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Specific Heat Capacity

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Abstract:

In this report, the specific heat capacity(SHC) for an aluminium block under constant pressure was measured by investigating the heating and cooling process of the material in particular time intervals. The same experiment was conducted with two different methodologies; an adiabatic jacket was used for the first part, and an isolated jacket was used for the second. SHC of the aluminium block was determined as $1.3 \pm 0.9 \frac{kj}{kg \times k}$, and from the graph as $C = 1.2 \pm\ 0.1\ \frac{kj}{kg \times k}$ from the first methodology and the second investigation was calculated as $1.14 \pm 0.001 \frac{kj}{kg \times k}$. These results were determined by using the relation between C_p with the SHC formulas (1),(2),(3) and the gradients of the graphs.

Introduction:

The main object of this experiment was to measure the SHC of the aluminium bloc. Every material has different conductivity and thermal properties. The theory states that every object can store a significant amount of heat inside; from material to material, this amount changes because the distribution of the atomic scale of each element or material is different.
To determine a solid material's heat capacity, equation(1) can be used.

$$E = m \times C_p \times (T_f - T_i) \tag{1}$$

Where E denotes the energy supplied to the material, m represents the mass of the block and C_p specific heat capacity of the material, and T represents the temperature. This equation is valid if no energy is going out from the system; when the calculations have been made, it is assumed that the system is closed and ideal. However, in practice, systems are not closed, so in an open system, a material-specific heat capacity can be measured using Equations (2) and Equation (3). When an object is heating, the equation(2) below must be used.

$$W = m \times C_p \times \left(\frac{dT}{dt}\right) heating + Q \tag{2}$$

Where W represents the power supplied to the material, m is mass, C means specific heat capacity, d cap T over d t is the gradient of any temperature point with respect to the time, and Q is the energy that goes to surroundings. When the material is cooling, the following equation above must be used.

$$0 = mC_p \times \left(\frac{dT}{dt}\right) cooling + Q \tag{3}$$

These two essential assumptions must be taken when these formulas are used.The first experiment was conducted under constant pressure, and the metal object extension was neglected. Furthermore, equation(2) and equation(3) are related to equation (1). When they were solved simultaneously, the equation(1) would be obtained, which will allow for calculating SHC of the material

Moreover, to calculate the uncertainty in large data sets, equation (4) was used.

$$\bar{x}\Delta = \frac{2\sigma}{\sqrt{N}} \tag{4}$$

Where $\Delta\bar{x}$ stands for average uncertainty, σ denotes the standard derivation of the data set. It can be calculated in equation (5), and N represents the number of repeatings in the experiment.

$$\sqrt{\frac{1}{N}\left(\sum_{i=1}^{N}(Xi^2)\right) - \bar{x}^2} \qquad (5)$$

N in this equation represents the number of repeating (xi), which denotes each value in the data set, and $\bar{x}$ shows the average of the data and can be calculated by adding all values in a data set and dividing by a number of terms. Finally, the uncertainty of other variables in the equations was added by using equation (6)

$$\Delta C = \left|\frac{m}{T}\right| \times \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta t}{T}\right)^2} \qquad (6)$$

Where T is the period, m is the mass of the block, and Δ on the right-hand side, terms are errors of these measurements.ΔC is the total error of the calculation.

Methodology:

In this experiment, two different methods were used to calculate the specific heat capacity of the aluminium block.

The first method: The present study utilised an experimental technique to determine the specific heat capacity (SHC) of an aluminium block with a mass of $1.015k \pm 0.5\ kg$ through the application of an adiabatic jacket. The block was carefully placed within the jacket and then sealed with an isolator foam. Subsequently, a power supply was connected to the jacket to heat the block, while a thermocouple was strategically positioned within the jacket to monitor the temperature of the material. It should be noted that readings from an analogue thermometer may introduce parallax errors, a phenomenon that will be further discussed in the subsequent discussion section. The power supply was set to 12 volts, and both the temperature of the block and the number of joules supplied to it were recorded every 30 seconds until the block reached 45°C. The initial and final temperatures of the system were recorded, and the energy supplied to the material and the mass of the metal block were also determined. By substituting these variables into equation (1), the value of C was calculated for each 30-second time interval to minimise errors. However, the average value of C was determined by using these calculations, along with their associated errors.

