1 Project Title

Arduino-based experimental for the study of unsteady heat transfer temperature of metals

2 Project Objective

The aim of this experiment is to investigate the rate of temperature change of a metal cylinder in unsteady heat transfer

The metal rod is between two heat sources, and to investigate the relationship between the experimental hypothesis and the temperature of the heat source, its position in metal, length, material and other factors.

The completion of this experiment will contribute to the study and understanding of unsteady state heat transfer.

3 Hypotheses

1. Before reaching the steady state, the rate of temperature change at the point becomes faster with the enhancement of thermal conductivity of the material.

2. Before reaching a steady state, the rate of temperature change at the point becomes faster with the shortening of the metal length.

3. Before reaching the steady state, the rate of temperature change at the point becomes faster with the increase of heat source temperature difference.

4 Methodology

The experiments were carried out using two materials(Iron and Aluminum), a combination of length variation(250mm & 250mm*2), temperature variation by adjusting the temperature of the domestic kettle, and ten sensors set at different locations to collect the temperature variation at different distances. More information in Methodology.

The experiments will focus on these variables, while using the data generated to obtain additional phenomena and conclusions beyond the hypothesis, in order to investigate the variation of temperature in the heat transfer of metals in a non-stationary state.

4.1 Real Experiment Methodology

In this experiment, we use 250mm 10mm diameter carbon steel bar and 250mm 10mm diameter pure aluminum bar as the experimental objects. We install the test sample at about 25cm above the desktop through our designed 3D printing parts, so that it can be fully placed in contact with other objects. On both sides of the polished smooth sample, we close it to the copper sheet soaked in water for a long time as the heat source.

We use Arduino's hardware platform as the data collector, and use MATLAB software to monitor and process the recorded data in real time. We use DS18B20 sensor as our temperature sensor, install it in the 3D printing part, and make it fully in thermal contact with the point to be measured. At the same time, We put two waterproof temperature sensors into cold and hot water at both ends. This will be used to monitor the heat source and prevent the failure of the experiment due to possible unstable factors of the heat source.

The real experiment will be completed within 2 weeks after the mid-term examination. At that time, the data can be collected and analyzed.

4.1.1 Instrument Detailed

These are the main metal parts used in our experiment,Stick 1 and Sheet 2 which are purchased off the shelf.

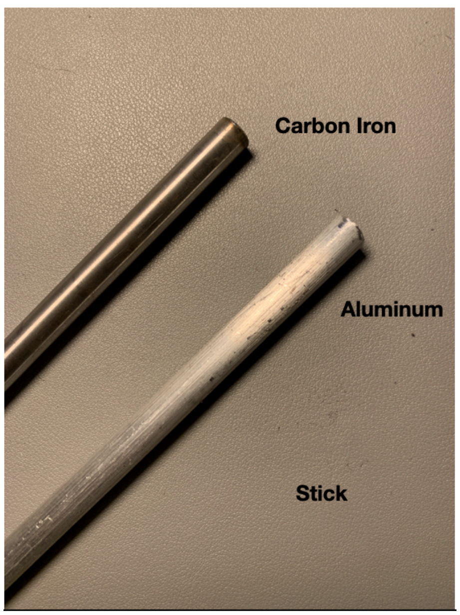

Figure 1: Iron Stick & Aluminnum Stick

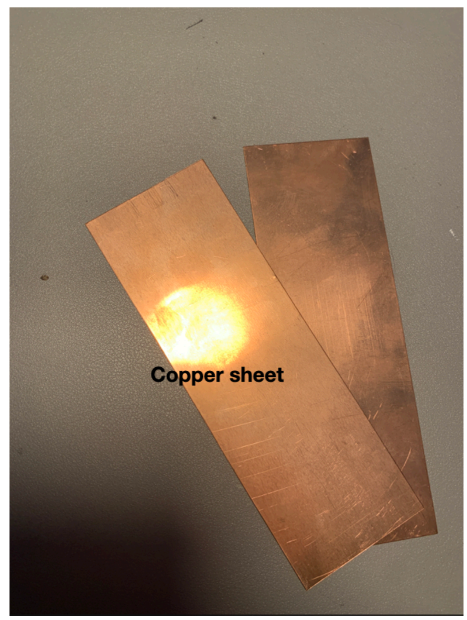

Figure 2: Copper Sheet

In experiment,we use 2 kinds of sensor form.One is the waterproof form which is already installed in a waterproof sleeve, which will be used in monitoring the temperature of heat source, water.Another is direct the sensor, which will be installed into the parts and fix and contact to measure the temperature.

