**KONSTAN**
JURNAL FISIKA DAN PENDIDIKAN FISIKA
Volume 7, Number 2, December 2022
E-ISSN : 2460-9129 dan P-ISSN : 2460-9110
http://jurnalkonstan.ac.id/index.php/jurnal

# Deviation Analysis of Temperature Distribution in Copper Bar Heat Conduction Process Experiments Against Numerical Calculations

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**Article Info:**

Sent:
Sept 22, 2022
Revision:
Dec 27, 2022
Accepted:
Dec 27, 2022

**Keywords:**
Heat Conduction, Experiments, Numerical calculations.

**Abstract**

In the process of heat transfer by conduction, besides the quantities in the form of surface area, length or thickness of the rod, and the temperature difference between the ends of the rod and the value of the thermal conductivity, other factors also affect the rate of heat transfer to the rod, one of which is environmental factors. As long as heat flows from the high to the low temperature, the temperature decrease is not uniform at any time interval. This is a sign of the influence of the ambient temperature for each part of the material. Temperature observations were carried out experimentally in an open environment in the laboratory and then compared with the results of numerical calculations as the ideal condition for the heat conduction process. The Boltzmann transport equation for the induction process on metal rods is solved using *finite differences* with an explicit method to obtain the temperature distribution. The results showed differences in the temperature distribution pattern of copper rods with numerical calculations and experiments. This difference is caused by the amount of heat released into the environment. The higher the temperature at the observation point, the greater the heat released into the atmosphere.



## INTRODUCTION

In the industrial world, we often select an appropriate material based on a material's essential characteristics and physical properties. Several considerations need to be made to choose the best or close to the best material for an application. One of the necessary material properties is thermal conductivity. The material's thermal conductivity can be known through the transfer of heat/heat in the material. Heat transfer or heat transfer process is a process to transfer heat from one part to another part of the material that occurs because of a temperature difference. Heat transfer in a material is significant in determining the heat conductivity of a material. The transfer of heat through a solid material is called conduction.

In heat transfer by conduction, no material from the metal moves. If the solid is a metal, then the transfer of heat energy is assisted by free electrons, which move throughout the metal while receiving and giving heat energy when colliding with metal atoms [1]. In the process of heat transfer by conduction, there is a heat transfer rate. The heat transfer rate states how fast heat is transferred through the medium. Some quantities affect the heat transfer rate, namely the object's surface area, the thing, the length or thickness of the object, and the temperature difference between the ends of the object and are also influenced by a quantity called thermal conductivity. Based on the results of observations on heat transfer experiments by conduction at the Applied Physics Laboratory, in the test rod, heat flows from the high temperature to the low temperature, but the decrease is not uniform in each time interval. This is a sign of the influence of ambient temperature for each part of the material, resulting in differences in temperature distribution along the material during the heat transfer process.

A study is needed to determine the influence of environmental factors on temperature distribution in the process of heat transfer by conduction. Observations were carried out experimentally in an open environment in the laboratory, making numerical calculations of heat distribution as a comparison. In the experiment, both sides of the rod were given a constant temperature around $99^{oC}$ (boiling water) and the other end at about 4 $^{o}$ C(ice water), so that the conduction process in the stem can be observed, which is characterized by the occurrence of temperature distribution at the observed points. This temperature distribution pattern is then compared with the temperature distribution pattern resulting from a numerical calculation simulation.

Heat transfer is the transfer of energy that occurs due to a temperature difference between objects or materials. On the principle of thermodynamics, the energy transferred is called heat (heat). On the other hand, heat transfer does not only try to explain how the heat energy is transferred from one part of the object to another, but it is necessary to pay attention to the rate of transfer that occurs under certain conditions. Because when heat is transferred, the temperature drop will not appear evenly because it will be affected by the speed of heat transfer because when the transfer process takes place, the system is not in a state of equilibrium.

