made of aluminum. The water vessel was insulated from all sides except the lower surface which is in contact with the testing specimens. The aim of the expansion pipe that shown in Figure 1 is to accommodate the expansion of water when its temperature increased. The testing specimen is inserted in the middle space between the upper and lower parts of the apparatus core. The entire core was insulated by asbestos and surrounded by Teflon shell to reduce the thermal losses.

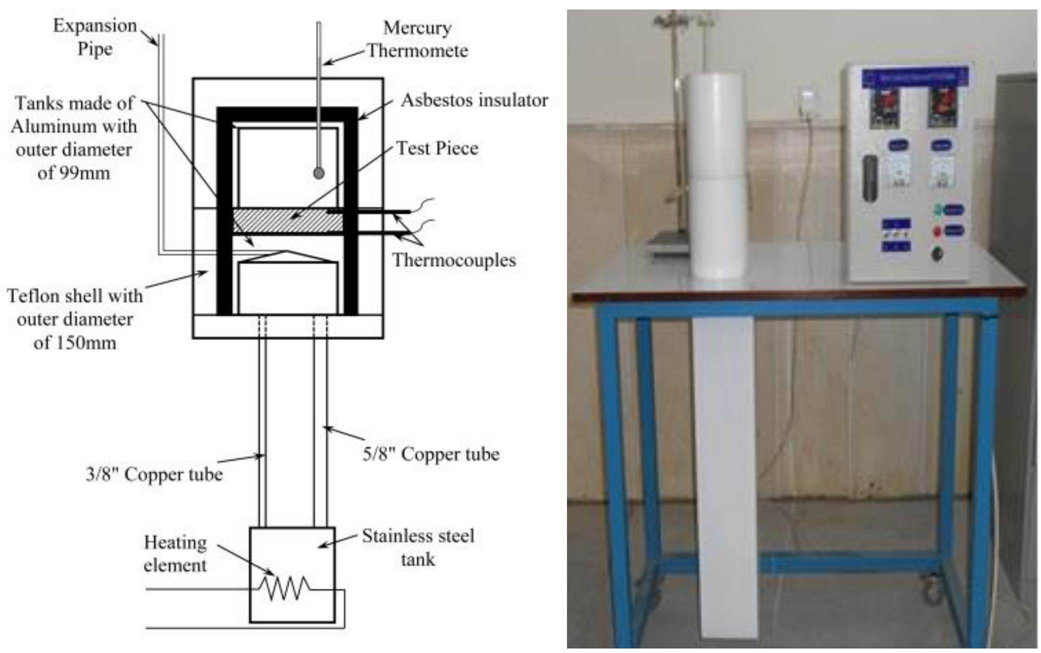

Figure 1. Thermal conductivity measurement apparatus

Mercury thermometer is used to measure the water temperature inside the upper tank. The calibrated K-type thermocouples [19] are used to measure the temperature across the specimen. The accuracy of each one is ±0.1°C. The water temperature is controlled by an adjustable thermostat.

3. THEORY AND FORMULA

The heat transferred through the test piece (Q) to the heat sink is calculated using the following equation:

$$Q = \frac{m}{\tau} c_p \, \Delta t_w \qquad (1)$$

where, m - the mass of the water inside the heat sink (kg), τ - the elapsed time to change the water temperature in the heat sink (s), c_p is the specific heat of water which is equal to (4.18 kJ/kg °C), and Δt_w is the change in water temperature during time τ (°C).

The specimen thermal conductivity can be calculated using the Fourier's as follows:

$$Q = -k\,A \frac{dt}{dx} \qquad (2)$$

where, Q - the heat flowing through the specimen (W), that obtained from the equation (1), k - the thermal conductivity of the specimen (W/m °C), A - the cross sectional area of the specimen normal to the direction of heat flow (m^2), dt – the temperature difference across the specimen (°C), dx – is the thickness of the specimen (m).