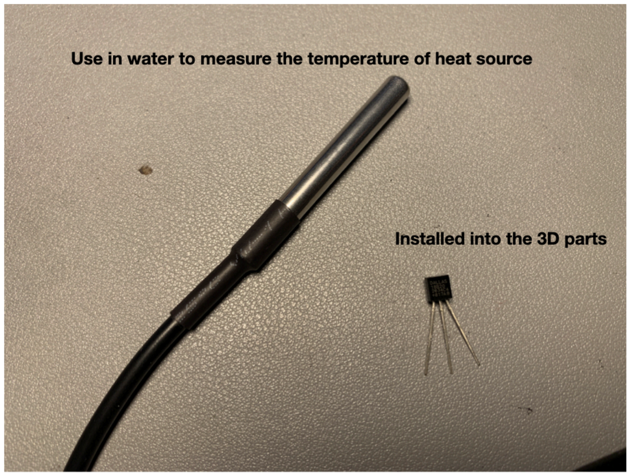

Figure 3: Sensors

This is the 3D simulation image of the experimental facility 4. In this image, you can see that the red part is the part I designed that needs 3D printing, which is used to fix and assemble the experimental object and sensor

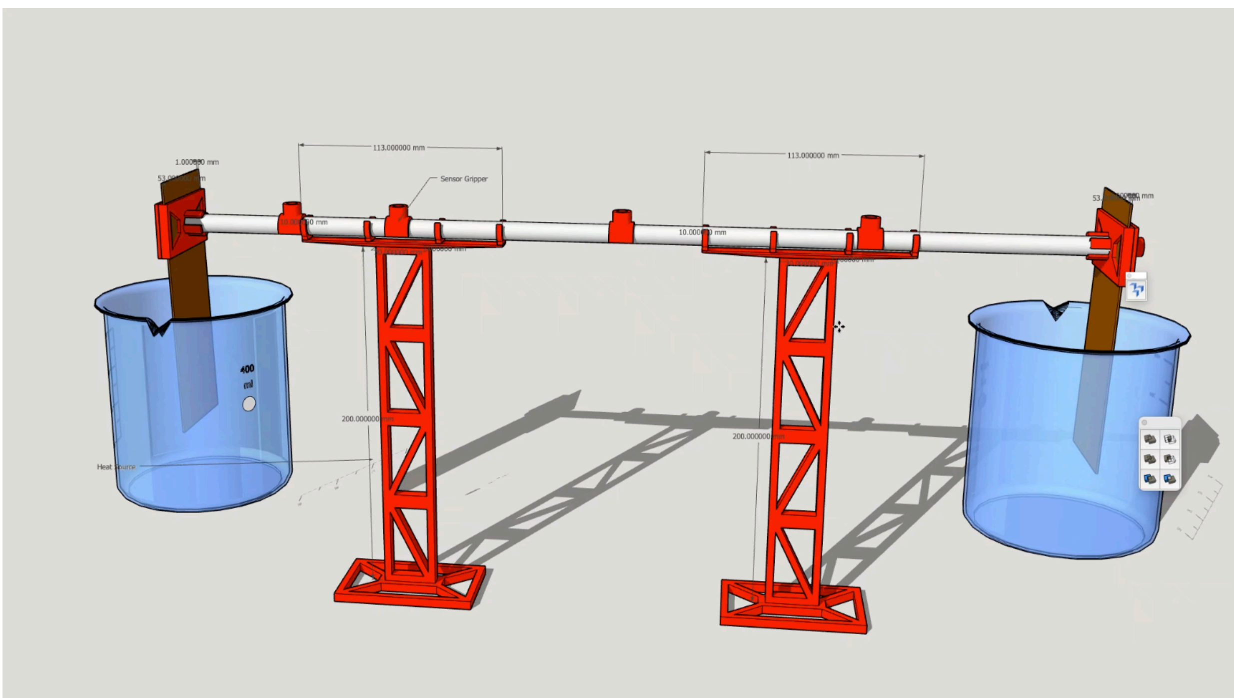

Figure 4: All Instruments(with 3D parts red)

The 3D parts include the support stand 5 for fixing the metal rod, the sheet stick connector 6 for connecting the metal rod to the copper sheet, the sheet fixer 7 for holding the copper sheet and mounting the sensor at both ends, and the sensor plier 8 for fixing the sensor to the metal rod, These main parts are made of resin or nylon to prevent melting due to high temperature.

