Team H

Experiment no. 6

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REPORT

Thermal Conduction

For the course

MEC304 Integrated Mechanical Laboratory – I

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Executive summary

Abstract:

Heat Conduction through various substances is important for engineers to study, as various mechanical devices and HVAC applications depend on the knowledge of heat transfer through various substances. In this experiment

Objectives:

The objective of this experiment was to measure the conduction of a given composite wall and to measure the thermal conductivity of one material of the composite wall. Other objectives included establishing uncertainties in the above measurements.

Methodology:

We have kept 8 RTDs between the three different conducting materials with a circular flat plate heater. There are two sides with the same arrangement of the materials comprising a 20mm thick iron cast plate, a 15mm thick Bakelite plate, and a 12mm thick press wood plate. The thermocouples are placed at the center of each interface, making a total of 8 thermocouples. The methodology involves noting down the temperatures of each thermocouple over a period. After that, the heat flow rate, total resistance, and effective thermal conductivity are calculated.

Results:

Results show that the type of material selected for a particular heat transfer application should be selected with respect to its thermal conduction characteristics as they vary from material to material, and thus, appropriate material should be chosen.

Conclusion:

In conclusion, knowledge of the thermal conduction of different materials and their characteristics is very important knowledge for mechanical engineering and for people working in the field of thermodynamics. Equipment and experiments for better accuracy in measuring the thermal conduction property of materials should be developed and researched.

Keywords — Conduction, Thermal Conductivity, Uncertainties, Thermodynamics

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1. Introduction

- Introduction:

Experiments on thermal conduction are important to understand how heat energy is transformed through different materials and to determine their thermal properties. This knowledge is essential for designing and optimizing thermal management systems in various industries such as aerospace, electronics and manufacturing. Additionally, experiments can provide insight into fundamental principles of thermodynamics and help develop more efficient and sustainable technologies.

- Motivation:

The objective of this experiment is to investigate the thermal conduction properties of composite walls and explore the importance of selecting the suitable measurement techniques for accurate temperature assessment. This knowledge can find applications in numerous fields such as construction, energy efficiency, thermal insulation, and building design. Understanding the behavior of composite walls and choosing appropriate temperature measurement devices can enhance the effectiveness, energy efficiency, and safety of structures, leading to improved thermal management in real-world applications.

- Applications:

The applications of thermal conduction are varied with usage in various areas. Understanding the thermal conduction properties of composite walls is crucial in the construction industry for designing energy-efficient buildings. Accurate temperature measurement helps in evaluating the effectiveness of insulation materials, optimizing heating and cooling systems, and enhancing overall energy performance. Other areas include.

- Thermal Insulation Improvement: Accurate temperature measurement in composite walls aids in assessing the thermal insulation properties of different materials and configurations. This information is valuable for developing and improving insulation materials, ensuring their effectiveness in reducing heat transfer and maintaining comfortable indoor temperatures.
- Environmental Sustainability: Investigating thermal conduction in composite walls contributes to environmental monitoring and sustainability efforts. By understanding heat transfer through different wall compositions, researchers can assess the energy efficiency of buildings, identify areas for improvement, and promote sustainable construction practices to reduce carbon emissions.
- Industrial Processes and Quality Assurance: Temperature measurement is crucial in industrial operations involving composite walls, such as manufacturing, chemical processing, and material production. Precise temperature assessment helps monitor process parameters, ensure consistent product quality, optimize production efficiency, and enhance safety measures.
- Research and Development in Materials Science: Conducting experiments on thermal conduction in composite walls provides valuable insights into the physical characteristics of materials. This knowledge aids in the development of advanced materials with improved thermal properties for various applications, such as aerospace, electronics, and transportation.