Moreover, with the data recorded during the experiment, a graph plotted energy supplied versus time, and by placing the best-fit line to the graph and calculating its gradient, the C value was determined. The error for this calculation was determined by using the Excel LINEST function.

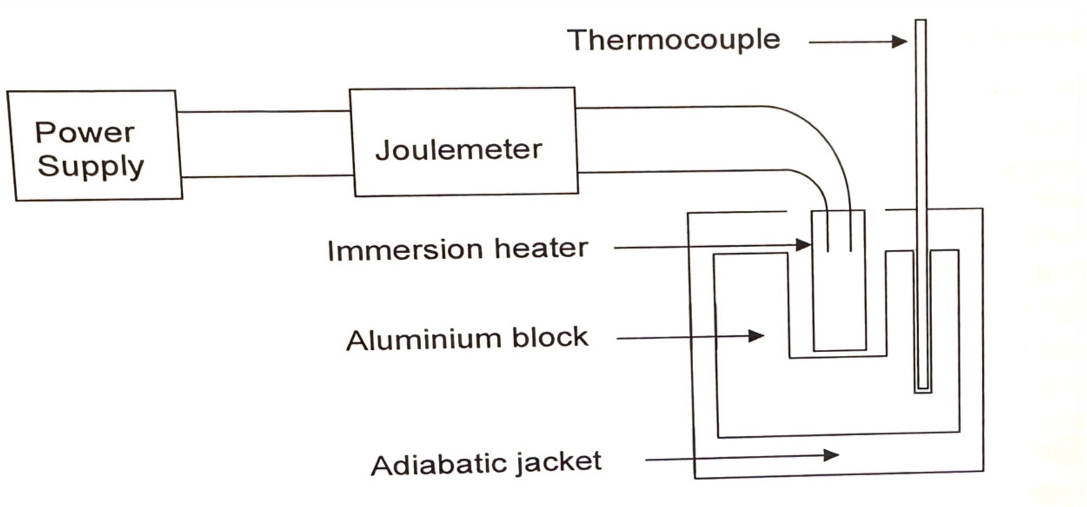

Figure 1: Shows the adiabatic jacket and the system that was used in the first method. (4CCP1100 Physics Skills & Techniques Laboratory Manuel 78)

The second method: The present study aimed to determine the specific heat capacity (SHC) of a metal block through the employment of an isothermal jacket method. The metal block was heated utilising the isothermal jacket, which provided a constant temperature environment around the material. This was achieved by circulating a continuous stream of water in a jacket surrounding the block, with temperature measurement being carried out through a thermometer. Following the placement of the metal block inside the jacket and the initiation of water flow, the initial temperatures of both the water and the metal block were recorded. Subsequently, an immersion heater was turned on, supplying heat to the metal block. Every 30 seconds, readings of the number of the joules provided to the block and its temperature were recorded until it reached a temperature of 45°C. Upon reaching 45°C, the immersion heater was turned off, and cooling results were taken by measuring the temperature of the metal block every two minutes until it reached its initial temperature. The temperature of the metal block was measured using thermocouples.

The W, power supply was calculated by $\frac{E}{t}$ which energy per time for the heating period and then, graphs were plotted by temperature versus time for heating and cooling periods. Then, the curve of the best-fit line was drawn to calculate $\frac{dT}{dt}$. By substituting these variables and solving equation (2) and equation(3) simultaneously, the value of C was calculated for different temperatures. Finally, a final graph was plotted with SHC of C versus the block's temperature, and the average value of C was calculated along with its error using the LINEST function.

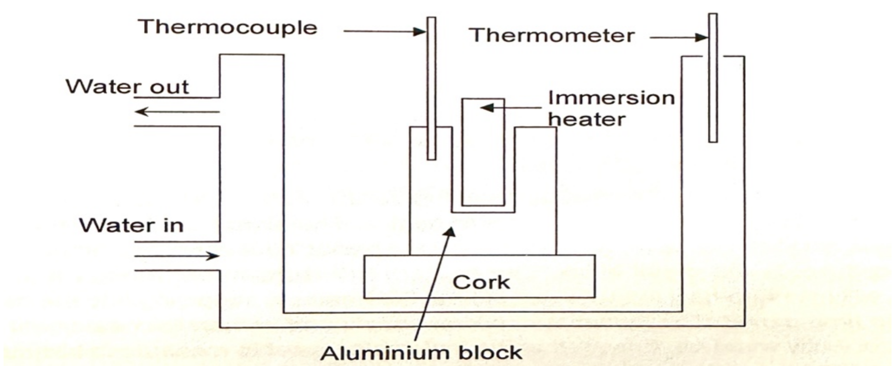

Figure 2:the Experimental setup for the isothermal jacket while heating the metal block(4CCP1100 Physics Skills & Techniques Laboratory Manuel , pp 80)