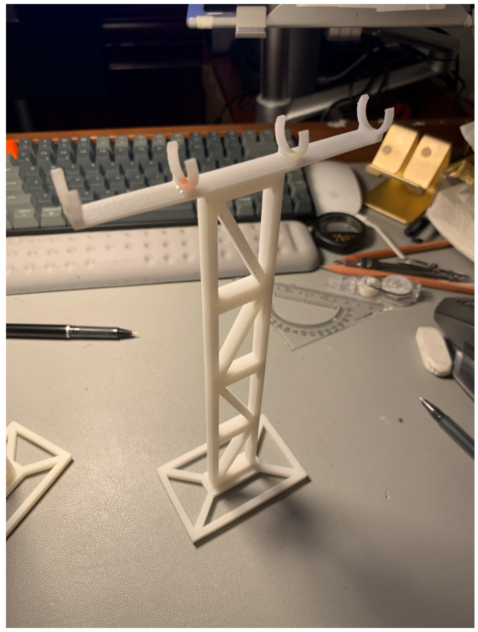

Figure 5: Support Stand

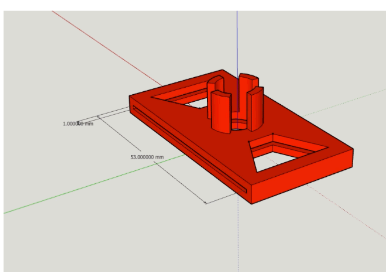

Figure 6: Sheet Stick Connector

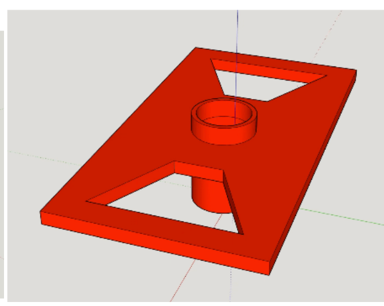

Figure 7: Sheet Fixer

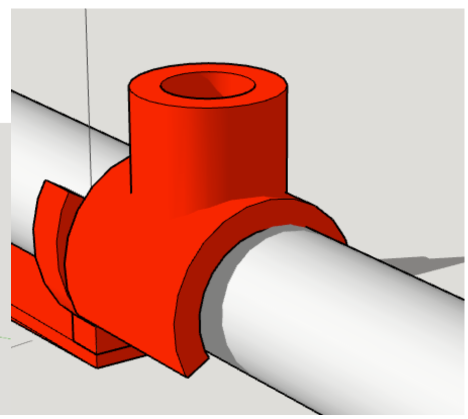

Figure 8: Senor Plier

4.1.2 Program Detailed

We have written an program to let the sensors and Arduino collect data and send to computer, plot the graph at the same time with the aid of MATLAB, Further details, we shown it by recording a video. refered to the video https://b23.tv/ADx0Op

4.2 Virtual Experiment Method

In this experiment, parallel virtual experiments are used as auxiliary and control. In this experiment, we use the finite element physical field simulation software COMSOL 9 as our

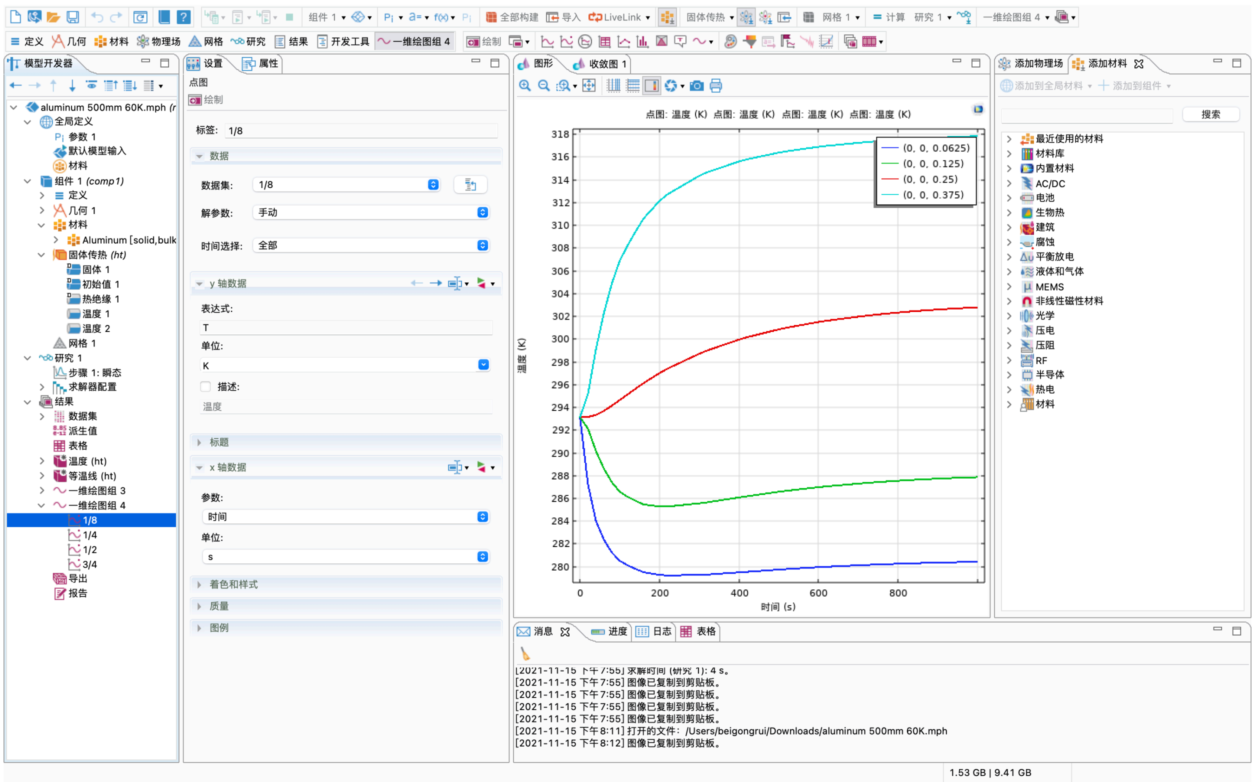

Figure 9: COMSOL inferface

main software. He will simulate and analyze the unsteady heat conduction experiment by solving the numerical interpretation of the following formula

$$\rho C_{\rho}\frac{\partial T}{\partial t} + \rho C_{\rho}\mathbf{u}\cdot\nabla T + \nabla\cdot\mathbf{q} = Q + Q_{\mathrm{ted}} \tag{4.1}$$

