

Abstract:

This experiment investigate the possibility of measuring a temperature using four different devices [RTD resistance temperature doctor, thermocouple, thermistor , thermometer] ~~and accomplished familiar characteristics for each different kind of devices and the principle working and mathematical function behavior (Linear or exponential).~~

The RTD is composed of certain metallic elements whose change in resistance is a function of temperature. A thermocouple consists of a welded 'hot' junction between two dissimilar metals -usually wires - and a reference junction at the opposite ends of the parent materials. A thermistor compose of sintered semiconductor material which exhibits a large change in resistance proportional to a small change in temperature. Thermistors usually have negative temperature coefficients which means the resistance of the thermistor decreases as the temperature increases. Thermometer contains a liquid (usually mercury or an alcohol solution) in a reservoir whose volume is linearly dependent on the temperature (directly proportional).

~~Based on the experiment results the following was found:~~ *It was sheet*  
For RTD:  $T_{\text{theor}}=42.1323^{\circ}\text{C}$ ,  $T_{\text{exp}}=41.954875^{\circ}\text{C}$  and percentage error  $E\%=0.4211\%$ , *white,*  
For Thermistor:  $T_{\text{theor}}=44.4587^{\circ}\text{C}$ ,  $T_{\text{exp}}=44.4586^{\circ}\text{C}$  and percentage error  $E\%=4.948 \times 10^{-5}\%$ , *and.*  
For Thermocouple:  $T_{\text{theor}}=31.1388^{\circ}\text{C}$ ,  $T_{\text{exp}}=31.22117^{\circ}\text{C}$  and percentage error  $E\%=-0.2645\%$ .  
According on the error values found the Thermistor is the most accurate device.

Nomenclature:

$$A=3.90802 \cdot 10^3$$

$$B=-5.80195 \cdot 10^{-7}$$

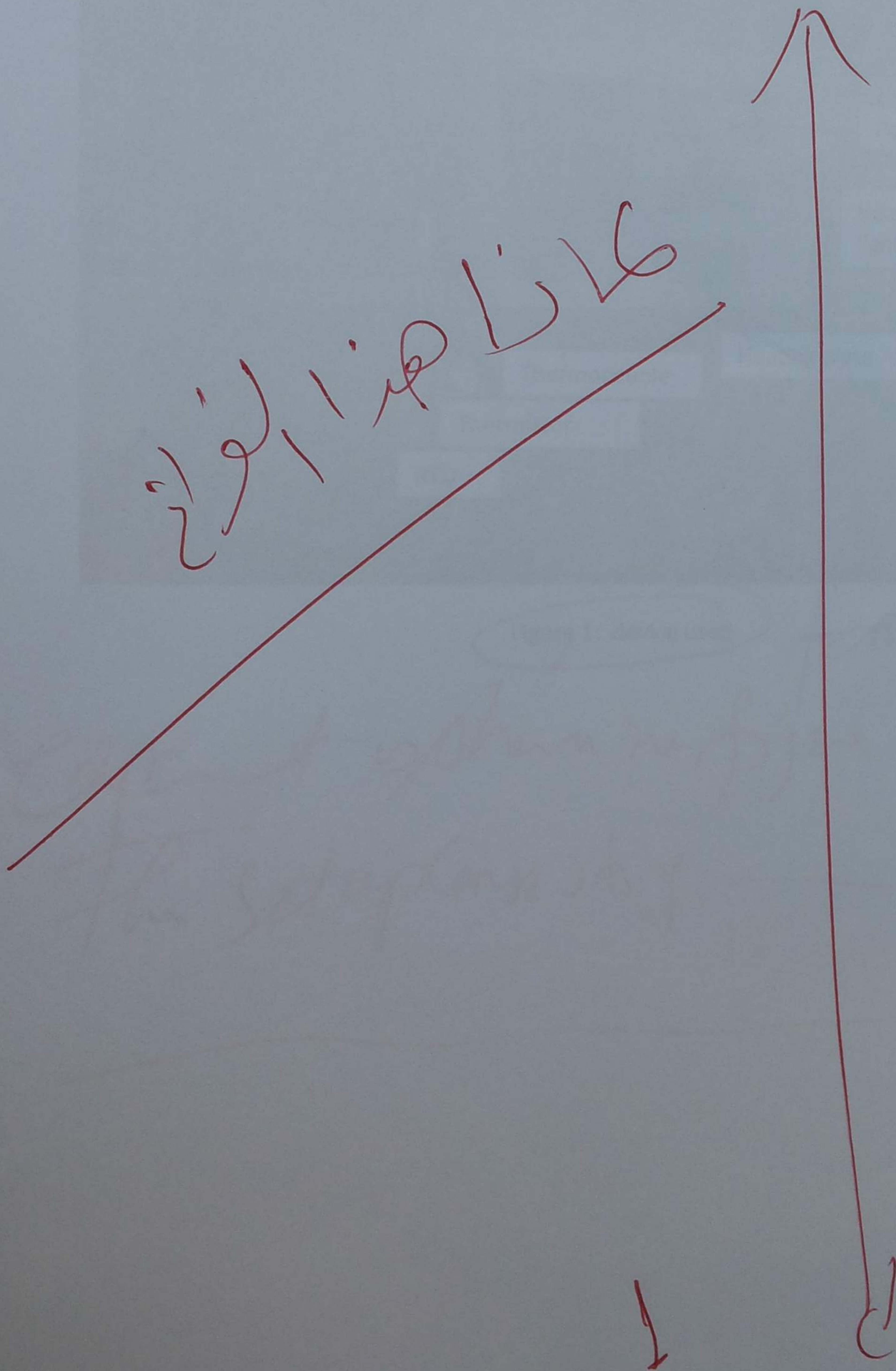
R: measured resistance ( $\Omega$ )