4. EXPERIMENTAL SETUP

The thermal conductivity test was carried out through temperature range of 30 to 65°C. The behavior of the thermal conductivity was observed by taking several readings for the mentioned temperature range. The behavior of specimen thermal conductivity can be used to determine whether the material can be used as thermal insulators or not. After specimen reaches the steady state at the selected temperature, the elapsed time was calculated using a stopwatch. the temperature difference across the specimen was taken, and the amount of heat flow was calculated by the sensible heat change in the water tank using the Eq. (1). Eq. (2) was used to calculate the specimen thermal conductivity.

5. RESULTS AND DISCUSSIONS

Figure 2 shows the effect of specimen temperature on the thermal conductivity, it can be seen from the figure that, as the specimen temperature increases its thermal conductivity decreases.

As shown in the Figure 2, the thermal conductivity behavior of the first specimen can be divided into three sections. The first stage covers the temperature range extended from 27 to 48°C. This section can be represented by the following formula:

warm 1:

$$k = -0.00008T^2 + 0.0033T + 0.0524 \qquad (3)$$

where, k – the thermal conductivity (W/m °C), T – the average temperature of the specimen (°C).

The second curve section coverings a limited temperature difference; namely from 48 to 50°C. in which the thermal conductivity directly proportional to the average temperature of the specimen. This increment of the thermal conductivity happens in this type of samples (wo1) is stronger than other samples, due to the effect of bigger air gaps between the particles with respect to other samples. This section can be represented by the following formula:

middle 1:

$$k = 0.0104T - 0.4662 \qquad (4)$$

Finally, the third section of the curve extends from 50 to 64°C and can be represented as follows:

hot 1:

$$k = -0.00006T^2 + 0.0046T - 0.0308 \qquad (5)$$

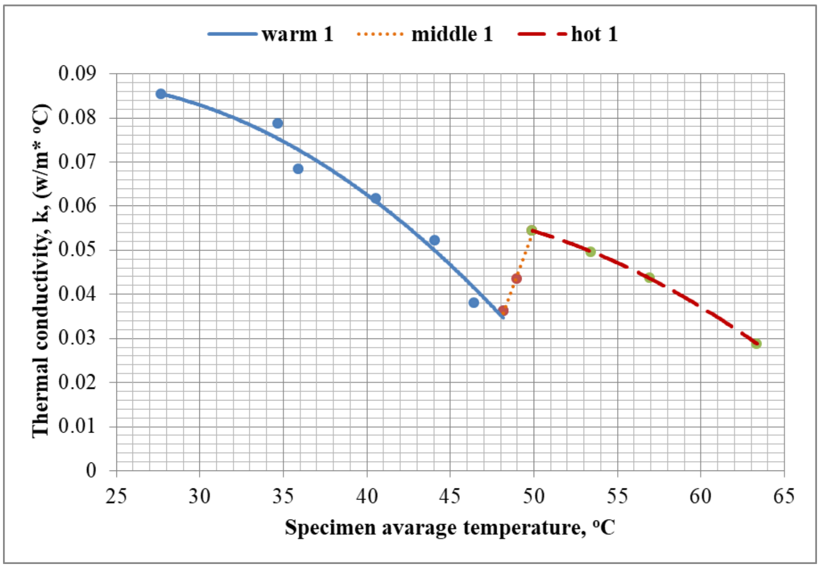

Figure 2. Thermal conductivity relation with the average temperature of the first sample (wo1)

