Experimental Investigation to Measure the Spatial and Temporal Distribution of Temperature in Porous Media

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Abstract

The spatial and temporal distributions of temperatures through different locations of Cellular Concrete Block were measured by computerized temperature meter (CTMO1). Copper-constantan thermocouples types (T) were used for receiving the signals of heating response and connecting with (CTMO1) device. The thermal conductivity of Cellular Concrete Block has been calculated.

The measured thermal conductivity ranges from $90.4 w/m.^oC$ to $7.58 w/m.^oC$, and has an inverse temperature functionality. The results agree well experimental work for (Slifka et al,1998) for Magnesium oxide material.

الخلاصة

تضمن العمل إجراء الجانب العملي لغرض قياس التوزيع الحراري المكاني وألزماني لمادة سيراميكية تعرف تجاريا بالثرمستون وذلك باستخدام جهاز Interface الذي يأخذ الاستجابة نتيجة تسليط الحرارة وخزنها ومن ثم معالجتها بواسطة برنامج صمم لهذا الغرض حيث تحول الاستجابة الى درجات حرارة مع تغير الزمن. تم قياس درجات الحرارة بتثبيت قطعة ثنائية المعدن (ثرموكبل) على مناطق مختلفة في النموذج, تم تثبيت 9 حساسات (ثرموكبل) على مناطق مختلفة في النموذج وبإبعاد مختلفة. بينت هذه النتائج التوزيع المكاني باتجاه المحور العمودي والأفقي وكذلك في نقاط مختلفة أخرى على مستوى السطح.

تم قياس الموصلية الحرارية لمادة الثرمستون بالاعتماد على قيم فرق درجات الحرارة لمواقع مختلفة السمك للعينة المستخدمة حيث تم حساب الموصلية الحرارية بتغير الزمن وتراوحت هذه القيم بين $90.4W/m^oC$ الى $7.58W/m^oC$ وتم الاستنتاج ان الموصلية الحرارية تقل كلما ازدادت الحرارة وهذه النتائج مشابهة للنتائج العملية للمصدر [6] الخاص بقياس الموصلية الحرارية لمادة اوكسيد المغنيسيوم.

1. Introduction

There are essentially two types porous solids; those produced by packing or sintering solid particles or cylinders together and those produced by casting or foaming a material during solidification. In both cases, the final product consists of interspersed regions of solid and fluid(or void). Depending on the final structure, the void regions may be isolated from one another or continuous as in the case of an interconnected pore structure. (Nozad and Whitaker, 1985)performed transient experiments to verify the volume averaged, one-equation model for transient conduction in porous media verify the numerical results obtained for the spatially periodic model considered in his work. The experimental apparatus was square cylinder of 102mm x102mm cross-section and 203mm long. Heating and cooling of the test section was achieved with two heat exchangers positioned at the end of the chamber. Initially, cold water flowed through both heat exchangers to bring the system to an uniform temperature. Next control valves are changed to send hot water through the top heat exchanger .Thermocouples positioned at several locations within the medium are used to record the subsequent temperature rise. Temperature measurements were used to determine the effective thermal conductivity of the medium (for the air-aluminum medium). He estimates the relative uncertainty in k_e to be ± 5 % for all fluid-solid combinations. (Hadley ,1986) conducted experiments to measure the effective thermal conductivity of two and three-phase porous media composed of packed metal powders saturated with air and water. Thermal conductivity measurements were obtained by placing 9.5mm thick disks of compacted metal powders within a cylindrical test cell 61mm in diameter by 230mm long. To measure the thermal conductivity of simple, one-dimensional heat conduction in the sample was assumed and a steady-state temperature gradient was imposed. The temperature gradient is then used calculate the effect thermal conductivity of a sample. Temperature measurements were made with thermistors calibrated to $\pm 0.01^oC$. (Slifka et al,1998) showed an experimental technique, which were done by using a one-sided guarded hot plate, which is a modified version of the ASTMC177 specification. The thermal conductivity of polycrystalline magnesium oxide has been measured over the temperature range from $400K$ to $1300K$ using a modified guarded-hot-plate design. Three different thicknesses of specimens having 93% of theoretical density were tested to verify the operation, accuracy, and reproducibility of our apparatus. The measured thermal conductivity ranges from $30w/m.K$ down to $8w/m.K$, and has an inverse-temperature functionality. The specimen rests between two sensor plates and experiences an upward, one-dimensional heat flow.