$R^0$ : RTD normal resistance at  $0(C^{\circ})$ ,  $R^0=100\Omega$

T: calculated temperature in ( $C^{\circ}$ )

### Objectives:

The aim of this experiment is to become familiar with different thermometers (RTD, Thermocouple, Thermistor) and their thermal response. Then to be able to examine some of their properties and behavior such as the voltages/temperatures relationship of a thermocouple, resistance/temperatures relationship of RTD and thermistor.



Apparatus used :

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The setup used for this

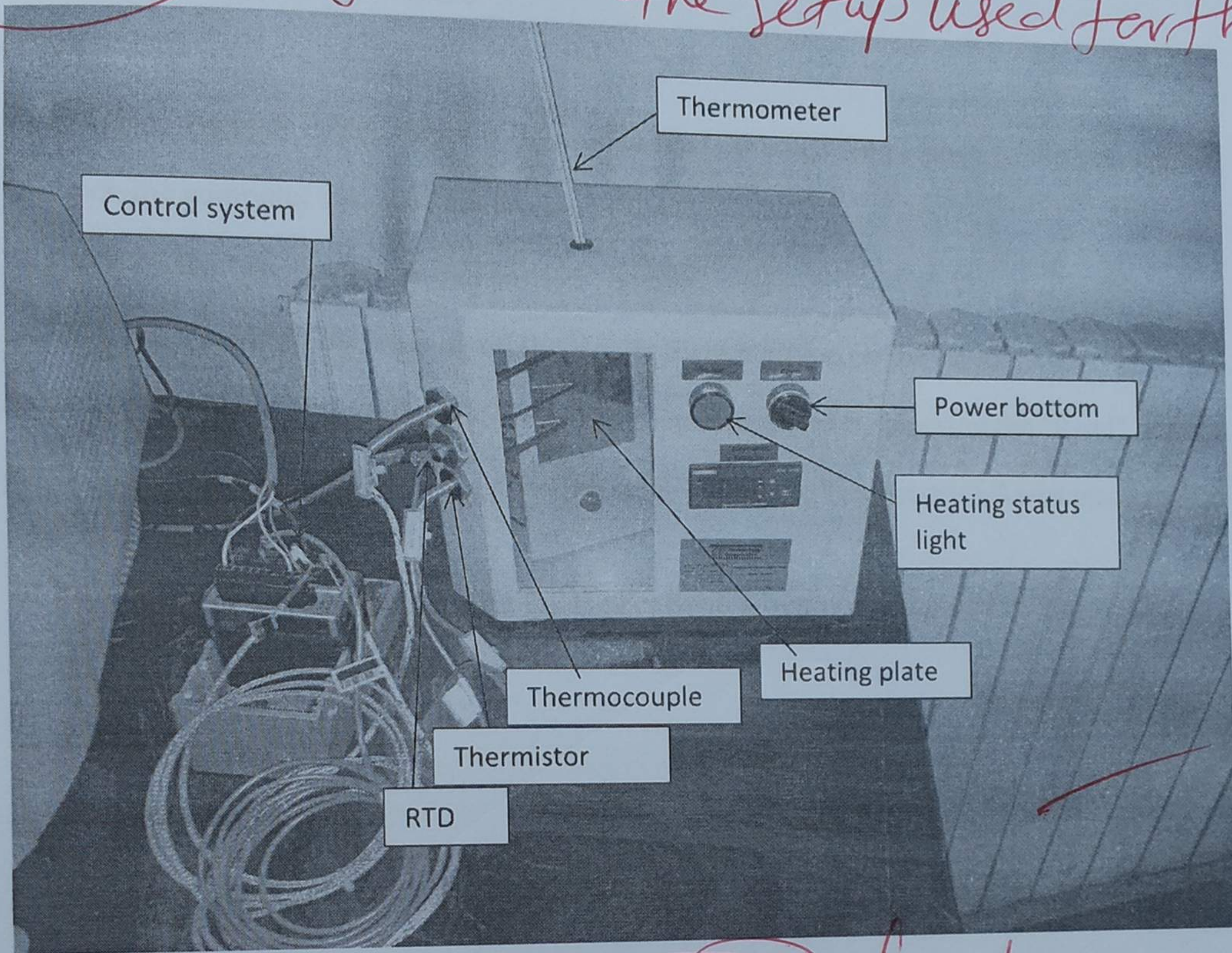
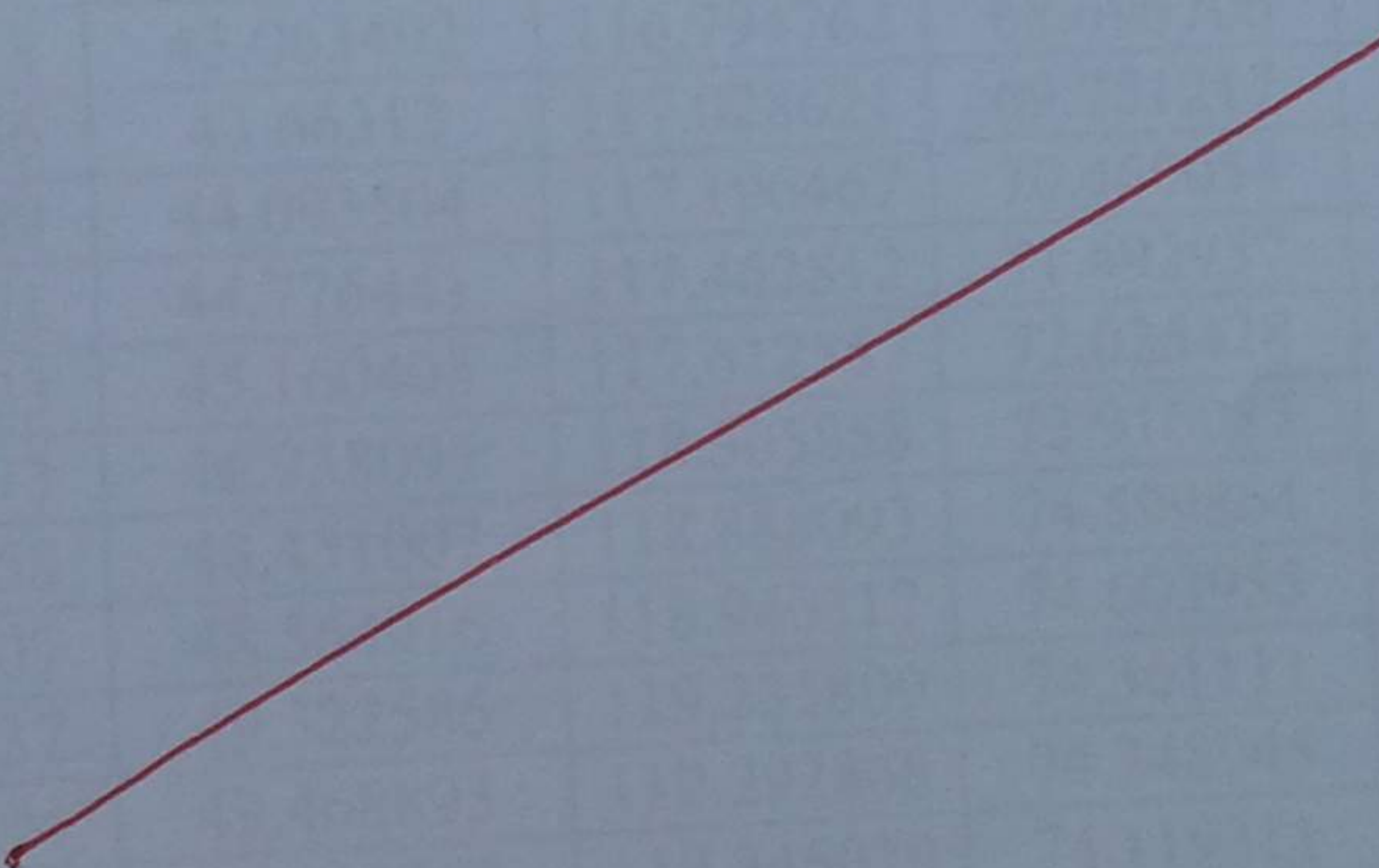