Results:

For investigation one:

The specific Heat Capacity of the aluminium block was calculated by rearranging equation(1) for each 30-second time interval; the values of SHC will be displayed below. It should be noted that all of the calculations were done using Kelvin as a unit of temperature.

Order of each individual time interval(30s)	Specific heat capacity values ($\frac{kj}{kg\times k}$)
1	3.25
2	1.68
3	1.68
4	1.28
5	1.18
6	1.23
7	1.18
8	1.07
9	1.12
10	1.15
11	1.18
12	1.03
13	1.19
14	1.15
15	1.08
16	1.26
17	1.05
18	1.08
19	1.2
20	1.08
21	1.23
22	1.93
23	1.08
24	1.07

Figure 3: Shows the values of SHC for the metal block for each 30-second time interval.

The average value of SHC, along with its uncertainty, was calculated using Equation (4)and Equation (5) as $C = 1.3 \pm 0.2\frac{kj}{kg\times k}$. The literature value for the SHC of aluminium is $0.9\frac{kj}{kg\times k}$, so the error compared with the literature value was determined as %44.

Furthermore, the energy supplied, and the change in the temperature values were recorded during the experiment, and a graph plotted with these values displayed below.

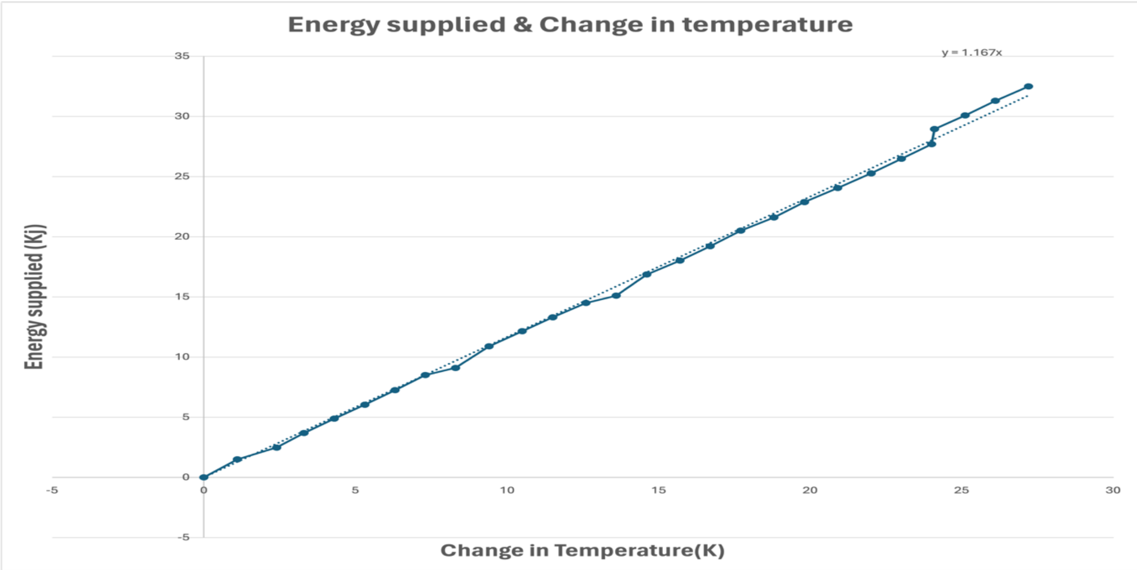

Figure 4: Shows Energy supplied(kj) versus change in the temperature in Kelvins, with its line of best fit. The error bars are too small to observe. For the x-axis, the uncertainty is $\pm 0.05\ K$, and for the y-axis, the uncertainty is $\pm 0.001\ Kj$.

The SHC for the metal block, along with its uncertainty, was calculated by taking the gradient of the best-fit line and Excel LINEST function, and it was calculated as $C = 1.2 \pm 0.1\ \frac{kj}{kg \times k}$. The error was %33 compared to the literature value.