In present work the spatial and temporal distribution of temperatures were measured by using (CTMO1) device through heating the Cellular Concrete Block by plate heater from down side. Thermal conductivity of tested sample has been calculated over temperature range from 46^oC to 138^oC.

2.Experimental Work

2.1.Experimental Equipments

Details of experimental set-up are shown in figure (1) . In order to get a uniform heat flux a plate heater was used to produce output power nearly 1000 watt. This was insulated with all wires net container by using glass wool in order to give an accepted insulation for heater container.

A variable voltage device was used to supply different value of voltage with range of $(0-240)$ volt. This variation is controlled by changing of internal resistance until reaches required value of voltage. That means, it has been controlled of the heat flux value requirement in the experimental work. Digital voltmeter was used to measure the voltage value, and the current value was measured by using digital ammeter at each value of voltage was fixed. Then, the electrical power supply was calculated by these values of current and voltage.

A computerized temperature meter (CTMO1) was used to record the temperature readings at different position in the test sample by using thermocouples type (T).Copper-constantan thermocouples type (T) were extensively used for temperature measurements in range -250^oC to 350^oC. These thermocouples were used to measure the temperature at difference positions inside the test sample. The thermocouples were calibrated by using results produced by (Alwan ,1989). He used correction temperature equations depend on the number of thermocouples in order to obtain the true temperature for every thermocouple, hence the constants a_o, a_1, a_2, and a_3 were determined. The general equation is:

$$T_{true} = a_o + a_1 T + a_2 T^2 + a_3 T^3 \qquad \text{---------------} \quad (1)$$

This equation was used to correct the temperature readings through test sample. There is an interface card logically used to change the measured data (temperature) from test sample to personal computer (PC). This device can transform (15) thermocouple readings to digital readings at the same time as shown in figure (1). The temperature range achieved by this device is (0 to 500) ^{o}C . Time recording represented a true time between times steps which was programmed to calculate the real time required. The (CTMO1) device was calibrated by using a thermometer reading air temperature at the same time of (CTMO1) readings at different time intervals. This process was calibrated as described by (Jassim, 2008). He shows that the reading must be started after 18 seconds from the switching on of (CTMO1) in order to give more stability for readings.

The test sample (cellular concrete block) dimensions are (14cm×12cm×10cm) with porosity of 0.09, and it is fulfilled with water. The area of surface subjected to uniform heat flux is 14×12 cm^2 .

2.2. Experimental procedure

The value of heat flux was determined by choosing value of variable voltage, and the current in order to calculate the electrical power supply as:

Power = voltage × current

The value of heat flux was determined by choosing the value of voltage from voltage device, and measured the currents of the voltage. Then, it was calculated the electrical power supply. The value of choosing voltage was $150 volts$. Then, the electrical power was $1501.735 watt$ .The value of power divided by the surface area of test sample, which was $0.0168 m^2$. Then, the value of heat flux using through experimental work was $29865.178 w/m^2$.

Nine thermocouples were fixed on the test sample at different location as shown in figure (2). Values of temperature measurements were tabled with different time intervals and heat flux value of $29865.178 w/m^2$ as shown in table (1). All temperatures reading were calibrated by using equation 1 with different constants value for every thermocouple as described in more details in (Alwan,1989).

Table (1) experimental values of temperature measurements through different locations of tested sample.

[illegible]	[illegible]	[illegible]	T_3	T_4	T_5	T_6	T_7	T_8	T_9
[illegible]	[illegible]	[illegible]	45.01	34.50	35.02	30.05	29.5	28.01	28
300	72.64	72.02	71.78	[illegible]	[illegible]	39.02	38.94	33.02	32.50
600	83.44	82.99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34.88
1200	102.99	102.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45.99
1800	120.13	119.97	[illegible]	70.99	71.03	[illegible]	[illegible]	[illegible]	47.03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64.55	63.93	52.88	51.99