4.2.1 Virtual experiment operation

First do the experiment of Aluminium 250mm

1. Construct a 5mm radius and 250mm length cylinder, and select "Aluminum [solid,bulk]" as the material.

2. Set the initial temperature is 293.15K, set the temperature of the cylinder bottom surface is 273K.

3. Set the temperature of the cylinder top surface is 333K.

4. Set "time step" of "unsteady state" in the "research" is (0,20,1000), click"calulate".

5. Set the length of the sectional line is the whole length of the cylinder, and set four sectional points:1/8,1/4,1/2,3/4 in the "data set".

6. Set a "point diagram" in "one-dimensional plot", choose the whole length in the data set. Click "plot".
7. Set another four "point diagram" in"one-dimensional plot", choose 1/8,1/4,1/2,3/4 in the "data set", respectively. Click "plot".
8. Put all ploting data to shear plate, and derive them to one file.
9. Plot "two-dimensional" figures in Excel according to the data in files.
10. Change the the temperature of the cylinder top surface to "343K, 353K, 363K, 373K", respectively. And do the follow steps.
11. Obeserve the pictures in Comsol and Excel, then analyze them to verify our hypotheses.

Next change the material into Fe:

1. Construct a 5mm radius and 250mm length cylinder, and select "Iron[solid,0.00025/s strain rate]" as the material.
2. Then repeat the steps in "1)Aluminum 250mm".

Finally Change the length into 500mm

1. Construct a 5mm radius and 500mm length cylinder, and select "Aluminum [solid,bulk]" as the material.
2. Then repeat the steps in "1)Aluminum 250mm".

4.3 Detailed steps for verify the hypotheses

4.3.1 Hypothesis 1

Before reaching the steady-state, the speed of temperature change at the point becomes faster with the enhancement of thermal conductivity of the material.

steps: choose a fixed sectional point, keep the temperature difference and the length of the cylinder same, compare the slopes of the "two-dimensional" figures in Excel of different material (aluminum and iron).

4.3.2 Hypothesis 2

Before reaching a steady-state, the speed of temperature change at the point becomes faster with the shortening of the metal length.

steps: choose a fixed sectional point, keep the temperature difference and material of the cylinder constant. Change the length of the cylinder (aluminum 250mm and 500mm). Compare the slopes of the "two-dimensional" figures in Excel of different length.

4.3.3 Hypothesis 3

Before reaching the steady-state, the speed of temperature change at the point becomes faster with the increase of heat source temperature.

steps: choose a fixed sectional point, keep material and length of the cylinder constant. Change the temperature difference.Compare the slopes of the "two-dimensional" figures in Excel of different temperature difference.

5 Result & Discussion

5.1 Observations

1. The temperature of the points which are closer to the lower temperature will decrease first and then increase. Seen in 10 The two below curve. Which is hard to analyze its data.

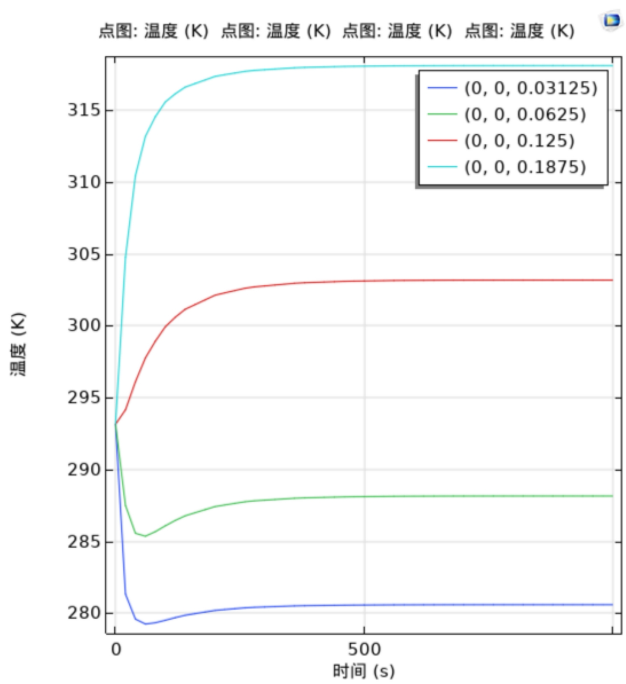

Figure 10: Observation 1

2. The temperature increases linearly first and then gradually flattens, similar to the exponential equation.

3. All temperature of all four points will finally reach the steady state.

4. The final steady-state temperature corresponding to all points increases as the distance from the origin increases,which is actually linear distributed finally,which is also called as Fourier's Law in thermal equilibrium.