For investigation two:
For this part of the experiment, two graphs were plotted for heating and cooling periods temperature versus time.

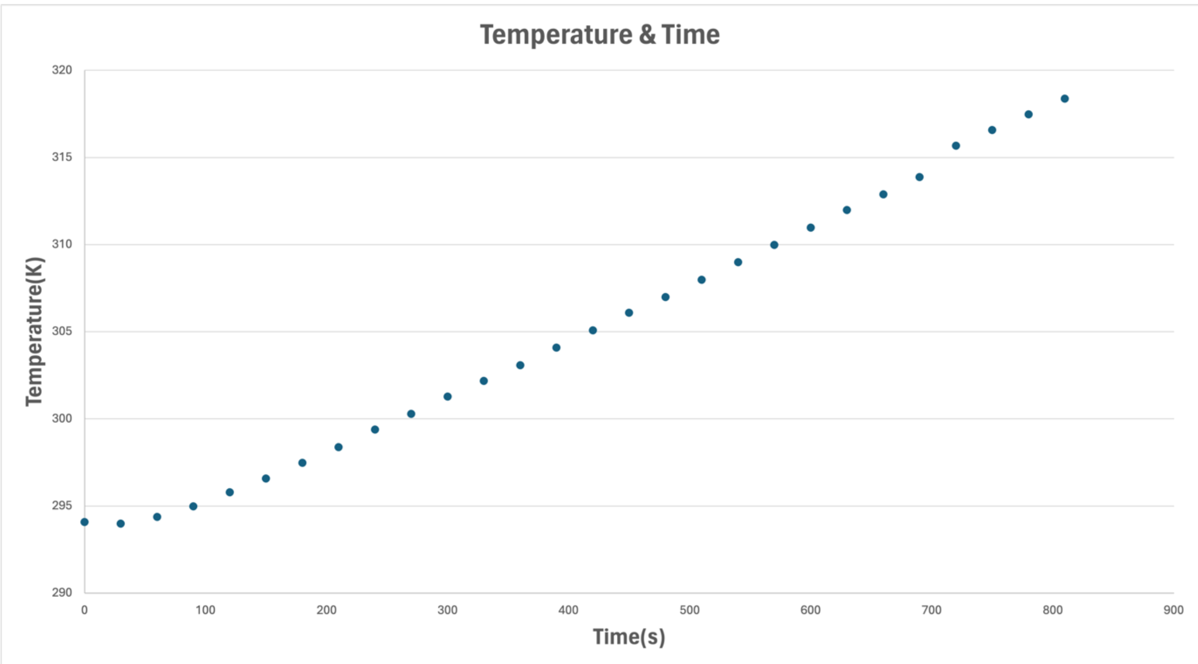

Figure 5 shows the data for temperature versus time in seconds for the heating period. The error bars are too small to observe the x-asis uncertainty is $\pm 0.01s$, $\pm 0.05K$ for the y-axis.

Moreover, the cooling part of the graph was plotted below.