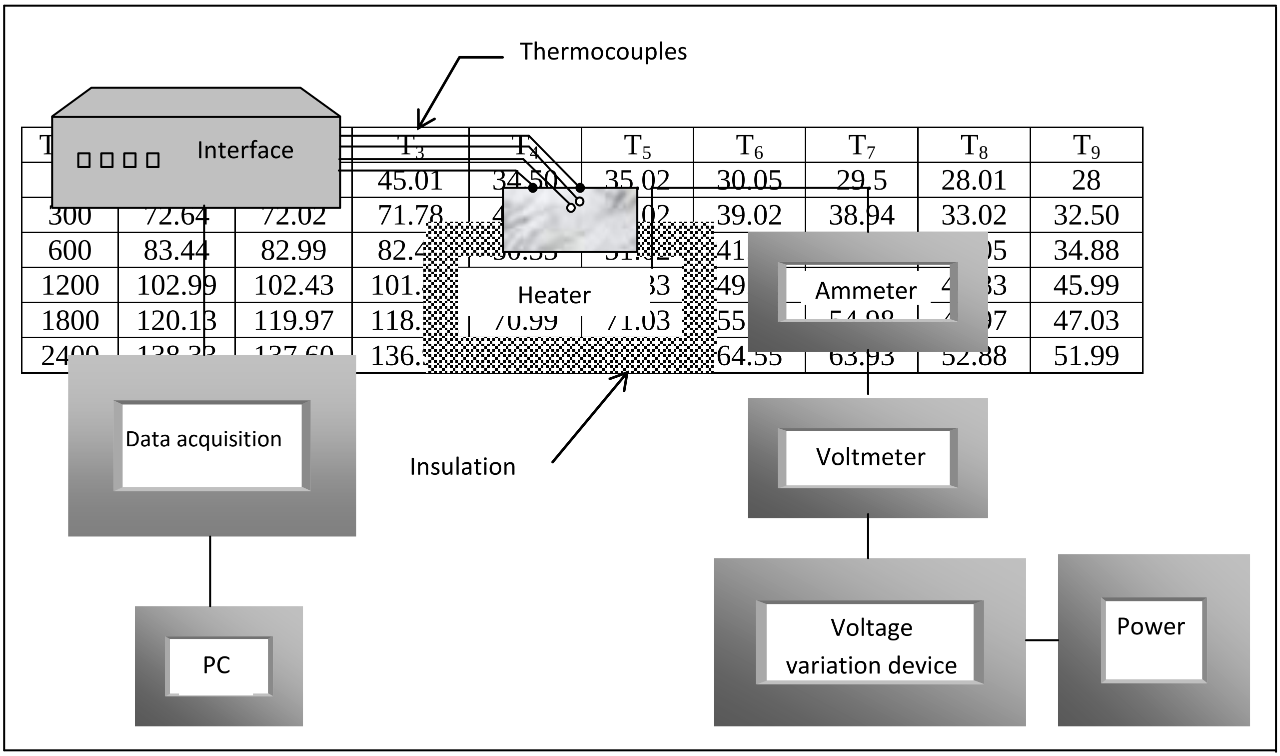


Fig (1) schematic diagram of experimental rig set-up.

3. Calculation of Thermal Conductivity

Thermal conductivity of Cellular Concrete Block was calculated over a temperature range as shown in table (1) at different positions of thermocouples at sample test. It has been calculated these values of thermal conductivity at any distance separated between two thermocouples. The Fourier conduction equation in one dimension was used to calculate this thermal conductivity from the data from any thickness of specimens tested described by (Holman,2007) as:

$$q = kA\frac{dT}{dx} \qquad \text{----------- (2)}$$

Where heat flux supplied equal $\frac{q}{A} = q^{\#}$, then equation (1) becomes

$$\frac{q}{A} = q^{\#} = k\frac{dT}{dx} \qquad \text{------------ (3)}$$

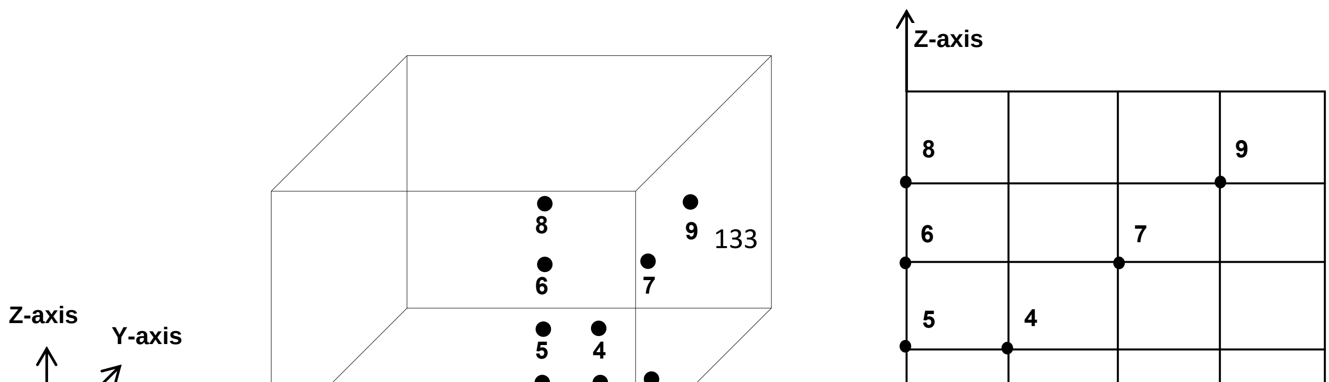
Where ΔT is the temperature difference, A is the cross sectional area that heat flows through, q is the heat flow rate, Δx is the length over which the temperature difference is measured, k is the thermal conductivity. By measuring two temperatures of different thickness in z-axis. It has been solved the equation (2) in order to generate a set of thermal conductivity results for each combination of five thicknesses tested. Table (2) shows these gradients of temperatures for these five thicknesses at different intervals times. While table (3) illustrates the thermal conductivity data for the five pairs of data from the five thicknesses of sample tested.

Table(2) experimental values of temperature gradients for the five thicknesses of tested sample.

$Time(s)$	$\Delta T(1-5)$ ^oC	$\Delta T(1-6)$ ^oC	$\Delta T(1-8)$ ^oC	$\Delta T(2-4)$ ^oC	$\Delta T(3-7)$ ^oC
60	11.07	16.04	18.08	11.49	15.51
300	27.62	33.62	39.62	27.66	32.84
600	32.42	42.41	48.39	32.66	42.06
1200	41.66	53.77	56.16	42.01	52.60
1800	49.10	65.03	71.16	48.98	63.81
2400	58.45	73.78	85.45	59,09	73.02

Table(3) experimental values of thermal conductivity k for the five pairs of data from the five thicknesses of Cellular Concrete Block.

$k1-5\ w/m.^oc$	$k1-6\ w/m.^oc$	$k1-8\ w/m.^oc$	$k2-4\ w/m.^oc$	$k3-7\ w/m.^oc$
40.467	65.167	90.850	38.988	67.51
16.219	31.091	41.458	16.195	31.829
13.817	24.647	33.944	13.716	24.852
10.753	19.439	29.248	10.663	19.872
9.123	16.073	23.082	9.146	16.381
7.664	14.167	19.222	7.581	14.314



4. Results and Discussion

Figure (4) shows the temporal variation of temperature measurements of Cellular Concrete Block at different positions of it as shown in figure(2). It has been shown the temperature was increased with increasing the time and also increasing the value of heat flux. This figure represents that the temperature measurements of a nine thermocouples at different locations on this sample. The maximum value which was measured at 2400 seconds. These points are at the center of sample, and near the bottom of surface, which was closed to heater see figure(2) (i.e. at thermocouples numbers 1,2,3). This figure indicated fast temperature variation with increasing time at points 1,2,3 than other points. This ensured the dependence of heat transfer rate on the solid phase thermal conductivity when fluid phase is stagnant.

Figure (5) represents the spatial distribution of temperature profiles through x-axis at different intervals time. This figure shows numbers of points on x-axis, which were fixed and connected by numbers of thermocouples in order to measure these temperatures of that sample. It has been shown the temperature was decreased at faraway from the center point of the bottom surface. The maximum value of temperature was measured at center point (i.e. point 1) at time 2400 seconds. This is due to that the center point (i.e.point1) was closed to heat source. That was due to the heat flux subjected at lower surface of material and heat diffusion to inside depth of material. Also, the heat flux subjected at lower surface of material and heat diffusion to inside depth material.

Figure (6) shows the spatial distribution of temperature profiles through z-axis at different time intervals of measurement of tested sample. It has been shown high negative gradient of temperature and back to shallow gradient to ambient temperature.