Figure 1: device used

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Experiment is shown in figure (1) below.  
The setup consists of

Experimental setup and procedure:

- 1- Standard mercury thermometer is inserted to read the exact temperature of the heat source.
  - 2- Open the computer and start the program (TMT).
  - 3- Click on the "Thermometer comparison" bottom.
  - 4- Turn the Heater on by pressing on the Heater Switch button on the screen.
  - 5- Start recording the readings of different temperature values by pressing the "Read" bottom.
  - 6- The readings will appear on the (Temperature-Voltage or Temperature-Resistance graph) as read points.
  - 7- Turn the heater off by pressing on the Heater Switch button on the screen.
  - 8- Turn the Fan on (cooling).
  - 9- Repeat the same procedure.
  - 10- Compare the results.
- 

Data observed:

Table 1: data observed for temperature measurement devices while heating .

| Thermocouple                        |                  | RTD                                 |                          | Thermistor                          |                           |
|-------------------------------------|------------------|-------------------------------------|--------------------------|-------------------------------------|---------------------------|
| Heating T<br>( $^{\circ}\text{C}$ ) | Heating<br>V(mV) | Heating T<br>( $^{\circ}\text{C}$ ) | Heating<br>R( $\Omega$ ) | Heating T<br>( $^{\circ}\text{C}$ ) | Heating R<br>( $\Omega$ ) |
| 26.120446                           | 1.335305         | 28.203398                           | 110.999325               | 30.758838                           | 4680.606197               |
| 26.889715                           | 1.375173         | 29.701741                           | 111.583679               | 35.193417                           | 3887.645119               |
| 27.664533                           | 1.415357         | 31.093485                           | 112.126459               | 39.217991                           | 3298.278916               |
| 27.837131                           | 1.424312         | 31.369961                           | 112.234285               | 40.001537                           | 3195.779901               |
| 28.834887                           | 1.476109         | 33.00434                            | 112.871693               | 44.458678                           | 2677.54079                |
| 29.457091                           | 1.508434         | 33.952778                           | 113.241583               | 46.924902                           | 2432.441499               |
| 30.361822                           | 1.555469         | 35.264361                           | 113.753101               | 50.229092                           | 2143.272438               |
| 31.22117                            | 1.60018          | 36.454846                           | 114.21739                | 53.209183                           | 1915.856505               |
| 32.25675                            | 1.654105         | 37.850315                           | 114.761623               | 56.700798                           | 1683.826815               |
| 33.345519                           | 1.710854         | 39.261767                           | 115.312089               | 60.234118                           | 1481.302141               |
| 33.902815                           | 1.739922         | 39.950289                           | 115.580613               | 61.952422                           | 1393.037432               |
| 34.910747                           | 1.79253          | 41.131114                           | 116.041134               | 64.749037                           | 1262.017236               |
| 35.344918                           | 1.815205         | 41.626145                           | 116.234197               | 65.844751                           | 1214.600427               |
| 35.635965                           | 1.830411         | 41.954875                           | 116.362401               | 66.536659                           | 1185.717504               |
| 36.627089                           | 1.882218         | 43.063492                           | 116.794762               | 68.696706                           | 1100.521958               |
| 37.186064                           | 1.911456         | 43.66313                            | 117.028621               | 69.751217                           | 1061.512176               |
| 37.598909                           | 1.933059         | 44.093504                           | 117.196467               | 70.460054                           | 1036.18783                |
| 38.267898                           | 1.968081         | 44.776441                           | 117.462812               | 71.492957                           | 1000.525713               |
| 38.652494                           | 1.988223         | 45.160403                           | 117.612557               | 72.025428                           | 982.697158                |
| 40.541937                           | 2.087273         | 46.938097                           | 118.305858               | 73.916087                           | 922.29649                 |
| 42.311369                           | 2.180168         | 48.431007                           | 118.888093               | 74.599864                           | 901.518309                |
| 42.491016                           | 2.189607         | 48.564916                           | 118.940317               | 74.603955                           | 901.395643                |
| 43.515051                           | 2.243437         | 49.322586                           | 119.235809               | 74.361111                           | 908.71119                 |
| 43.729109                           | 2.254694         | 49.468893                           | 119.292868               | 74.248945                           | 912.113304                |
| 43.947402                           | 2.266177         | 49.602767                           | 119.345079               | 74.119311                           | 916.063661                |
| 44.075236                           | 2.272902         | 49.685518                           | 119.377352               | 74.023632                           | 918.992008                |
| 44.408202                           | 2.290422         | 49.8792                             | 119.452888               | 73.755057                           | 927.27011                 |

Table 2: data observed for temperature measurement devices while cooling .

| Thermocouple                        |                  | RTD                                 |                          | Thermistor                          |                          |
|-------------------------------------|------------------|-------------------------------------|--------------------------|-------------------------------------|--------------------------|
| Cooling T<br>( $^{\circ}\text{C}$ ) | Cooling<br>V(mV) | Cooling T<br>( $^{\circ}\text{C}$ ) | Cooling<br>R( $\Omega$ ) | Cooling T<br>( $^{\circ}\text{C}$ ) | Cooling<br>R( $\Omega$ ) |
| 25.48235                            | 1.302257         | 26.71812                            | 110.420067               | 26.687255                           | 5574.096744              |
| 44.942816                           | 2.318562         | 50.17356                            | 119.567688               | 73.184434                           | 945.14623                |
| 45.110193                           | 2.327374         | 50.259617                           | 119.601251               | 72.978859                           | 951.683846               |
| 45.20961                            | 2.332608         | 50.311156                           | 119.621351               | 72.857753                           | 955.559728               |
| 45.266521                           | 2.335605         | 50.334117                           | 119.630305               | 72.808734                           | 957.133738               |
| 45.320331                           | 2.338439         | 50.356515                           | 119.639041               | 72.747139                           | 959.115801               |