In several types of materials, the conduction rate is different. That means the heat transfer speed is affected by the conducting material used. The heat conduction (H) rate is affected by a constant k, a physical quantity called the thermal conductivity of the conducting material used.[2]

Heat conduction will occur if there is a temperature difference between different locations on an object. If there is a temperature gradient along a cylindrical rod with a small cross-sectional area (assumed to be one dimensional), then the quantity of heat transported dQ with time dt is a function of the cross-sectional area A and the temperature gradient dT/dx perpendicular to the surface.

This temperature distribution is generally a location and time function and follows the Boltzmann transport equation [3].

$$\frac{\partial T}{\partial t} = \frac{k}{\rho\, c}\, \frac{\partial^2 T}{\partial x^2} \tag{1}$$

Information:

$k$ = coefficient of heat conductivity (W/mK)

$\rho$ = Density ( $kg\ /\ m^3$ )

$c$ = Heat Type ( $J\ /(\ kg\ K\ )$)

Equation 1 is then solved using finite differences [4],[5] so that equation 1 becomes:

$$\frac{T_i^{n+1} - T_i^n}{\Delta t} = \alpha \left( \frac{T_{i-1}^n - 2T_i^n + T_{i+1}^n}{\Delta x^2} \right) \tag{2}$$

With α=k/ρc

The temperature distribution is determined using the explicit method [6],[7],[8],[9], so equation 2 becomes:

$$T_i^{n+1} = T_i^n + \frac{\alpha \Delta t}{\Delta x^2} (T_{i-1}^n - 2T_i^n + T_{i+1}^n) \tag{3}$$

Information:

α = k/ϱc

$\Delta\, t = step$ − time size $t$ ( $s$ )
$\Delta\, x = step$ − position size $x$ ( $m$ )
$n$ = time $t$
$i$ = positon $x$

The method for calculating the temperature distribution using the explicit method is described as follows:

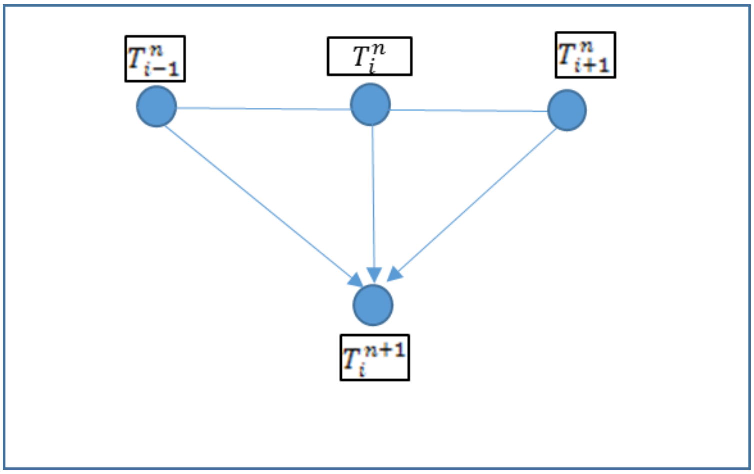


**Figure 1** . Explicit Method Calculations

## RESEARCH METHODS

This study used experimental and simulation methods at the Applied Physics Laboratory for five months. The research methodology includes: preliminary analyses, preparing equipment and trials using copper metal rods as samples, and making numerical calculations using the Excel application [10], [11]. The results of data processing and analysis of experimental results and outcomes of numerical calculations are compared to know the differences in experimental results and numerical simulations so that the effect of environmental factors on the conduction heat transfer process can be identified.

In detail, the research stages and achievement indicators for each step can be seen in Figure 2.