Figure (7) designates the isothermal contour map of temperature distribution through x-z plane at time 1800 seconds. It has been seen that the temperature increasing when faraway from the center point and the base of the sample. That means when faraway from the heat source.

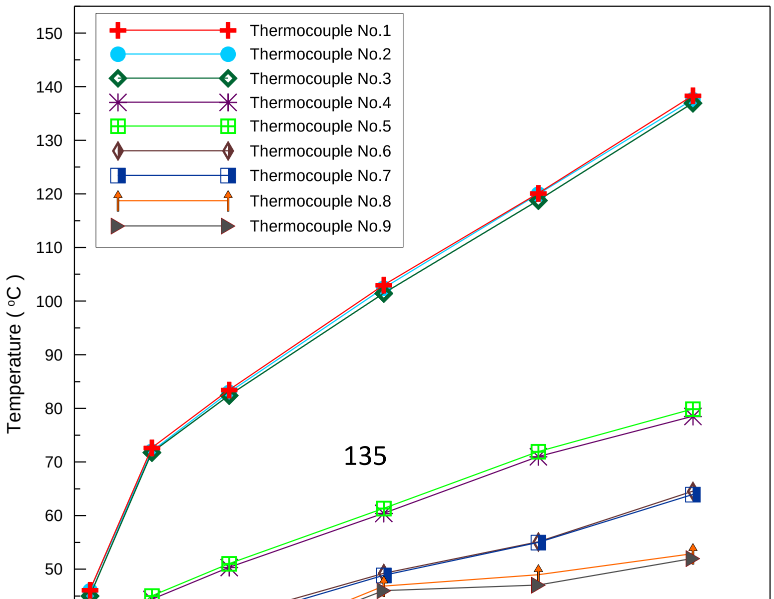
Figure (8) shows the relation between the thermal conductivity at time. It has been illustrated that these measured values of thermal conductivity decreasing with increasing time. It has been shown in this paper, the thermal conductivity was calculated with different intervals time for testing. This was more indicated point in measurement and calculation than another author (Slifka et al,1998). Obviously, it was shown, the time is important parameter in this research, and it was a function of temperature measurements.

Figure (9) shows the thermal conductivity results for the five specimen pair combinations at different intervals time. It has been noted that the thermal conductivity data values decreasing with temperature increasing. Table (3) shows the thermal conductivity data for the five pairs of data from the five thicknesses of specimens tested. The values of thermal conductivity range from $90.4 w/m.^{o}C$ down to $7.58 w/m.^{o}C$ as temperature increases. It has been seen from these results same response of thermal conductivity with increasing the temperature at different thicknesses of specimen and intervals time of measurements. It has been indicated that the results through thicknesses of pair combinations points $1-5$ and points $2-4$ were more compare well with data found in the (Touloukian,1970).

Table (3) shows the temperature gradient between over two pairs combination on the sample tested. It has been shown higher values of temperature gradient when the distance between two pairs increasing. That means this sample was an insulation. It has been noted from table the temperature decreasing as faraway from the base. Then the thermal conductivity of this porous media was more lower than metal. This is the fact that the porous media better insulator than another material.

5. Conculsion

1. Experimental work was done in order to measure the spatial and temporal distribution of temperature profiles at different locations of points on the tested sample. These measurements were achieved by using a computerized temperature meter device (CMTO1), which was connected with nine thermocouples type T in order to receive the signal heating from sample which was produced by heating the sample by heater plate. This equipment has facilities to read the spatial and temporal distribution of temperature by special soft ware, which was built .This interface equipment gave more reliable and minimize error through the measurements.
2. It has been calculated the thermal conductivity of Cellular Concrete Block using an unsteady-state technique. Thermal conductivity was calculated over a temperature range from 46^oC to 138^oC. Five different thicknesses of specimen were used. So that, it has been analyzed the data in five different pairings to solve for the one unknown in equation (2), thermal conductivity k. The results are at least as good as the recommended literature values for Polycrystalline Magnesium Oxide (Slifka et al,1998).