|           |          |           |            |           |             |
|-----------|----------|-----------|------------|-----------|-------------|
| 45.320331 | 2.338439 | 50.356515 | 119.639041 | 72.747139 | 959.115801  |
| 45.365892 | 2.340839 | 50.37779  | 119.647338 | 72.653948 | 962.12363   |
| 45.421398 | 2.343762 | 50.398583 | 119.655447 | 72.538442 | 965.866832  |
| 45.421398 | 2.343762 | 50.398583 | 119.655447 | 72.538442 | 965.866832  |
| 45.461059 | 2.34585  | 50.414157 | 119.661521 | 72.412541 | 969.966142  |
| 45.461059 | 2.34585  | 50.414157 | 119.661521 | 72.412541 | 969.966142  |
| 45.503235 | 2.348072 | 50.429411 | 119.66747  | 72.274855 | 974.472253  |
| 45.548807 | 2.350472 | 50.444183 | 119.673231 | 72.130164 | 979.233711  |
| 45.921007 | 2.370079 | 50.520534 | 119.703008 | 70.149203 | 1047.206524 |
| 45.97674  | 2.373015 | 50.528562 | 119.706139 | 69.629253 | 1065.941308 |
| 46.064723 | 2.377651 | 50.521417 | 119.703352 | 68.509996 | 1107.600308 |
| 46.158613 | 2.382598 | 50.466502 | 119.681936 | 66.722288 | 1178.104054 |
| 46.215066 | 2.385573 | 50.321352 | 119.625327 | 64.110347 | 1290.640431 |
| 46.211685 | 2.385395 | 50.309471 | 119.620694 | 63.967883 | 1297.126728 |
| 46.203121 | 2.384944 | 50.217953 | 119.585002 | 63.014884 | 1341.495653 |
| 46.205951 | 2.385093 | 50.186645 | 119.572791 | 62.760627 | 1353.627107 |
| 46.190356 | 2.384271 | 50.127803 | 119.549843 | 62.305688 | 1375.650726 |
| 46.17704  | 2.383569 | 50.101472 | 119.539574 | 62.080353 | 1386.711978 |
| 46.160879 | 2.382718 | 50.048813 | 119.519037 | 61.610422 | 1410.111213 |
| 46.13     | 2.381091 | 49.978173 | 119.491488 | 61.038647 | 1439.197537 |
| 46.080144 | 2.378464 | 49.874464 | 119.451041 | 60.284265 | 1478.636651 |
| 46.006482 | 2.374582 | 49.721958 | 119.391564 | 59.390986 | 1526.95656  |
| 45.962877 | 2.372285 | 49.663606 | 119.368806 | 59.018538 | 1547.63836  |
| 45.928585 | 2.370478 | 49.566409 | 119.330899 | 58.499273 | 1577.013199 |
| 45.817537 | 2.364628 | 49.370418 | 119.254463 | 57.505624 | 1635.030635 |
| 45.772523 | 2.362256 | 49.29522  | 119.225136 | 57.135869 | 1657.243887 |
| 45.721512 | 2.359569 | 49.185675 | 119.182413 | 56.571406 | 1691.82704  |
| 45.673947 | 2.357063 | 49.104783 | 119.150866 | 56.22578  | 1713.41194  |
| 45.63597  | 2.355063 | 49.033684 | 119.123137 | 55.910124 | 1733.402177 |
| 45.422666 | 2.343828 | 48.681821 | 118.98591  | 54.765479 | 1808.173585 |
| 45.090042 | 2.326313 | 48.136491 | 118.773232 | 53.180691 | 1917.895521 |
| 44.989178 | 2.321002 | 47.960886 | 118.704746 | 52.736885 | 1949.979034 |
| 44.944398 | 2.318645 | 47.896551 | 118.679655 | 52.548597 | 1963.776497 |
| 44.912932 | 2.316988 | 47.827484 | 118.652719 | 52.376745 | 1976.467459 |
| 44.848046 | 2.313572 | 47.738285 | 118.617931 | 52.115866 | 1995.913207 |
| 44.760481 | 2.308963 | 47.609064 | 118.567535 | 51.75378  | 2023.267807 |
| 44.693017 | 2.305412 | 47.501985 | 118.525774 | 51.4267   | 2048.348072 |
| 44.658156 | 2.303577 | 47.462042 | 118.510196 | 51.316959 | 2056.842718 |
| 44.592408 | 2.300116 | 47.377826 | 118.477352 | 51.102121 | 2073.589806 |
| 44.42716  | 2.29142  | 47.157192 | 118.391305 | 50.627426 | 2111.150748 |
| 44.184202 | 2.278635 | 46.840824 | 118.267921 | 49.991612 | 2162.689397 |
| 43.234939 | 2.228708 | 45.543291 | 117.761883 | 47.503569 | 2378.717385 |
| 42.309453 | 2.180068 | 44.366565 | 117.30296  | 45.628237 | 2557.947341 |
| 42.067841 | 2.167375 | 44.083489 | 117.192561 | 45.201275 | 2600.883699 |
| 42.042852 | 2.166063 | 44.048637 | 117.178969 | 45.144282 | 2606.677181 |
| 42.023257 | 2.165033 | 44.025002 | 117.169751 | 45.115616 | 2609.596766 |
| 41.857981 | 2.156353 | 43.830481 | 117.093888 | 44.839108 | 2637.951472 |
| 41.799481 | 2.15328  | 43.775364 | 117.072392 | 44.752943 | 2646.859178 |

sample of calculation

Temperature calculation for the Resistance Temperature Detector (RTD)

$$T = \frac{R_0 - R}{-0.5(R_0 A + \sqrt{R_0^2 A^2 - 4R_0 B(R_0 - R)})}$$

where:

T: calculated temperature in  $^{\circ}\text{C}$

$R_0$ : RTD nominal resistance at  $0^{\circ}\text{C}$ ,  $R_0 = 100\ \Omega$ .