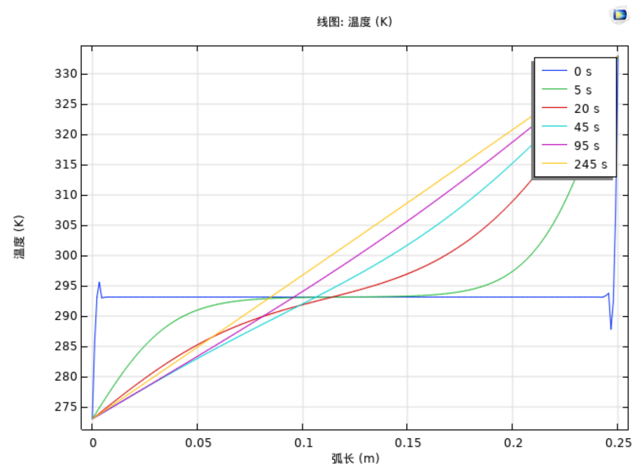

Figure 11: Observation 3

5. At the initial time, two peaks 15 appear in the two sections of the de curve. These two peaks may be due to the deviation of the numerical solution, which we ignore in the experiment.

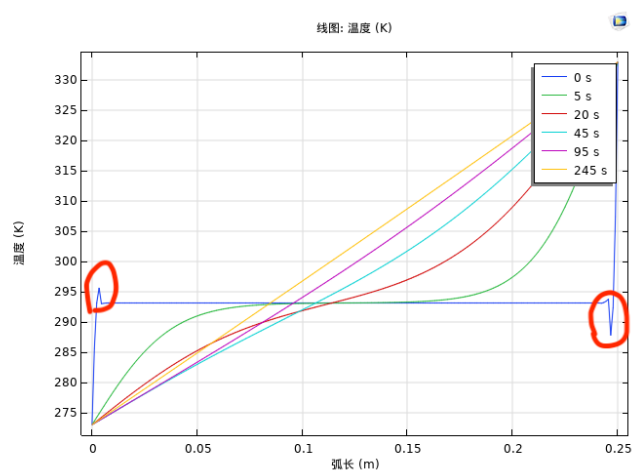

Figure 12: Observation 4

5.2 Data processing method

In this experiment, the dependent variable we explore is the speed of temperature change. Therefore, it is worth noting how to measure the speed of temperature change. In this data analysis, we will mainly compare two change speeds. One is the maximum slope of temperature in the whole change process, that is, the maximum temperature change rate;

The second is the average slope of temperature in the whole change process. When determining this value, we need to first determine when the experiment ends, that is, the temperature will not change sharply. We set this index at 0.01K/s, which means if the temperature doesn't change more than 0.01 degree per second.We will regard the system got equilibrium,the experiment end. By using this point we seperate the data into two part.The first part is the temperature change stage and the second part is stationary part.We calculate the average rate in temperature change stage as our average slope of temperature.

In the subsequent analysis, we will mainly use these two indicators as our standard to measure the fast full temperature change.

5.3 Hypothesis 1

Before discussing the results of hypothesis 1, it is necessary to clarify the concept of thermal conductivity rate.By Wikipedia , thermal conductivity rate could be simply defined by 5.1 :

$$q = -k \cdot \frac{T_2 - T_1}{L} \tag{5.1}$$

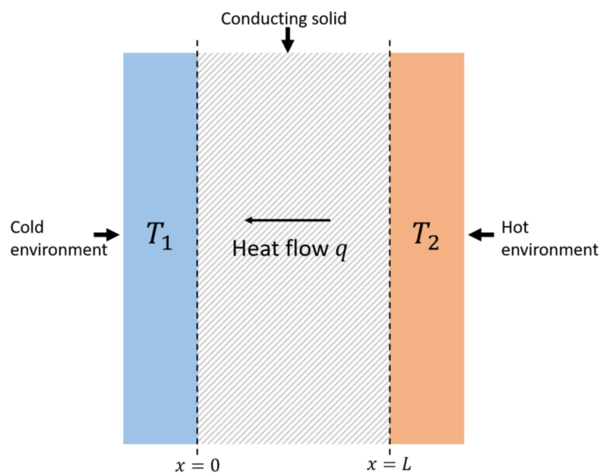

Figure 13: Thermal transfer Diagram

The thermal conductivity of a material is a measure of its ability to conduct heat. Generally speaking, metals have better thermal conductivity, which means that metals can transport more heat at the same time. By consulting the metal thermal conductivity data in COMSOL, we can find the following data :

Metal type	Thermal Conductivity Rate(Wm^-1K^-1)
Aluminum	237
Steel	80

Here, we first take the temperature change data of 250mm aluminum and iron at 1/2 of the whole length at the room temperature of 20°C, 0°C at one end and 100°C at the other end,and campare it with the Fe in same situation and same sampling point.