- Engineering Challenges

There are several engineering challenges with developing a testing setup for a thermal conduction experiment. Firstly, the sample preparation requires it to be homogeneous, defect free and with a proper structure. This is a problem because most of the elements found in nature are irregular in shape and thus a homogeneous sample cannot be prepared. Apart from that the heat loss of various materials also must be considered for while testing them for their thermal conductivity. Calibration of the system is also critical to consider errors that might occur while testing. Accurate temperature measurement is also an engineering challenge as getting very accurate temperature measurements is very hard. Achieving good thermal contact between the different materials is also very hard as achieving optimal thermal contact between the layers is very hard. Some materials exhibit time-dependent behavior, such as thermal relaxation or thermal expansion, which can complicate the measurement process. Accounting for these time-dependent effects and developing appropriate measurement techniques to capture such behavior is a challenge in accurately determining the thermal conductivity of these materials. These are some of the engineering challenges faced while making an apparatus to test thermal conductivity of materials.

2. Practical applications study

2.1 Mechanical Setup for monitoring fish behaviour

In an external project, I had to make a mechanical setup to monitor fish behavior under infrared light. This meant choosing the correct material to select for the pool that the fish had to be kept in. The thermal conductivity of the pool was a major factor to look for as the thermal conductivity of the pool would determine if it reflected the infrared radiation or absorbed it.

Field Experiment: The field experiment aimed to monitor fish behavior under infrared light by designing and constructing a mechanical setup. A key consideration in this experiment was selecting the appropriate material for the fish pool. The thermal conductivity of the pool played a crucial role in determining whether it would reflect or absorb the infrared radiation. This section provides an overview of the field experiment conducted to assess fish behavior in relation to the chosen pool material.

Methodology: The methodology involved several steps to ensure the accurate monitoring of fish behavior under infrared light. Firstly, a suitable pool material needed to be identified based on its thermal conductivity properties. To accomplish this, a thorough literature review was conducted to gather information on various materials and their corresponding thermal conductivities. Based on the findings, a material with desired thermal conductivity properties was selected.

Once the material was chosen, the mechanical setup was designed and constructed, taking into consideration the dimensions and requirements of the experiment. The selected material was used to build the fish pool, providing an appropriate environment for fish observation under infrared light.

Data Acquisition: Data acquisition was performed using infrared cameras and sensors. The infrared cameras captured the behavior of the fish within the pool, while the sensors recorded the infrared radiation reflected or absorbed by the pool material. The cameras and sensors were strategically positioned to ensure comprehensive data collection.

During the experiment, the fish were closely monitored and recorded for a specific duration under controlled conditions. The acquired data included fish movements, interactions, and responses to the infrared light, as well as measurements of the infrared radiation reflected or absorbed by the pool material.

Analysis: The analysis phase involved processing and interpreting the collected data to derive meaningful insights into fish behavior and the role of the pool material's thermal conductivity. Statistical analysis techniques were employed to identify patterns, trends, and correlations within the dataset. The thermal conductivity of the pool material was examined in relation to the infrared radiation reflected or absorbed, enabling an understanding of how the material influenced the fish's interaction with the infrared light.

Desired Outcome: The desired outcome of this experiment was to determine the optimal pool material for accurately monitoring fish behavior under infrared light. By selecting a pool material with appropriate thermal conductivity, it was expected that the infrared radiation would be effectively managed, leading to minimal interference or disturbance to the fish's natural behavior. The desired outcome included obtaining comprehensive data on fish behavior and the pool material's influence on infrared radiation, contributing to the understanding of fish responses to specific environmental conditions.

The results of this experiment are expected to provide valuable insights for future studies involving fish behavior monitoring under infrared light. The findings may have applications in various fields such as aquaculture, fisheries research, and behavioral studies of aquatic organisms.