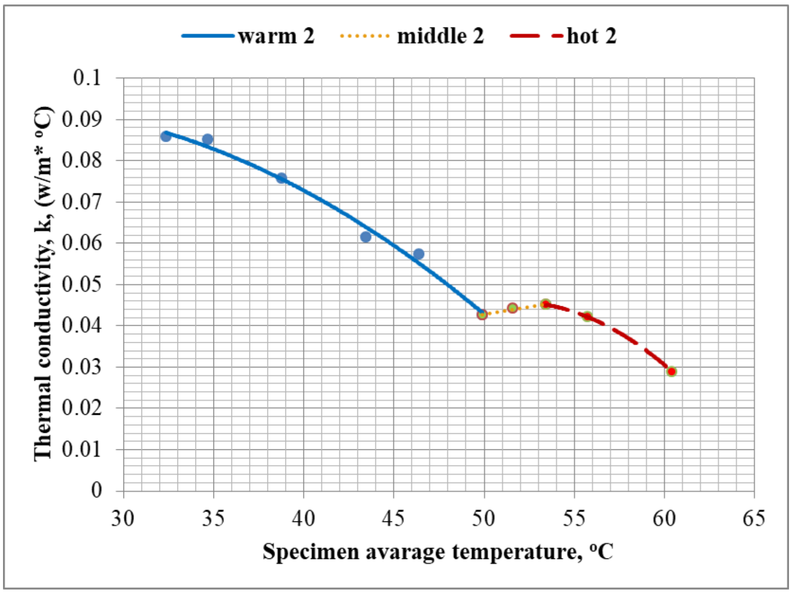

Figure 3. Thermal conductivity relation with the average temperature of the second sample (wo2)

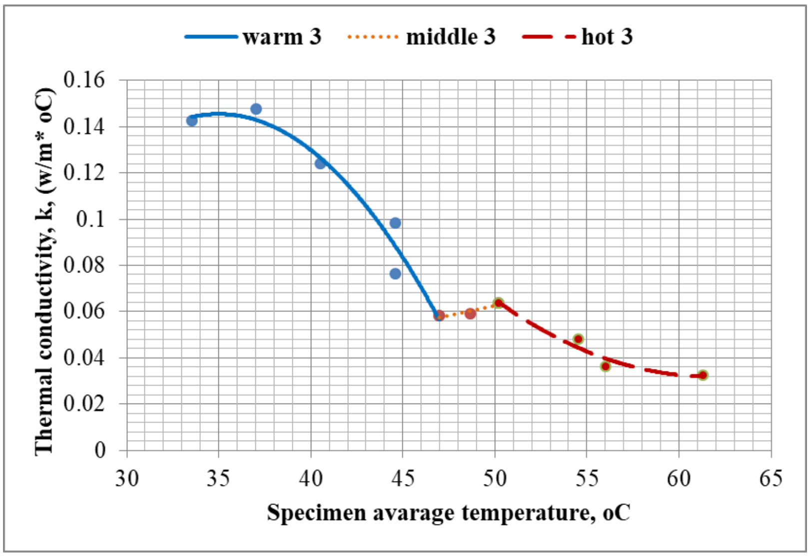

Figure 4. Thermal conductivity relation with the average temperature of the third sample (wo3)

The trends of the thermal conductivity of the second and third specimens are similar as that for the first one, as shown in Figures 3 and 4.

The three sections of the thermal conductivity of second sample can be covered by the following formulas:

$$k = -0.00007T^2 + 0.0029T + 0.0612 \quad (6)$$

$$k = 0.0007T + 0.008 \quad (7)$$

$$k = -0.0002T^2 + 0.0227T - 0.5416 \quad (8)$$

The trend of thermal conductivity of the third sample is just like that for the first and second samples. i.e., as the temperature increase the thermal of the sample decreases.

The formulas that cover the three sections of the curve shown in Figure 4 are as follows:

warm 3:

$$k = -0.0006T^2 + 0.0433T - 0.6122 \quad (9)$$

middle 3:

$$k = 0.0017T - 0.0239 \quad (10)$$

hot 3:

$$k = 0.0002T^2 - 0.0301T - 0.9591 \quad (11)$$

The formulas shown above are from the computer program, where each curve drawn according to the most appropriate function, so that; the middle zone for all samples has a linear equation, while the first and last portion have polynomial equations.

Generally, the first region for all samples limited by the temperature range approximately between (27-47°C). In this zone, there is an inversely proportion between the thermal conductivity and the temperature, where the curve has a polynomial function to the power 2 as given in the Eqns. (3), (6) and (9). This behavior is the same for all types of sawdust samples under study; namely (wo1, wo2 and wo3) but the differences are in the values of thermal conductivity.