We have not fully completed the data analysis of this hypothesis, and further reports will be presented in the future.

5.4 Hypothesis 2

In this hypothesis, due to the change of length, we can have two understandings of the same position. First, the position in proportion, such as the midpoint; The second understanding is the same point in distance, such as 125mm from the heat source. Therefore, we analyze these two understandings separately here.

Firstly, we assume that it is the same point in proportion, so we extract the temperature change of aluminum under the conditions of 500mm and 250mm:

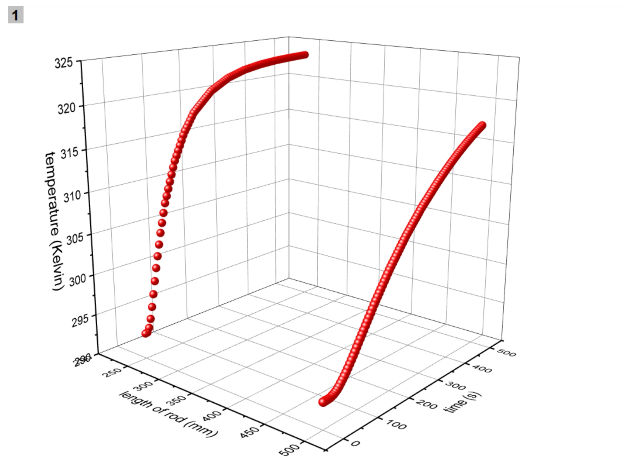

Figure 14: Maximum Point

The left hand sides curve represents the temperature of the center point of 250mm Aluminum rod, and the right hand sides curve represents 500mms. Its obvious to see that the 250mms Aluminum rod possesses a shorter time to reach the thermal equilibrium.

Because the shorter the cylinder is, the faster the speed of temperature change is. Then the hypothesis 2 is correct.

We have not fully completed the data analysis of this hypothesis, and further reports will be presented in the future

5.5 Hypothesis 3

First, take a visual look 15 at the three-dimensional image of temperature change drawn on Aluminum, 250mm, midpoint and high-temperature end between 60 and 100 in 0 to 500s.

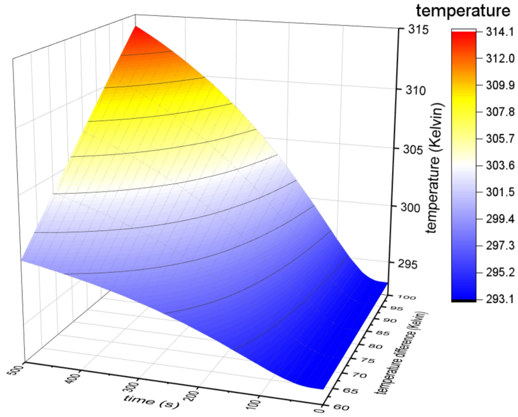

Figure 15: Hypothesis 3

There are two axis, one stands for time and the other represents ΔT. Its obvious to see that, when other variables controlled, larger the ΔT, the slope of the graph during the process of reaching thermal equilibrium is larger.

Because the ΔT is larger, the speed of temperature change is larger. Then the hypothesis 3 is correct.

Here we look into the detail of the data. Because the temperatures at both ends are not fixed, the steady-state temperatures at these points are different, and it is not meaningful to compare the average change rate. Therefore, here we analyze the relationship between the maximum rate and through the operation of MATLAB. We can get the time, temperature, value and corresponding position of the maximum slope in the figure, as shown in the following figure 16:

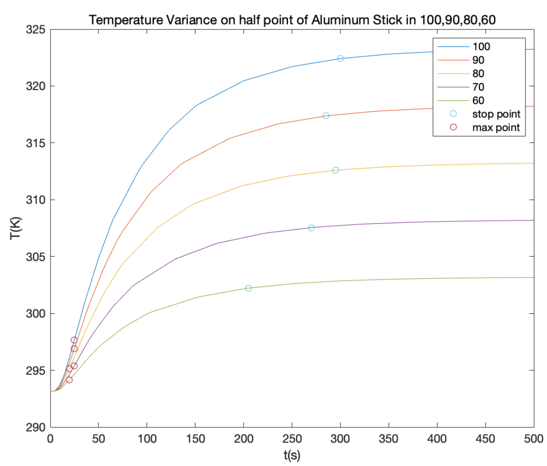

Figure 16: Maximum Point

And the chart below:

It is easy to find that the time to reach the maximum change rate is 20s to 25s, which is not at the beginning of the experiment. This may be because the temperature at the

Temperature	100K	90K	80K	70K	60K
Max Slope Time	25	25	20	25	20
Max Slope Temperature	297.66	296.90	295.13	295.40	294.15
Max Slope	0.31	0.26	0.20	0.15	0.10

midpoint does not start to rise at the beginning, and it is necessary to wait for the increase of the temperature difference.