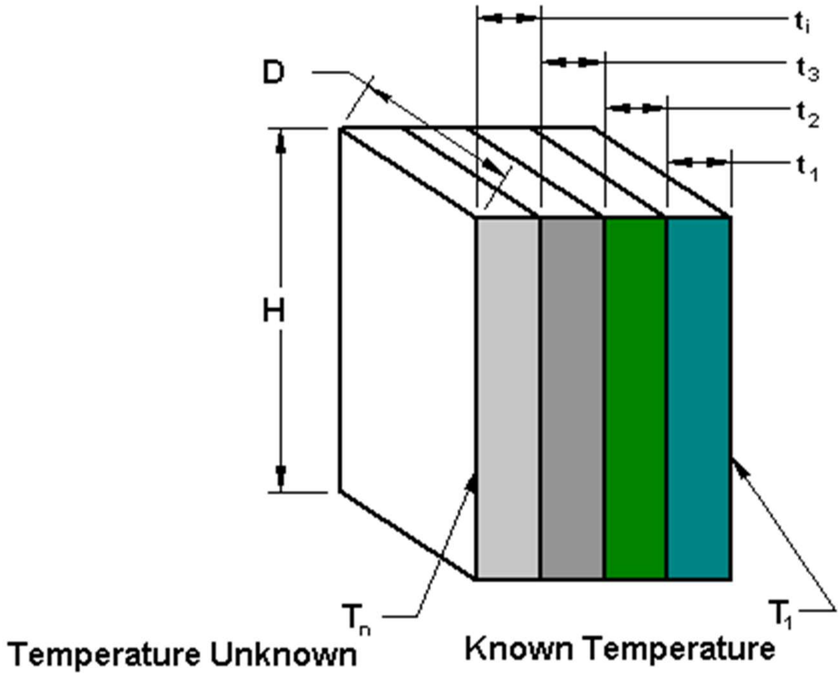
2.2 Observations and findings

We observed that the thermal conductivity plays an important role in the infrared light reflections on the surface of the pool.

3. Theoretical and conceptual basics

3.1 Theoretical basis

a. Conduction



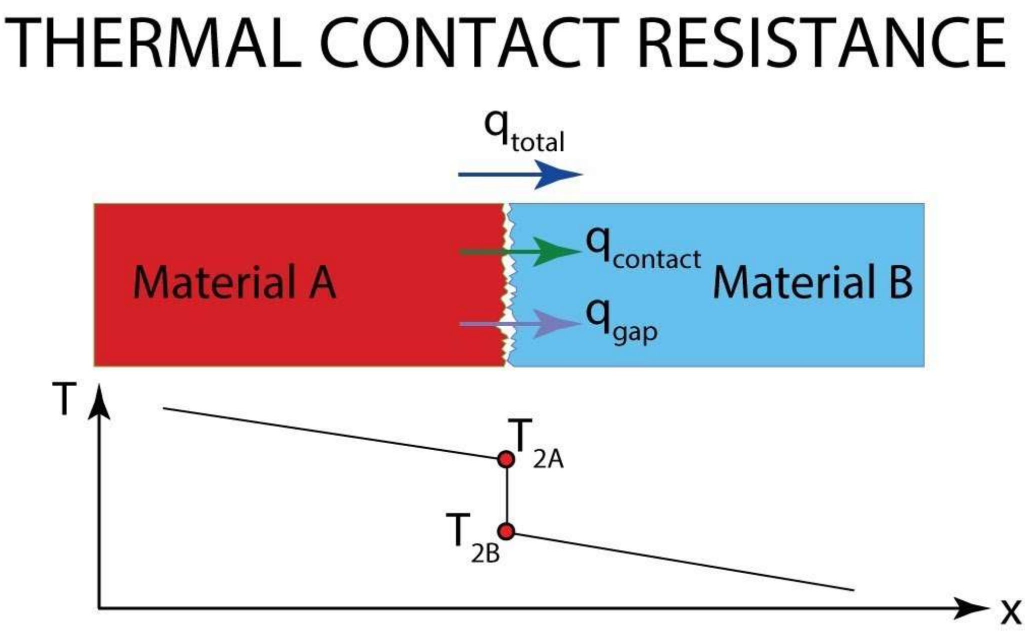
Engineer's Edge. (n.d.). Conduction through a Multilayer Isothermal Wall [Online image]. Retrieved from https://www.engineersedge.com/heat_transfer/conduction_multilayer_isothermal_wall.htm