R: measured resistance ( $\Omega$ ).

$$A = 3.90802 \times 10^{-3}$$

$$B = -5.80195 \times 10^{-7}$$

shaded data was used

$$R = 116.362401\ \Omega$$

$$T_{\text{exp}} = 41.954875^{\circ}\text{C}$$

$$T_{\text{theor}} = \frac{(100 - 116.362401)}{-0.5(100 \times 3.90802 \times 10^{-3} + \sqrt{(100 \times 3.90802 \times 10^{-3})^2 - 400 \times (-5.80195 \times 10^{-7})(100 - 116.362401)}}$$

$$T_{\text{theor}} = 42.1323^{\circ}\text{C}$$

$$\begin{aligned} \text{Error} &= T_{\text{theor}} - T_{\text{exp}} \\ &= 42.1323 - 41.954875 \\ &= 0.17744^{\circ}\text{C} \end{aligned}$$

$$\begin{aligned} \text{Error \%} &= \frac{T_{\text{theor}} - T_{\text{exp}}}{T_{\text{theor}}} \times 100\% \\ &= \frac{42.1323 - 41.954875}{42.1323} \times 100\% \\ &= 0.4211\% \end{aligned}$$

# Temperature calculation for Thermistor

$$T = \frac{1}{a + b(\ln(R)) + c(\ln(R))^3}$$

where

T: calculated temperature in (K),

R: Measured resistance in ( $\Omega$ )

a, b and c are Steinhart-Hart constants that have the following values:-

$$a = 1.2407635 \times 10^{-3}$$

$$b = 2.3612017 \times 10^{-4}$$

$$c = 8.97975 \times 10^{-8}$$

data shared was used

$$R = 2677.54079 \Omega$$

$$T_{exp} = 44.458678^\circ C$$

$$T_{theor} = \frac{1}{(1.2407635 \times 10^{-3}) + (2.3612017 \times 10^{-4}) \ln(2677.54079) + 8.97975 \times 10^{-8} (\ln(2677.54079))^3}$$

$$T_{theor} = 317.6087 K$$

$$= 44.4587^\circ C$$

$$Error = T_{theor} - T_{exp}$$

$$= 44.4587 - 44.458678$$

$$= 2.2 \times 10^{-5}^\circ C$$

$$Error \% = \frac{T_{theor} - T_{exp}}{T_{theor}} \times 100\%$$

$$= \frac{44.4587 - 44.458678}{44.4587} \times 100\%$$

$$= 4.948 \times 10^{-5} \%$$

temperature calculation for Thermocouple  
data shared was used

$$= V(1.978425 \times 10^{-2}) + V^2(-2.001204 \times 10^{-7}) + V^3(1.036969 \times 10^{-11}) \\ + V^4(-2.549687 \times 10^{-16}) + V^5(3.585153 \times 10^{-21}) + V^6(-5.344285 \times 10^{-26}) \\ + V^7(5.09989 \times 10^{-31})$$

where:

T: calculated temperature in  $^{\circ}\text{C}$

V: thermocouple voltage in microvolt

$$V = 1.60018 \text{ mV}$$

$$T_{\text{exp}} = 31.22117^{\circ}\text{C}$$

$$T_{\text{theor}} = (1.60018 \times 10^3) (1.978425 \times 10^{-2}) + (1.60018 \times 10^3)^2 (-2.001204 \times 10^{-7}) \\ + (1.60018 \times 10^3)^3 (1.036969 \times 10^{-11}) + (1.60018 \times 10^3)^4 (-2.549687 \times 10^{-16}) \\ + (1.60018 \times 10^3)^5 (3.585153 \times 10^{-21}) + (1.60018 \times 10^3)^6 (-5.344285 \times 10^{-26}) \\ + (1.60018 \times 10^3)^7 (5.09989 \times 10^{-31})$$

$$T_{\text{theor}} = 31.1388^{\circ}\text{C}$$

$$\text{Error} = T_{\text{theor}} - T_{\text{exp}} \\ = 31.1388 - 31.22117 \\ = -0.08237^{\circ}\text{C}$$

$$\text{Error } \% = \frac{T_{\text{theor}} - T_{\text{exp}}}{T_{\text{theor}}} \times 100\% \\ = \frac{31.1388 - 31.22117}{31.1388} \times 100\% \\ \text{Error } \% = -0.2645 \%$$