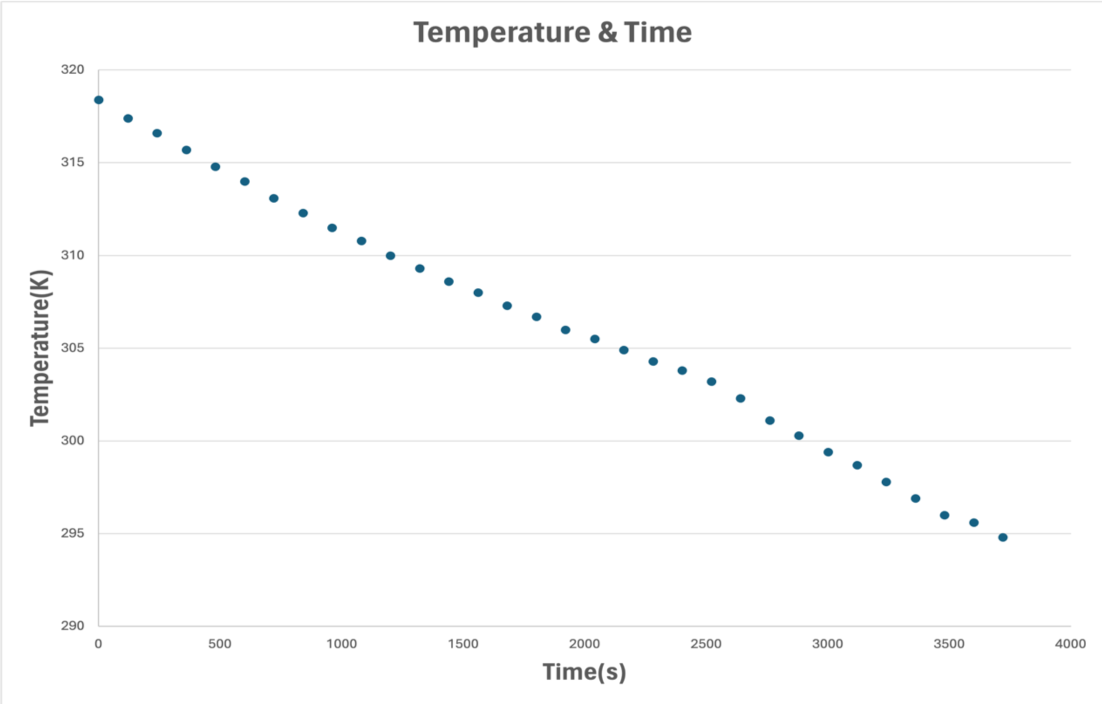

Figure 6 shows the data Temperature versus time in seconds for the cooling period. The error bars are too small to be observable for the x-axis. The uncertainty $\pm 0.01s$, for t y-axis it was$\pm 0.05K$.

For each graph, a curve of the best fit line was calculated by the freehand sketch method. equation(2) and equation (3) were solved simultaneously, and equation(7) was obtained. By substituting these values into equation (7), the SHC for the metal block was calculated for each data point alongside its error; the error was calculated using equation(6). The calculations are displayed in the chart below.

Temperatures(K)	Specific heat capacity($\frac{\boldsymbol{kj}}{\boldsymbol{kg \times k}}$)
295	1.13
296	1.17
297	1.21
298	1.23
299	1.19
300	1.19
302	1.10
303	1.09
306	1.13
310	1.14
313	1.20
314	1.02
316	1.20
317	1.10
3.18	1.10
The error of the temperature($\boldsymbol{\pm 0.05K}$)	The error of SHC (± 0.1)

Figure 7 shows the SHC for each temperature given with its uncertainties.
The graph was plotted with the data in Figure 7.