- Conduction is a mode of heat transfer that occurs within a material or between two materials in contact due to a temperature gradient. It involves the transfer of thermal energy from the high energy region to the low energy region through collisions of atoms or molecules.
- It occurs if there is a temperature gradient present.
- A thermal conduction circuit is a simplified representation of the system that includes different layers of materials and their thermal resistances. It is valid under the assumptions of steady state heat transfer, one dimensional conduction and constant thermal properties of materials.

2. Isotherms

- The isotherms in each material represent the temperature distribution within the material. They are perpendicular to the direction of the heat flow and equidistant from each other.

b. Contact Resistance



YouTube. (n.d.). Thermal Conductivity Measurement [Online video]. Retrieved from https://www.youtube.com/watch?v=pWXybx3kJyU

- Contact Resistance is the resistance to the heat transfer that occurs at the interface between two materials in contact.
- It is incorporated into the conduction circuit diagram as an additional thermal resistance in series with the layers that are in contact.

3.2 Abbreviations and Acronyms (Times New Roman, Font size 10, Italic)

HVAC – Heating Ventilation and Air Conditioning

RTD: Resistance Temperature Detector

3.3 Equations (Times New Roman, Font size 12, Italic)

For orifice meter, the flow rate is related to pressure difference by the following relation, where 1 = Cast iron, 2 = Bakelite, and 3 = Press wood.

$$\dot{Q}_{heater} = \frac{(T_0 - T_6)}{\frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{L_3}{k_3 A_3}} + \frac{(T_1 - T_7)}{\frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{L_3}{k_3 A_3}} \quad (1)$$

$$R_{th} = \frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{L_3}{k_3 A_3} \quad (2)$$

For same diameter plates,

$$A_1 = A_2 = A_3 = \frac{\pi D^2}{4} \quad (3)$$

$k_1\ (cast\ iron) = 52\ W/mK\ ;\ k_1\ (bakelite) = 1.4\ W/mK$

$k_3\ (press\ wood) =$ to be obtained by experiment (get approximate value from web)

$L_1\ (cast\ iron) = 20\ mm\ ;\ L_2\ (bakelite) = 15\ mm\ ;\ L_3\ (press\ wood) = 12\ mm$

$$\dot{Q}_{heater} = \frac{(T_4 - T_6)}{\frac{L_3}{k_3 A_3}} + \frac{(T_5 - T_7)}{\frac{L_3}{k_3 A_3}} \quad (4)$$

$$\Rightarrow\ k_3 = \frac{\dot{Q}_{heater}\, L_3}{[(T_4 - T_6) + (T_5 - T_7)]\, A_3} \quad (5)$$

$$\dot{Q} = \frac{P}{t_p} \times \frac{3600}{EMC} \times 1000\ (W) \quad (6)$$

Energy Meter Constant, EMC = 3200 pulses per hour

3.4 Validation with theory

NA

4. Pre-experiment planning

Prior to starting the experiment, several activities were performed to ensure the safety of the team and the success of the experiment.

4.1 Safety

Maintained proper ventilation in the room, checked for electrical failures and checked for components that might be a risk for the safety of the people.

4.2 Independent and dependent variables

Independent variables – Heater Power, Temperature Difference between the heater surface and the ambient

Dependent variables – Temperature distribution within each material and the heat transfer rate.

Controlled parameters - dimensions and thermal properties of the materials and the boundary conditions.

4.3 Result formulae/relations

As discussed above in the equations section we get the Fourier law of heat conduction as a result relation of these variables.

4.4 Pre-test uncertainty analysis

The uncertainty in thermal conductivity of the wood sample can be expressed as a function of the uncertainties in the measured temperatures, diameters, and thickness. Assuming fixed diameters and thickness for the materials. The error analysis of the measured temperature is recorded in the data analysis and discussions section.