## Results and discussion:

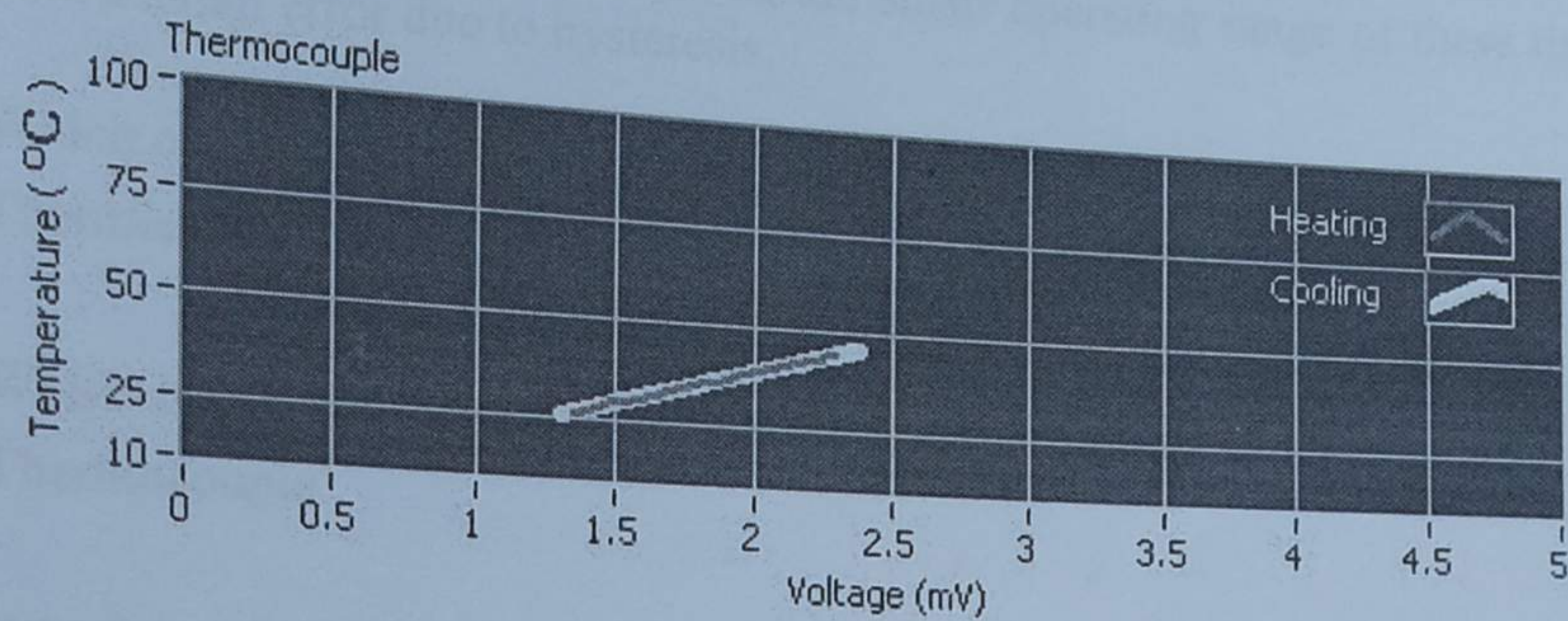


Figure 2: temperature variation as voltage change for thermocouple .

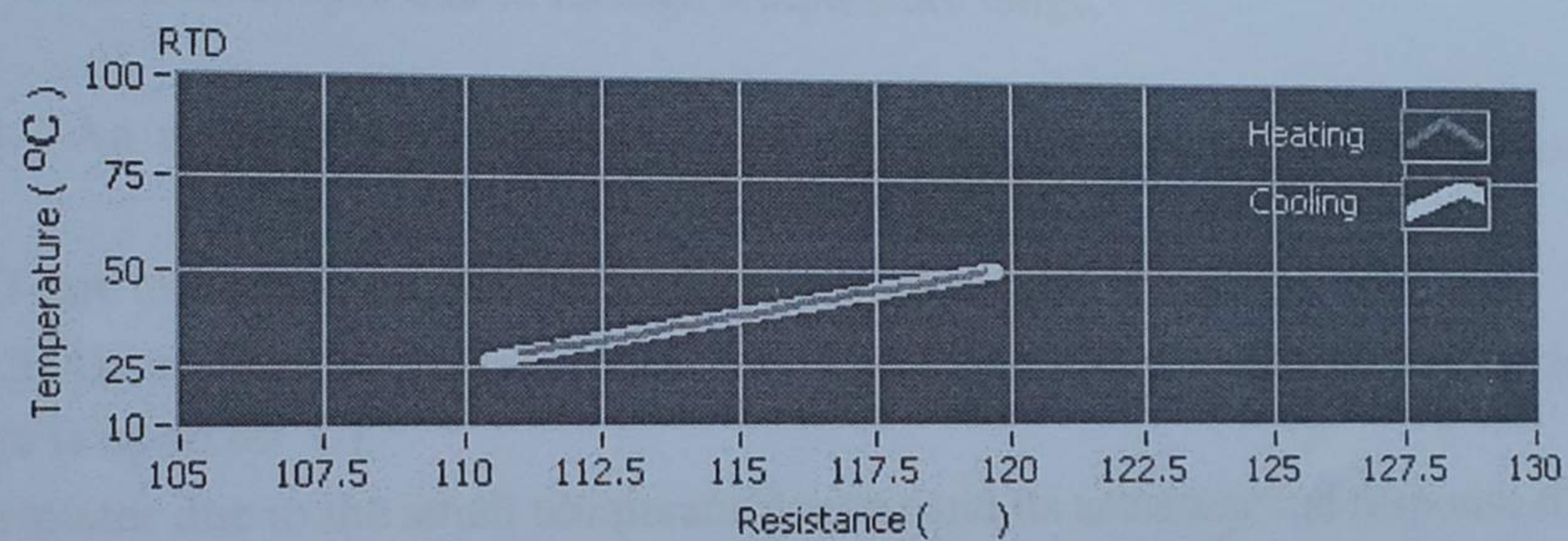


Figure 3: temperature variation as resistance change for RTD.