By plotting, we can find the relationship between the maximum slope and the heat source temperature. And apply Curve Fitting Tools,we derive that the linear relation between the temperature and Maximum Slope:

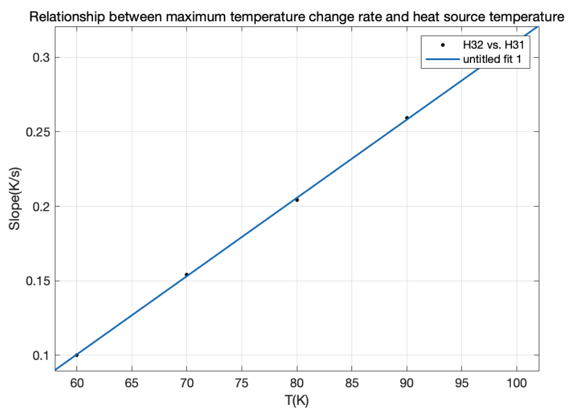

Figure 17: Relationship between maximum temperature change rate and heat source temperature

```
Result of CFTtool
 Linear model Poly1:
 f(x) =pl*x+p2
 where x is normalized by
 Coefficients (with 95 confididence)
 p1= 0.08311
 p2= 0.2056
 Goodness of fit:
 SSE: 4.854e-06
 R-square: 0.9998
 Adjusted R-square: 0.9998
 RMSE: 0.001272
```

Therefore, we can find that the two show a very clear linear relationship.

6 Conclusion & Recommendation

6.1 Conclusion

Based on our 3 simulation experiments, we conclude 3 result:

1. The ratio of temperature change with time will be different with the change of material.Better the thermal conductivity is, faster will the temperature change.
2. The ratio of temperature change with time will increase with the temperature difference between two sides of the rod increases.
3. The ratio of temperature change with time will decrease with the length of the metal rod's certain point to the heat source increases.

6.2 Recommendation

1. The time interval is 5 seconds per point, but for precise data, 5 second is too long, the time interval will be shorten to 1 second.
2. The range of time is also an issue. 500 seconds can let some of our experiment sets reaches a thermal equilibrium state, but some dont. For a picture of whole view, we should increase the range of our recording time to 1000 seconds.
3. More sampling point could be added,to get more precise data

7 Overall Budget

We have purchased most of the required materials and tools, and left a sufficient budget to meet the impact of uncertain factors, such as the damage of 3D printing parts and sensors. If necessary, we can purchase more materials from the remaining budget for testing, so as to make the experiment more sufficient.

Below is the budget list before 15th November,2021.The total spending is about RM 244.99. The Snapshot of the Invoice has been uploaded in OneDrive

Lab Budget(Midterm)					
Forming time	2021/11/15			Group 4	Guo Yiming
Exchange Rate Date	2021/11/15	RM/CNY	0.65	Guo Yiming,Yang Ziou,Zhang Zhirui	
Date	Price(CNY)	Price(RM)	Operator	Remarks	Voucher / Screenshot / Invoice
2021-10-16	CNY 15.00	MYR 9.75	guoyiming	0.5*50*150 Copper PieceX3	001
2021-10-17	CNY 14.80	MYR 9.62	guoyiming	Thermal Conductive Silicone Grease	002
2021-10-17	CNY 33.80	MYR 21.97	guoyiming	10mm*1m Carbon SteelX2	003
2021-10-17	CNY 9.37	MYR 6.09	guoyiming	Sensor for testing,LM35,DS18B20,DS18B20X1	004
2021-10-17	CNY 110.00	MYR 71.50	guoyiming	3D Printing,One nylon bracket, two copper connectors, four sensor grips	005
2021-10-17	CNY 5.86	MYR 3.81	guoyiming	Copper foil	006
2021-10-17	CNY 20.00	MYR 13.00	guoyiming	3D Printing,Copper piece fixer	007
2021-11-07	CNY 18.00	MYR 11.70	guoyiming	DS18B20 sensor 15 piece made in taiwan	008
2021-11-02	CNY 12.00	MYR 7.80	guoyiming	Aluminum 10mm 500mm 2 sticks	009
2021-10-31	CNY 130.00	MYR 84.50	guoyiming	3Dprinting(Resin support stand X2,white nylon support X2 white nylon plierX10)	010
2021-10-28	CNY 8.07	MYR 5.25	guoyiming	rubber for fix the parts	011
Total	CNY 376.90	MYR 244.99			

Figure 18: Midterm Budget

A MATLAB Program for Collecting Data(Test Version)