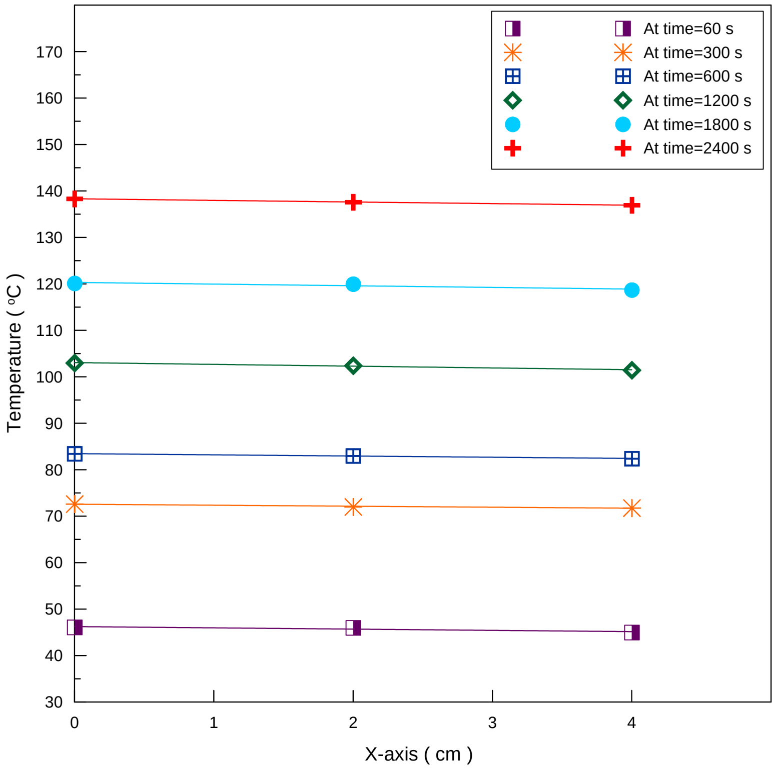
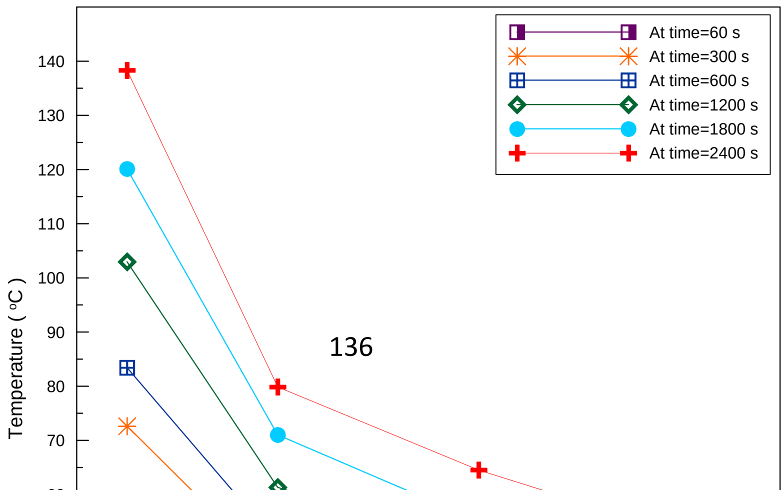


Figure (5) spatial temperature through x-axis of sample at different intervals time.