In the second portion of the all samples sawdust the thermal conductivity behavior is approximately limited by the temperature range (47-53℃). This may be considered as the critical zone in which the thermal conductivity suddenly increased as shown in Figures 2, 3 and 4. The controlling equations of three samples of sawdust are shown in (4), (7) and (10) respectively.

The final zone is characterized by a relatively high temperature which approximately begins from (52℃). The dropping in the thermal conductivity here happened according to the polynomial function as in formulas the (5), (8) and (11).

There is interference between each two followed zone because the tested material is non-homogeneous.

According to Powell et al. [21] the thermal conductivity of most non metalic materials decreases as their temperature increases. This physical phenomenon also appears in this study (see Figures 2-4) of thermal conductivity measurement of the sawdust for all samples. The difference between the thermal conductivity of different samples was due to the differences in the air gaps between their particles, therefore, the thermal conductivity of the first sample is less than the others, because it has larger particles size where the air gaps between them will increase more than other samples.

6. CONCLUSIONS

In general, for all sawdust samples under study, the thermal conductivity is inversely proportional to the working temperature.

At a relatively low temperature less than 45℃, it can be said that the first model (wo1) is the most appropriate for thermal insulation purposes because it has the lowest thermal conductivity.

When the temperature is more than 50℃, the differences in the thermal conductivity of the samples are insignificant, so the effect of particles size is eliminated. Thus, it is not recommended to separate the sawdust according to its particle size if they used as a thermal insulation for equipment at the high temperature.

The results obtained for the average of thermal conductivity of wood sawdust at different temperatures were very close and acceptable in comparison with the results of previous studies [17, 22].

In comparison with the thermal conductivity of the insulators that used for solar collector insulation [5, 17], the sawdust may be suitable for that purpose because it has the same activity as well as it is light and cheap especially in using of (wo1).

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REFERENCES

[1] Yunus, A. (2002). Heat Transfer: A Practical Approach. Second edition, New York: McGraw-Hill.

[2] Tritt, T.M. (2005). Thermal Conductivity: Theory, Properties, and Applications. Springer Science & Business Media. https://doi.org/10.1007/b136496

[3] Almohammed, O.A.M., Philippova, F.M., Hassan, F.I.A., Timerbaev, N.F., Fomin, A.A. (2021). Practical study on heat pump enhancement by the solar energy. In E3S Web of Conferences, 288: 01069. https://doi.org/10.1051/e3sconf/202128801069

[4] Salih, M.M.M., Alomar, O.R., Yassien, H.N.S. (2021). Impacts of adding porous media on performance of double-pass solar air heater under natural and forced air circulation processes. International Journal of Mechanical Sciences, 210: 106738. https://doi.org/10.1016/j.ijmecsci.2021.106738

[5] Kreith, F., Boehm, R.F. (1999). Heat and Mass Transfer. Mechanical Engineering Handbook, Ed. Frank Kreith, Boca Raton: CRC Press LLC.

[6] Yassien, H.N.S., Alomar, O.R., Salih, M.M.M. (2020). Performance analysis of triple-pass solar air heater system: Effects of adding a net of tubes below absorber surface. Solar Energy, 207: 813-824. https://doi.org/10.1016/j.solener.2020.07.041

[7] John, H., Lienhard, I.V., John, H., Lienhard, V. (2004). A Heat Transfer Textbook. 3rd edition. Cambridge, Mass: Phlogiston Press.

[8] Timerbaev, N.F., Almohammed, O.A.M., Ali, A.K. (2019). Longitudinal fin effect on effectiveness of double pipe heat exchanger. In Proceedings of the 4th International Conference on Industrial Engineering: ICIE, pp. 605-614. https://doi.org/10.1007/978-3-319-95630-5_63

[9] Wang, S.K. (2000). Handbook of Air Conditioning and Refrigeration. Second Edition, New York: McGraw-Hill.