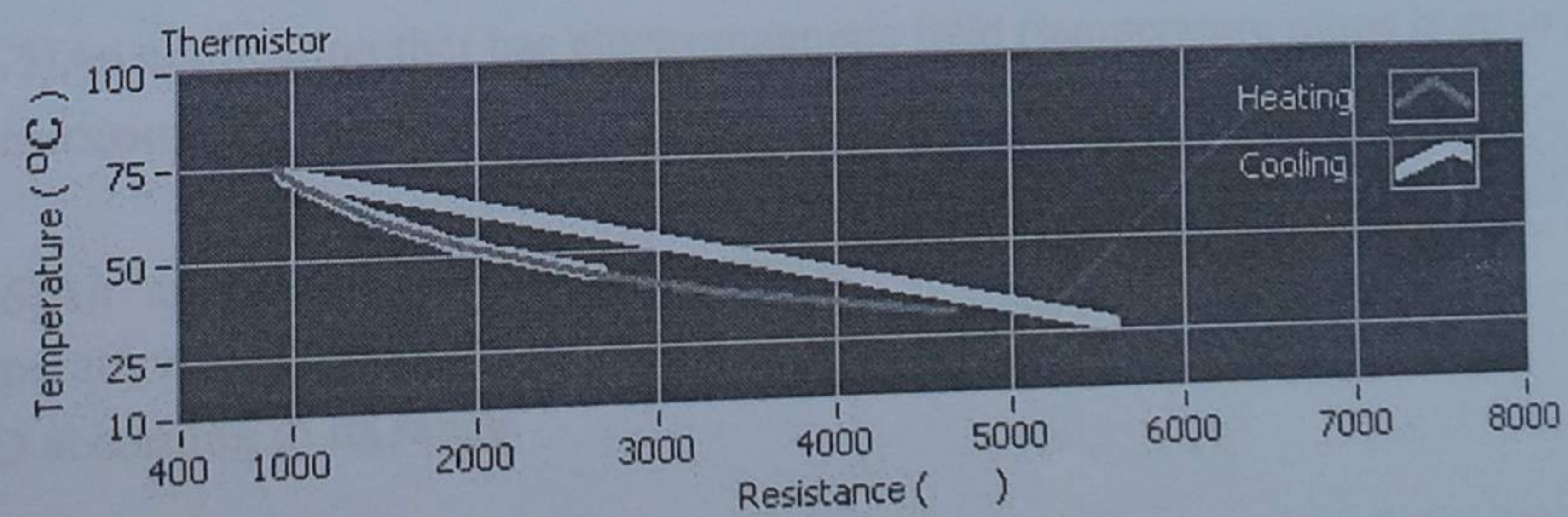


Figure 4: temperature variation as resistance change for thermistor.

### Summery and conclusions:

- 1) Are the cooling curves of the thermometers the same as the heating curves? Why?  
Yes, they are the same because of the small operating range of these thermometers with a small error due to hysteresis.
- 2) Which one of the thermometers has the fastest response time?  
Thermistor.
- 3) Which one of the thermometers has the slowest response time?  
Thermocouple.
- 4) Which one of the thermometers will be suitable for the following applications? Explain why?
  - 4.1) An application with a wide temperature range (above  $1000^{\circ}\text{C}$ ).  
Thermocouple due to its high temperature range.
  - 4.2) An application that needs a good response time (temperature range is up to  $500^{\circ}\text{C}$ ).  
RTD due to its temperature range and its response time.
  - 4.3) An application that needs accurate readings and fast response time temperature range is up to  $80^{\circ}\text{C}$ .  
Thermistor due to the small temperature range and its accuracy and response time.
  - 4.4) An application that needs a repetitive sensor (temperature range is up to  $500^{\circ}\text{C}$ ).  
RTD due to its repeatability.
  - 4.5) An application that has electromagnetic field (temperature range is up to  $500^{\circ}\text{C}$ ).  
Thermocouple.
  - 4.6) An application in which the wires length of the sensor does not affect the temperature readings (temperature range is up to  $500^{\circ}\text{C}$ ).  
RTD according to its range.
  - 4.7) An application in which the wires length of the sensor does not affect the temperature readings (temperature range is up to  $50^{\circ}\text{C}$ ).  
Thermistor according to its range.

The difference between the three measuring instruments is shown in the following table.

Table 3: comparison between thermocouple, RTD and thermistor:

| Factor                     | Thermocouple                              | RTD                              | Thermistor                            |
|----------------------------|-------------------------------------------|----------------------------------|---------------------------------------|
| Measuring method           | using voltage difference between two ends | resistance variation (positive ) | resistance variation (negative )      |
| Temperature range          | wide                                      | wide                             | low                                   |
| Stability                  | very high                                 | high                             | low                                   |
| Repeatability              | do not give same data                     | give same data                   | do not give same data                 |
| Accuracy(+/-)              | 0.5                                       | 0.01                             | 0.1                                   |
| Response time              | moderate                                  | good                             | best                                  |
| Cost                       | low                                       | high                             | low                                   |
| Precision from thermometer | close                                     | close                            | very close                            |
| Linearity                  | has small linear region                   | has small linear region          | no linear region (logarithmic curve ) |

So, picking the right instrument for measuring temperature should take into consideration the following points:

- 1) The type of application (temperature range).
- 2) The cost of the instrument.
- 3) The accuracy needed.

Sources of error:

- 1- Parallax error while reading the thermometer temperature.
- 2- Vibration in the stand which affect the RTD readings.
- 3- Heat loss in the devices.
- 4- Calibration of the three devices was not done in fixed environmental conditions.

References :

- 1- <http://www.temperatures.com/sensors/csensors/resistance-temperature-detectors-rtds/>
- 2- <http://www.temperatures.com/sensors/csensors/thermistors/2/>