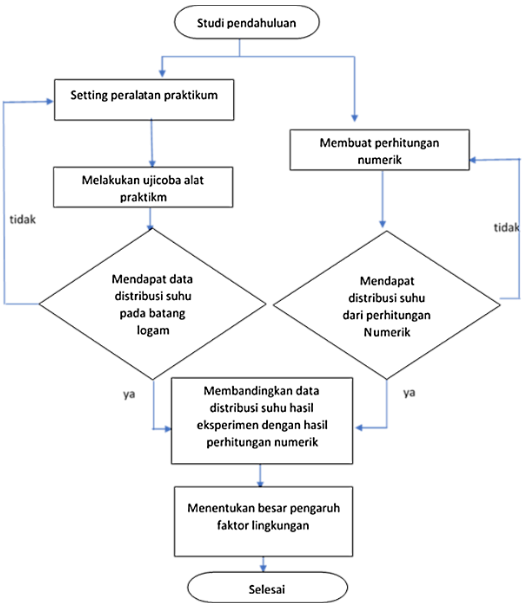


**Figure 2**. Research Stages

The experimental equipment is set as shown in Figure 3. The end of the metal rod on the left is placed in boiling water; adding hot water when it boils is intended to make the temperature constant. The right end of the metal rod is placed in cold water (ice water), and the ice water is kept at a constant temperature by putting ice cubes at the bottom. Then the temperature on several parts of the metal rod is measured to see the temperature distribution during the heat conduction process. At this stage, a trial was carried out using a copper metal rod as a sample.

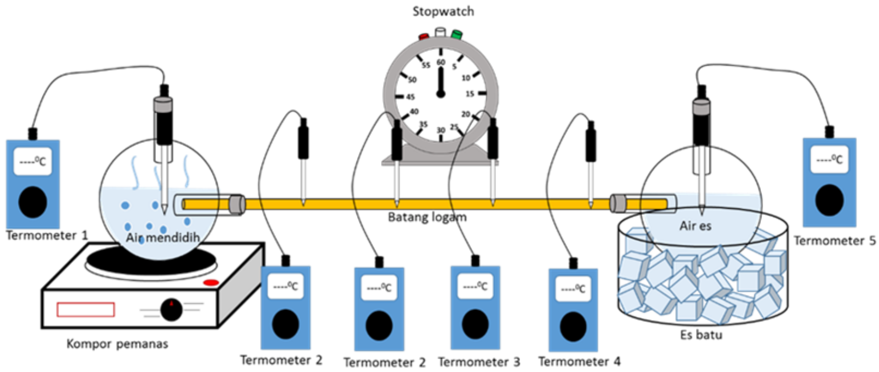


**Figure 3** . Sketches of Experimental Equipment Settings

The Boltzmann transport equation for the induction process on metal rods is solved by using finite differences with the explicit method (equation 3) to obtain the temperature distribution. Experimental results of temperature distribution data are compared with the results of numerical calculations.

The influence of environmental factors can be observed from the difference between the experimental data and the results of numerical calculations—achievement indicators: Results of the analysis of the effect of the environment on conduction heat transfer experimentally.

## RESULTS AND DISCUSSION

The equipment used in the experiment were two glass flasks each for placing hot and cold water, a metal rod, six thermometers, a stopwatch, a heating stove, ice storage, and statives. A metal rod connects two flasks filled with hot and cold water. Each thermometer is placed on the hot and cold flask along the stem every 20 cm. The heating stove and ice storage are placed in the hot and cold flasks to maintain the desired fixed temperature. Figure 4 shows the experimental tool settings.

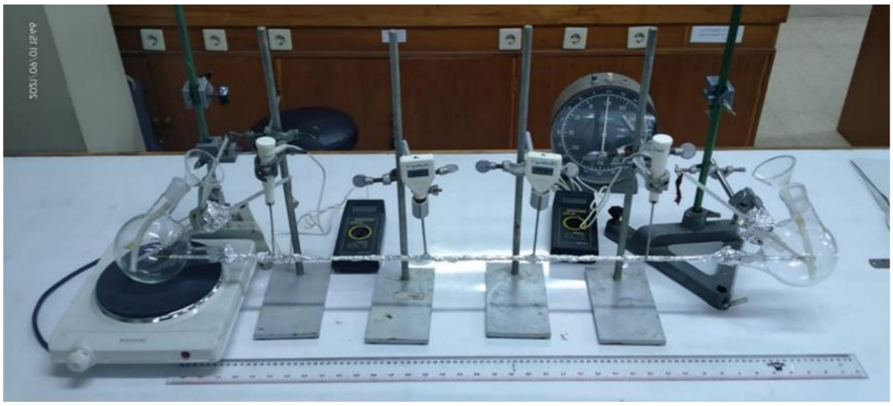

**Figure 4** . Experimental Equipment Design

In this study, metal rods used copper as a test material, with the specifications listed in Table 1 below.