[10] Ravi, M.R., Jhalani, A., Sinha, S., Ray, A. (2004). Development of a semi-empirical model for pyrolysis of an annular sawdust bed. Journal of Analytical and Applied Pyrolysis, 71(1): 353-374. https://doi.org/10.1016/S0165-2370(03)00102-5

[11] Yu, Z.T., Xu, X., Fan, L.W., Hu, Y.C., Cen, K.F. (2011). Experimental measurements of thermal conductivity of wood species in China: Effects of density, temperature, and moisture content. Forest Products Journal, 61(2): 130-135. https://doi.org/10.13073/0015-7473-61.2.130

[12] Folaranmi, J. (2009). Effect of additives on the thermal conductivity of clay. Leonardo Journal of Sciences, 14: 74-77.

[13] AL-Obaidi, M.F., AL-Ajaj, I.A. (2015). Effect of sawdust wood on physical properties of recycled polyethylene terephthalate (RPET). International Journal of Innovative Research in Science, Engineering and Technology, 4(1): 18443-18441.

[14] Hossain, M.F., Shuvo, S.N., Islam, M.A. (2014). Effect of types of wood on the thermal conductivities of wood sawdust particle reinforced composites. Procedia Engineering, 90: 46-51. https://doi.org/10.1016/j.proeng.2014.11.812

[15] Ogedengbe, T.I., Fatomilola, E.O., Bello, O.R. (2013). Evaluation of thermal conductivity of selected biomass composites. Research Journal of Engineering and Applied Sciences, 2(4): 326-335.

[16] Almohammed, O.A.M., Timerbaev, N.F., Ahmad, B.I. (2019). Heat pump application for water distillation. In 2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), pp. 1-5. https://doi.org/10.1109/FarEastCon.2019.8934168

[17] Oluyamo, S.S., Bello, O.R. (2014). Particle sizes and

thermal insulation properties of some selected wood materials for solar device applications. IOSR-JAP, 6(2): 54-58. https://doi.org/10.9790/4861-06215458
[18] Oluyamo, S.S., Aramide, T.M., Adekoya, M.A., Famutimi, O.F. (2017). Variation of bulk and particle thermal properties of some selected wood materials for solar device applications. IOSR Journal of Applied Physics, 14-17. https://doi.org/10.9790/4861-0903011417
[19] Mustafa, A.O.A. (2018). Design and manufacturing the thermal conductivity measuring apparatus for solid materials and fluidized bed (In Arabic), Iraqi patent No.5278, Central Organization for Standardization and Quality Control. https://www.cosqc.gov.iq/Home/patents#.
[20] Abedalh, A.S., Shaalan, Z.A., Yassien, H.N.S. (2021). Mixed convective of hybrid nanofluids flow in a backward-facing step. Case Studies in Thermal Engineering, 25: 100868. https://doi.org/10.1016/j.csite.2021.100868
[21] Powell, R.W., Ho, C.Y., Liley, P.E. (1966). Thermal conductivity of selected materials. Washington, DC: US Department of Commerce, National Bureau of Standards.
[22] Voumbo, M.L., Wereme, A., Sissoko, G. (2010). Characterization of local insulators: Sawdust and wool of kapok. Research Journal of Applied Sciences, Engineering and Technology, 2(2): 138-142.

NOMENCLATURE

A	cross sectional area, m^2
c_p	specific heat, kJ/kg ℃
dt	temperature difference across the specimen, ℃
dx	thickness of the specimen, m
k	thermal conductivity, W/m ℃
m	mass of the water, kg
Q	heat transferred through the test piece, W
T	average temperature of the specimen, ℃
wo1	group sample with particle size ≥ 1.18 mm
wo2	group sample with particle size of 0.6 to 1.18mm
wo3	Group sample with particle size ≤ 0.6 mm

Greek symbols

Δt_w	change in water temperature, ℃
τ	time, s