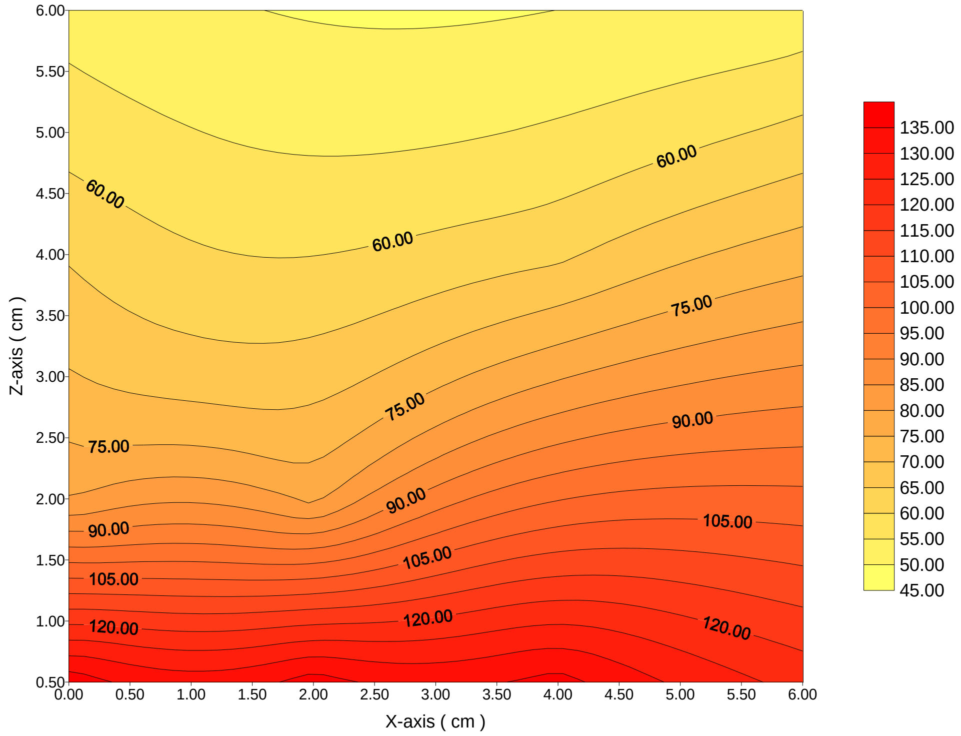
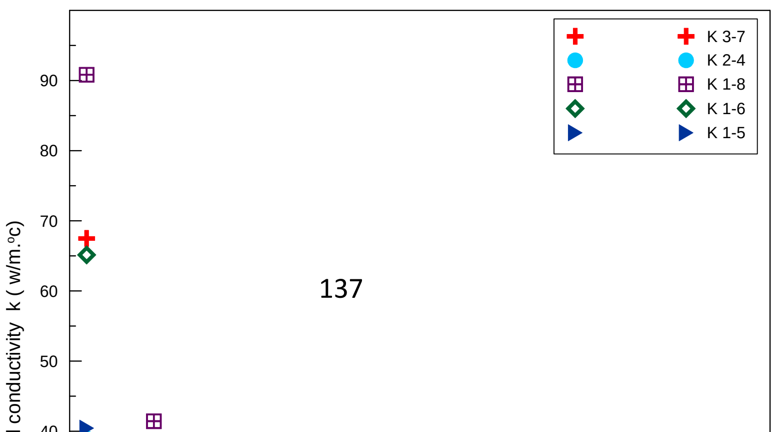


Figure (7) isothermal contour map of front plane (x-z) at 2400 s



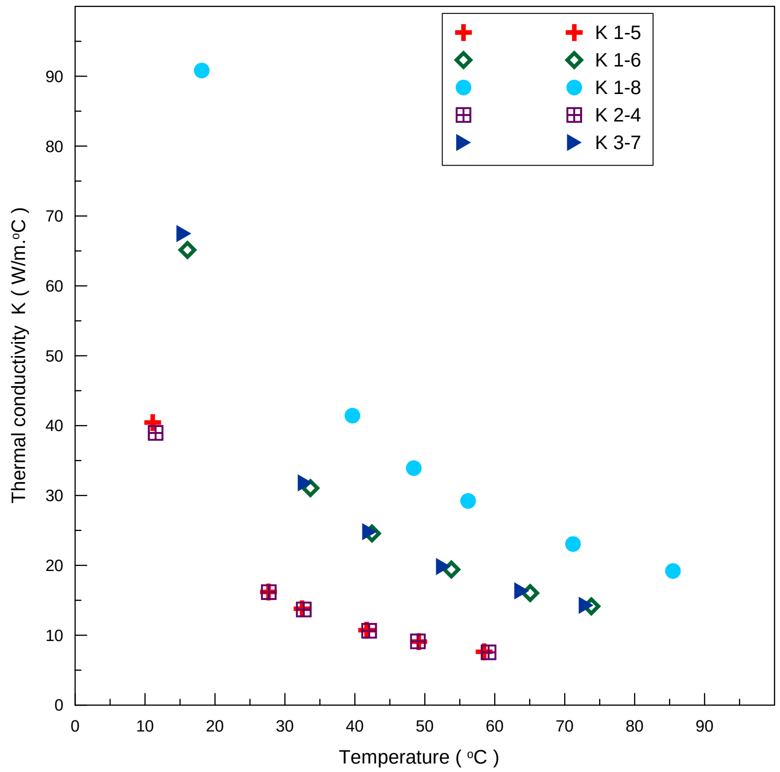


Figure (9) variation of thermal conductivity k with temperature for different location of thermocouples

6. References

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