**Table 1** . Specifications of copper material in Trial

| Magnitude | Mark |
|---|---|
| Stem length | 1 m |
| Material Conductivity | 386 W/m K |
| Specific Heat Materials | 385 J/kg K |
| Mass Meeting | 8960 kg/ $^{m3}$ |
| Initial Temperature ($T_0$) | 26.3 °C |

The experiment started after placing a flask filled with hot water, reaching a temperature of 99$^{oC,}$ and a flask filled with cold water kept at 6$^{oC}$ together on each end of a copper rod. Temperature changes are recorded every 30 seconds, so temperature distribution data is obtained along the copper rod, as shown in Figure 5 below.

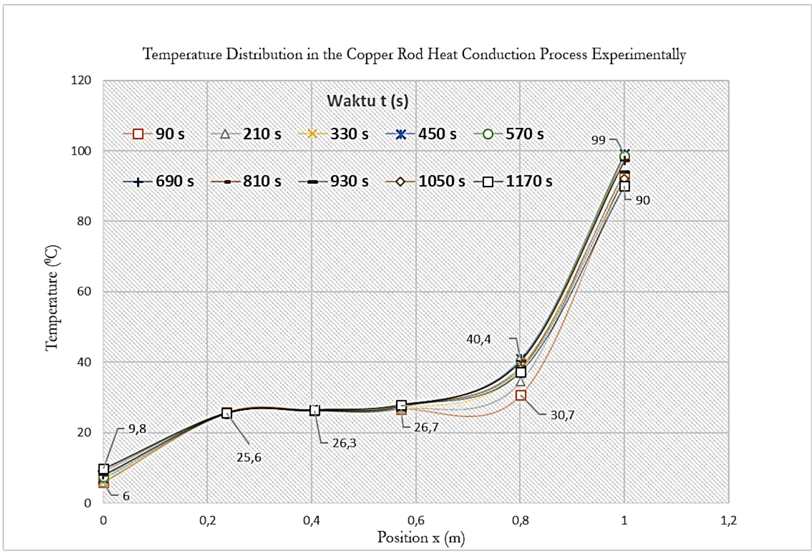


**Figure 5**. Experimental Temperature Distribution of Copper Rod Heat Conduction

As seen in Figure 5, the tip of the rod placed in the hot flask (x=10m) experiences a temperature increase until it is equal to the water temperature in the flask of $^{99oC}$ at t=330s. Heat propagation occurred during the observation range; at position x=0.8 cm, there was an increase in temperature from $^{30.7oC}$ (90 s) to $^{40.4oC}$ (1170 s). Positions 0.6cm, 0.4cm and 0.2cm were respectively at a steady temperature throughout the observation time, namely 26.7$^{oC}$, 26.3$^{oC}$ and 25.6$^{oC}$ . There was a change in temperature of 3.8 $^{o}$C at the end of the stem, which was placed in a cold flask, which was initially 6 $^{o}$C (90 s) to 9.8 $^{o}$C.

From the experimental data, heat propagation occurs by conduction along the metal rod from the end of the pipe placed in the hot flask to the end of the line placed in the cold flask. The further away from the heat source, the smaller the temperature change over the observation period. A diagonal pattern occurs in the position range of 0.2m to 0.6m.

With the Boltzmann transport, the equation is solved using the finite difference, and the temperature distribution is determined using the explicit method. Then, the results of calculating the temperature distribution of the heat conduction process of copper rods numerical are obtained as follows.