A.1 Function to interpret the signal from DS18B20

```
        function [celsius] = gettemperature(sensor,addr)
reset(sensor);
write(sensor, addr, hex2dec('44'), true);

reset(sensor);
write(sensor, addr, hex2dec('BE')); % read command - 'BE'
data = read(sensor, addr, 9);
crc = data(9);
if ~checkCRC(sensor, data(1:8), crc, 'crc8')
    error('Invalid data read.');
end
raw = bitshift(data(2),8)+data(1);
cfg = bitshift(bitand(data(5), hex2dec('60')), -5);
switch cfg
    case bin2dec('00')  % 9-bit resolution, 93.75 ms conversion time
        raw = bitand(raw, hex2dec('fff8'));
    case bin2dec('01')  % 10-bit resolution, 187.5 ms conversion time
        raw = bitand(raw, hex2dec('fffC'));
    case bin2dec('10')  % 11-bit resolution, 375 ms conversion time
        raw = bitand(raw, hex2dec('fffE'));
    case bin2dec('11')  % 12-bit resolution, 750 ms conversion time
    otherwise
        error('Invalid resolution configuration');
end
% Convert temperature reading from unsigned 16-bit value to signed 16-bit.
raw = typecast(uint16(raw), 'int16');
celsius = double(raw) / 16.0;
fahrenheit = celsius * 1.8 + 32.0;
end
```

A.2 Data Collecting from two sensor in parallel one pin(10)

```
        clc
clear
a = arduino('/dev/cu.usbmodem14301','Uno','libraries','PaulStoffregen/OneWire'
    );
sensor = addon(a, 'PaulStoffregen/OneWire', 'D10');
addr = sensor.AvailableAddresses{1};
addr2 = sensor.AvailableAddresses{2};

celsiusdatabase=[];
h1 = animatedline('Color','r');
h2 = animatedline('Color','b');

legend('1st sensor','2nd sensor')
ylim([20 200]);

for hsecond=1:300
pause(0.5)
celsius1=gettemperature(sensor,addr);
celsius2=gettemperature(sensor,addr2)-5;

addpoints(h1,hsecond,celsius1);
addpoints(h2,hsecond,celsius2);

sprintf('Temperature 1 = %.4f Celsius', celsius1)
sprintf('Temperature 2 = %.4f Celsius', celsius2)

xlim([1 max(100,hsecond)]);

drawnow
celsiusdatabase=[celsiusdatabase;[hsecond,celsius1 ,celsius2]];
end
```

B MATLAB Data Proceding Program(Completed)

B.1 get temperature difference

```
function [Hdiff] = getdiff(Hdata)
% Written By Guo 2021/11/16
Hdata1=Hdata;
Hdata2=Hdata;

Hdata1(end,:)=[];
```

```
Hdata2(1,:)=[]; %shift the data for 1 position
Hdiff=Hdata2-Hdata1; %get the difference
Hdiff(:,1)=[];
Hdiff=[Hdata1(:,1),Hdiff]; %delete and add the time coordinate.
end
```

B.2 get average slope

```
function [stoppoint] = getavrate(Hdata,stopslope,startposition)
Hdata1=Hdata;
Hdiff=getdiff(Hdata1);
sizenumber=size(Hdiff);
stoppoint=[];
for i=2:sizenumber(2)
    j=startposition;
    while Hdiff(j,i)>stopslope
        j=j+1;
    end
    avslope=(Hdata(j,i)-Hdata(1,i))/(Hdata(j,1)-Hdata(1,1));
    stoppoint=[stoppoint,[Hdiff(j,1);Hdata1(j,i);avslope]];
end
```

B.3 get the maximum slope

```
function [hmax] = getmaxrate(Hdata)
Hdiff=getdiff(Hdata);
sizenumber=size(Hdiff);
Hnumber=sizenumber(2);
hmax=[];
for i=2:Hnumber
    [maxnumber,maxposition]=max(Hdiff(:,i));
    maxslope=maxnumber/(Hdata(2,1)-Hdata(1,1));
    hmax=[hmax,[Hdiff(maxposition,1);Hdata(maxposition,i);maxslope]];
end
```

C Hypotheis 3 Data Analysis

```
hold off
clear
load Vdata


```

```
H3data=[Al250100(:,1),Al250100(:,4),Al25090(:,4),Al25080(:,4),Al25070(:,4),
    Al25060(:,4)];


H3data1=H3data;
H3data2=H3data;
H3data1(1,:)=[];
H3data2(end,:)=[];
H3diff=[H3data2(:,1),(H3data1-H3data2)/5];
H3diff(:,2)=[];
H3stop=[];
for i=1:5
    test=8;
    while H3diff(test,i+1)>0.01
        test=test+1;
    end
    H3stop=[H3stop,[H3diff(test,1);H3data(test,i+1)]];
end
H3stop=H3stop';

plot(H3data(:,1),H3data(:,2),H3data(:,1),H3data(:,3),H3data(:,1),H3data(:,4),
    H3data(:,1),H3data(:,5),H3data(:,1),H3data(:,6))
hold on
scatter(H3stop(:,1),H3stop(:,2));
hold on
hmax=getmaxrate(H3data);
hmax=hmax';
scatter(hmax(:,1),hmax(:,2));
hold on
legend('100','90','80','70','60','stop point','max point')
title('Temperature Variance on half point of Aluminum Stick in 100,90,80,60')
xlabel('t(s)')
ylabel('T(K)')
```