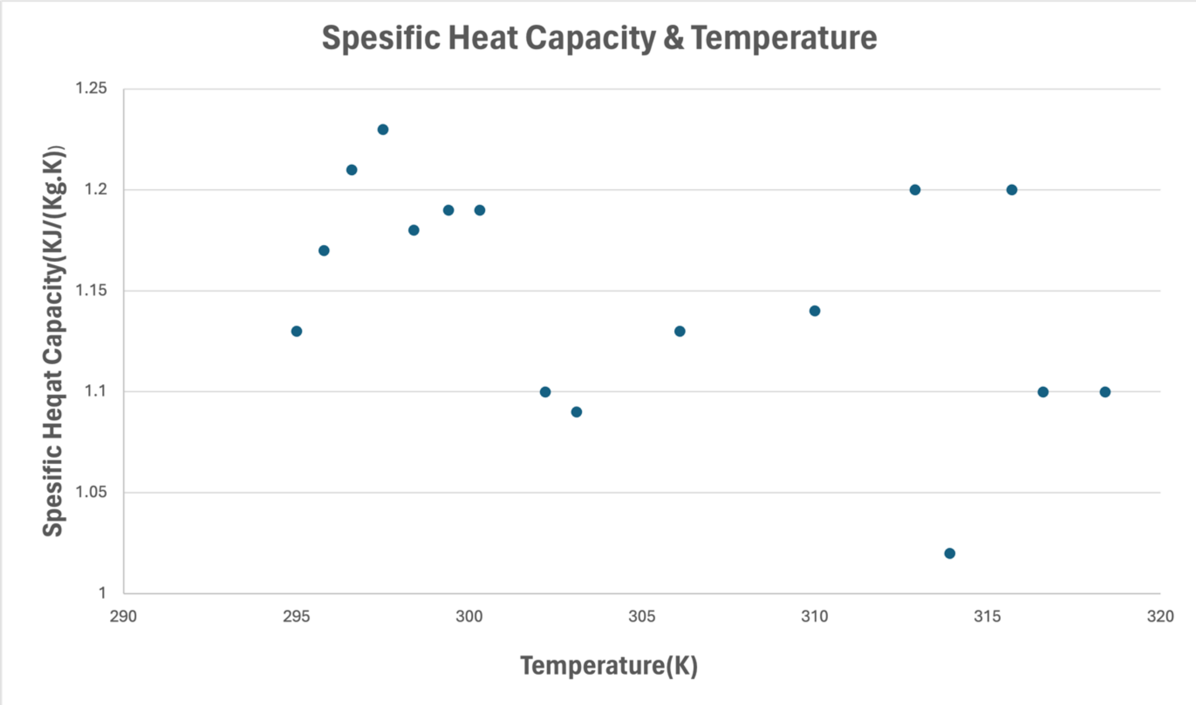

Figure 8 shows data of SHC for each temperature, the uncertainties too small to be observable relative to the values, and the uncertainty in the x-axis is $\pm 0.01 \frac{kj}{kg \times K}$ and $\pm 0.05\ K$ for the y-axis.

The average value of C was calculated as $1.24 \pm 0.1 \frac{kj}{kg \times K}$. The error % is 37 when compared to the literature value.

Discussion:

During the experiment, several sources of error were encountered that affected the accuracy of measurements taken. One of the factors that contributed to these errors was parallax and the conductor's reaction time. Repeated measurements were taken to mitigate these errors, but they were not fully effective due to the nature of the experiment. For instance, taking readings from a thermometer and timing events with a stopwatch were sources of error during the first part of the investigation. However, during the second part of the experiment, the primary source of error was the distance between the isolated jacket walls and the metal block inside it. This was because, at a certain point, the aluminium came into contact with the isolated jacket's inner surface, resulting in a drastic change in temperature that caused an error. Despite repeated measurements being taken throughout the experiment, errors could not be entirely eliminated.

Average values were calculated using appropriate error propagation formulas, and uncertainty was calculated as $\pm 0.1 \frac{kj}{kg \times K}$. However, when compared to literature values, the error for the first part of the experiment was 44% and %33, and for the second part, it was 37%. This indicates that there was a significant discrepancy between the measured values and the literature values.

To improve the accuracy of the experiment, several measures could be taken. For example, an isothermal jacket with a larger radius could be used, or a metal block with a smaller radius could be utilised to prevent contact between the surfaces. Additionally, the temperature of the water flowing inside the jacket could be lowered to ensure that the surrounding environment has a consistent temperature. This is because warm water was used during the experiment, which resulted in drastic changes in temperature being observed.

Furthermore, increasing the number of repeated measurements could help reduce the error further, as it would distribute the error across a larger dataset. In conclusion, the experiment encountered several sources of error, with contact between the metal block and the jacket being the primary source of error during the second part of the investigation. Throughout the experiment, parallax and reaction time were also sources of error. Despite these challenges, taking multiple readings and applying the least squares method effectively reduced uncertainty and led to more accurate results.

Conclusion:

The objective of the study was to compute the specific heat capacity (SHC) of a solid block of metal through the utilisation of SHC equations, specifically equations (1), (2), and (3). The resultant findings revealed that the equations were valid despite the precision being somewhat imprecise. The optimal outcome for the SHC of the block was determined as $C = 1.2 \pm 0.1 \frac{kj}{kg \times k}$ employing the initial methodology by determining the gradient of the line of best fit.

Moreover, equation (1) was authenticated and elucidated the relationship between the change in temperature and the energy supplied to a material. A further inquiry could focus on analysing different types of materials or varying masses. The object in question was a solid with a rigid body. What would be the variance if the SHC of a liquid material were to be calculated? In summary, the first methodology resulted in the most minor error, with a deviation of %33 from the literature value, with the SHC calculated as $C = 1.2 \pm 0.1 \frac{kj}{kg \times k}$. Suggestions for improving and further investigating the methods have been proposed.

References:

Department of Physics, 4CCP1100 Physics Skills & Techniques Laboratory Manuel, King's College London, London, 2023, pp 78

Department of Physics, 4CCP1100 Physics Skills & Techniques Laboratory Manuel, King's College London, London, 2023, pp 80