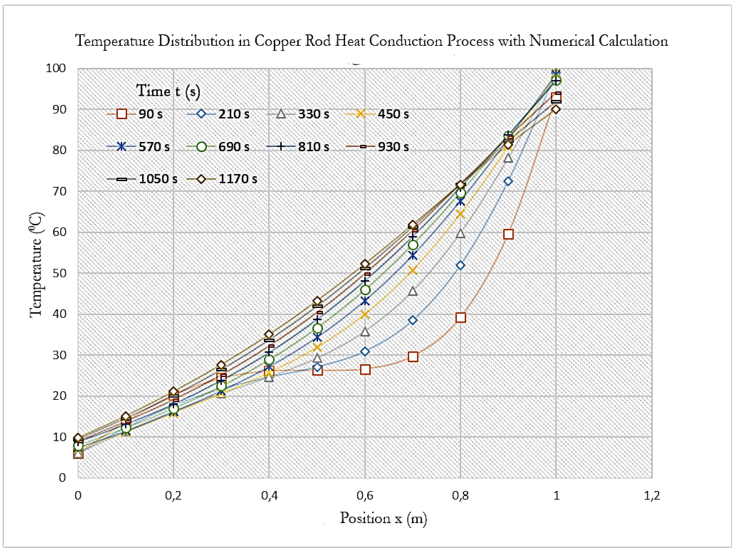


**Figure 6**. Temperature Distribution of Copper Rod Heat Conduction with Numerical Calculations

It can be seen in Figure 6, there is a regular distribution pattern of temperature rise at each observed position. The rate of heat gain is faster with increasing time, as seen at t=90s, and the curve slows in the position range of 0.4m to 0.8m. As time increases, the angle increases steadily.

Figure 7 shows the difference in the temperature distribution pattern of copper rods with numerical calculations and experiments. The difference in temperature distribution occurs because the analysis of heat conduction of copper rods with numerical calculations is in ideal conditions; there is no interaction and influence of the environment around the experiment. Environmental conditions strongly influence the experimental heat conduction process; there is direct contact between the system and the surrounding environment.

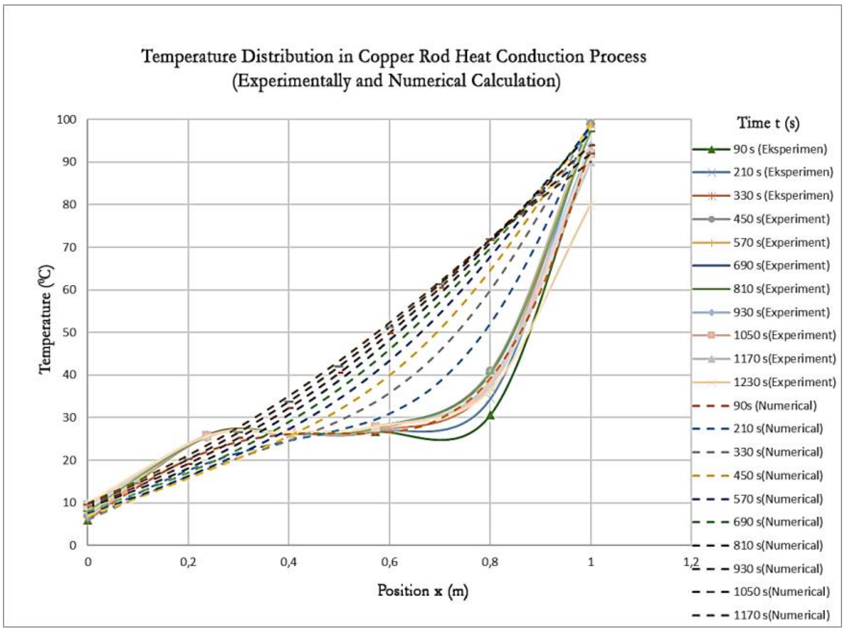


**Figure 7**. Comparison of Temperature Distribution on Copper Rod Heat Conduction by Experiment and Numerical Calculations