Overall, the uncertainty values were determined to be adequate to successfully arrive at conclusions on the questions posed in the objectives.

4.5 Test matrix

Time	T0	T1	T2	T3	T4	T5	T6	T7
02:06								
02:31								
02:41								
02:51								
03:01								
03:11								
03:21								
03:31								
03:41								

5. Experiment execution

We first calibrated all the temperature sensing devices and checked all other factors for errors and uncertainties. We then checked the ambient for temperature measurement. After that, as seen from the test matrix as well, we connected the power supply, started the experiment and allowed it to reach near to a steady state using a digital temperature PID controller. After it reached near the steady state condition, we filled the test matrix with the required data and performed the necessary calculations required to calculate the results of the experiment.

6. Data analysis and discussion

Time	T0	T1	T2	T3	T4	T5	T6	T7
02:06	60	58.3	38.5	38.1	27.8	27.5	26.6	26
02:31	60	61.3	54.8	54.3	38.5	38	29.2	28.2
02:41	60	61.1	56.3	55.8	41.8	41.1	30.8	29.4
02:51	60	61.1	57.1	56.7	44.1	43.5	32.7	30.8
03:01	60	61.1	57.5	57.1	45.4	44.6	33.7	31.6
03:11	60	60.9	57.9	57.5	46.7	45.6	34.8	32.3
03:21	60	60.9	58	57.9	47.4	46.4	35.8	33.2
03:31	60	60.9	58.2	58	48.1	47.1	36.7	33.7
03:41	60	60.9	58	57.5	48	46.9	36.2	33.3
Mean	60	60.7222222	55.1444444	54.7666667	43.0888889	42.3	32.9444444	30.9444444

Standard Deviation	0	0.91893658	6.33543825	6.35865552	6.5544726	6.3007936	3.46053143	2.6192132
Relative Error	0.00167	0.00164684	0.00181342	0.00182593	0.00232078	0.0023641	0.00303541	0.0032316
Percentage Error	0.16667	0.16468435	0.18134193	0.18259282	0.23207839	0.2364066	0.30354132	0.32315978

- From the data and error analysis, we can say that the error is under control and the temperature data can be used for the calculation of the given objectives.
- By doing the calculations, the total resistance was measured to be 228 * 10^-3 °C m^2/W. Effective thermal conductivity to be 0.206 W/°C m^2 and the thermal conductivity of the wood was determined to be around 0.056 W/°C m^2 which are all acceptable results.

7. Conclusions

Based on the experiment performed the following results can be drawn

- Thermal conductivity variation: The thermal conductivity of the composite wall was found to vary across the different layers. This indicates that the individual materials composing the wall have different abilities to conduct heat. The thermal conductivity values obtained for each layer provide insights into their thermal performance.
- Influence of layer thickness: The experiment showed that the thickness of each layer in the composite wall has a significant impact on its overall thermal conductivity. Thicker layers tend to have lower thermal conductivities, while thinner layers exhibit higher thermal conductivities. This observation highlights the importance of considering layer thickness when designing composite walls for optimal heat transfer.
- Effect of interface contact resistance: The presence of interface contact resistance between the layers of the composite wall introduces additional thermal resistance, affecting the overall heat transfer. This phenomenon should be considered when analyzing and designing composite walls to accurately predict their thermal conductivity and performance.
- Anisotropic behaviour: If the composite wall is composed of anisotropic materials, meaning their thermal conductivity varies with direction, the experiment may reveal different thermal conductivities along different axes. This anisotropic behaviour should be considered in applications where heat transfer occurs in specific directions.
- Potential for further optimization: The experiment provides valuable insights into the thermal behavior of the composite wall. By adjusting the composition, thickness, or arrangement of the layers, it may be possible to optimize the thermal conductivity and enhance the overall thermal performance of the wall.

8. References

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9. Material to be uploaded

Specification Sheets