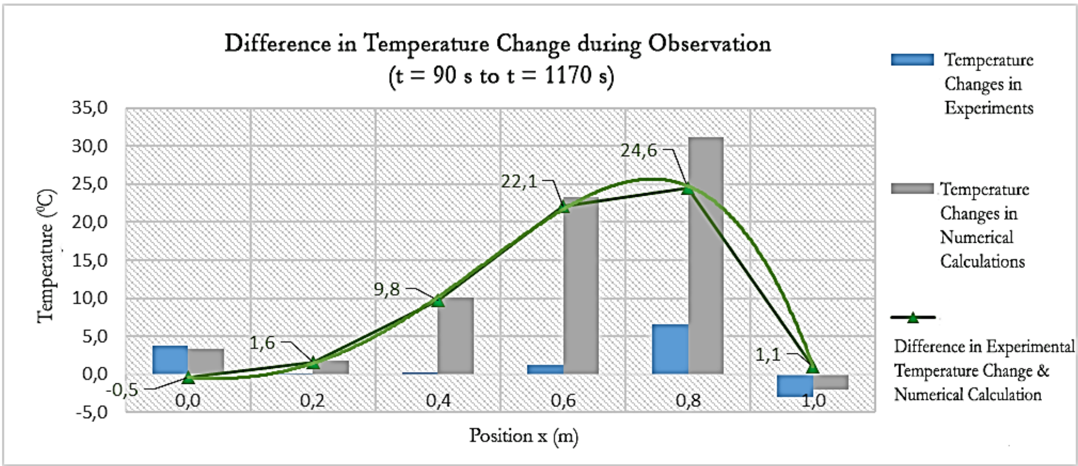


**Figure 8** . Difference in Temperature Change During Observation (t = 90s to t = 1170s)

As shown in the graph of Figure 8, the temperature change of copper rods with numerical calculations during the observation time interval between 90 s–1170 s increased 31.2$^{oC}$ at the 0.8 m observation point. Then successively increased by 23.3 $^{o}$C at 0.6 m, 10.1 $^{o}$C at 0.4 m, 1.7 $^{o}$C at 0.2 m and 3.3 $^{o}$C at the end of the stem in the cold flask (0 m ).

While the change in temperature, the copper rod in the experiment within the same observation time interval increased 6.6$^{oC}$ at the 0.8 m observation point. Then successively increased by 1.2$^{oC}$ at 0.6m, 0.3$^{oC}$ at 0.4m, 0.1oC at 0.2 m and 3.8$^{oC}$ at the end of the stem in the cold flask (0 m ).

There is a difference in temperature changes of copper rods with numerical calculations and experiments. The difference in successive temperature changes is 24.6 $^{o}$C at the observation point 0.8 m, 22.1 $^{o}$C at 0.6 m, 9.8 $^{o}$C at 0.4 m, 1.6 $^{o}$C at 0.2 m and -0 .5 $^{o}$C at the end of the stem in the cold flask (0m).

This temperature difference indicates the influence of the environment on the system during the experiment; there is a certain amount of heat released into the atmosphere. The higher the temperature at the observation point, the greater the heat released to the environment. Because the temperature difference to the environment is more significant, and the greater the possibility of heat transfer by radiation which in theory is directly proportional to the fourth power of temperature $H = e\sigma AT^4$).

## CONCLUSION

A temperature stem copper will difference pattern distribution with calculation numeric and experiment. Condition this occurs because on calculation conduction hot stem copper with calculation numeric is at an ideal condition, no there is interaction and influence environment around the experiment, meanwhile on an investigation, really influenced by condition environment, which results in there is a number released heat _ to big environment _ comparable with temperature. The taller on point observation, the hotter the removed from the environment, and the more significant, p this caused displacement hot in manner radiation.

For more understanding of a manner intact influence factor environment to distribution temperature on the conduction process, the necessary study carried on with various type ingredient metal in a manner experiment and numeric.

## ACKNOWLEDGEMENTS

The writer says thank you to the Research Unit and devotion Community (UPPM) Polytechnic Country Upper Bandung funding on the study.

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