

Module - ACDB4011 – L4 Chemistry

Lab Experiment 3: Calorimetry



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TABLE OF CONTENTS

Introduction	3
Results.....	4
Part 1: Measure the value of the heat capacity of the calorimeter ($HC_{\text{calorimeter}}$)	4
Part 2. Measure the specific Heat Capacity of a Metal ($C_{p \text{ metal}}$)	6
Table 1: Metal HC Recordings.....	6
Discussion.....	8
Conclusions	10
References	11
Appendix A: Materials & Methods.....	12

INTRODUCTION

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The hypothesis of the experiment is to measure the specific heat capacity of the metal, in this case Aluminium by analysing the heat transfer of energy using the temperature of the metal when moving it from boiling water into room temperature water and recording the decrease in temperature over a set time period, allowing the calculation of the specific heat capacity which in turn tells you how much energy is required to raise the temperature of the metal by 1 degree Celsius.

The purpose of the two parts of this experiment is to first measure the heat capacity of the calorimeter, before then measuring the heat capacity of the metal sample. This is done as the heat capacity of the calorimeter is needed for the final equation to calculate the specific heat of the metal.

The Variables used can be seen below:

Independent Variables:

- Temperature of Metal
- Duration of Experiment
- Stirring Rate

Dependent Variables:

- The temperature change of the water within the calorimeter

Control Variables:

- Mass of water
- Mass of the Metal
- Styrofoam Cup
- Thermometer
- Cup Lid
- Stirrer

The Equations used within this report can be seen below:

$$1. Q = m \times c_p \times \Delta T$$

$$2. -Q_{hot-water} = Q_{cold-water} + Q_{calorimeter}$$

$$3. Q_{calorimeter} = HC_{calorimeter} \times \Delta T_{calorimeter}$$

$$4. m_{metal} \times c_{p\ metal} \times \Delta T_{metal} = - (m_{water} \times c_{p\ water} \times \Delta T_{water} + HC_{calorimeter} \times \Delta T_{calorimeter})$$

RESULTS

PART 1: MEASURE THE VALUE OF THE HEAT CAPACITY OF THE CALORIMETER ($HC_{\text{CALORIMETER}}$)

Calculations

1. Measure the value of the heat capacity of the Calorimeter ($HC_{\text{calorimeter}}$)

$$T_{\text{Hot}} = 60^{\circ}\text{C} \quad M_{\text{Hot water}} = 50\text{g} \quad \Delta T_{\text{Hot water}} = -22^{\circ}\text{C}$$

$$T_{\text{Cold}} = 24^{\circ}\text{C} \quad M_{\text{Cold water}} = 50\text{g} \quad \Delta T_{\text{Cold water}} = 14^{\circ}\text{C}$$

$$T_{\text{max}} = 38^{\circ}\text{C} \quad \Delta T_{\text{calorimeter}} = 1674.4\text{J}$$

$$Q_{\text{Cold water}} = 2930.2\text{J}$$

$$HC_{\text{calorimeter}} = 119.6\text{J}/^{\circ}\text{C}$$

$$Q_{\text{Hot water}} = -4604.6\text{J}$$

$$Q_{\text{calorimeter}} = 1674.4\text{J}$$

Calcs

$$Q = m \times C_p \times \Delta T \quad \text{Equation 1}$$

$$Q_{\text{Hot}} = 50 \times 4.186 \times (-22) = -4604.6$$

$$Q_{\text{Cold}} = 50 \times 4.186 \times 14 = 2930.2$$

$$-Q_{\text{Hot water}} = Q_{\text{Cold water}} + Q_{\text{calorimeter}} \quad \text{Equation 2}$$

$$Q_{\text{calorimeter}} = -Q_{\text{Hot water}} - Q_{\text{Cold water}}$$

$$Q_{\text{calorimeter}} = -(-4604.6) - 2930.2$$

$$Q_c = 1674.4$$

$$HC_{\text{calorimeter}} = \frac{Q_{\text{calorimeter}}}{\Delta T_{\text{calorimeter}}}$$

Equation 3

$$HC_{\text{cal}} = \frac{1674.4}{14} = \underline{119.6\text{J}/^{\circ}\text{C}}$$

The above calculations use the results from part 1 of the test to calculate the Specific Heat Capacity of the Calorimeter. The value obtained is very high, this suggests an error within the value(s) obtained, which could be investigated and redone for a future experiment, either by ensuring that the current set up is correct, or by improving the equipment being used.

PART 2. MEASURE THE SPECIFIC HEAT CAPACITY OF A METAL ($C_{p \text{ METAL}}$)

Time (s)	T _{water} (°C)	Time (s)	T _{water} (°C)	Time (s)	T _{water} (°C)
10	27	100	30.5	190	29
20	28	110	30	200	29
30	29	120	30	210	29
40	29.5	130	29.5	220	29
50	29.5	140	29.5	230	29
60	29.5	150	29.5	240	29
70	30	160	29.5	250	29
80	30	170	29.5	260	29
90	30.5	180	29	270	29

Table 1: Metal HC Recordings

Type of metal: Aluminium

$$T_{\text{Hot}} = 90^{\circ}\text{C} \quad M_{\text{metal}} = 18.5\text{g} \quad \Delta T_{\text{metal}} = 59.5^{\circ}\text{C}$$

$$T_{\text{Cold}} = 26^{\circ}\text{C} \quad M_{\text{water}} = 30\text{g} \quad \Delta T_{\text{water}} = 4.5^{\circ}\text{C}$$

$$T_{\text{max}} = 30.5^{\circ}\text{C} \quad \Delta T_{\text{calorimeter}} = 4.5^{\circ}\text{C}$$

$$HC_{\text{calorimeter}} = 119.65\text{J/}^{\circ}\text{C}$$

$$C_{p \text{ metal}} = 1.00\text{J/g}^{\circ}\text{C}$$

Equation 1

$$M_{\text{metal}} \times C_{p \text{ metal}} \times \Delta T_{\text{metal}} = -(M_{\text{water}} \times C_{p \text{ water}} \times \Delta T_{\text{water}} + HC_{\text{calorimeter}})$$

$$18.5 \times C_{p \text{ metal}} \times 59.5 = -(30 \times 4.186 \times 4.5 + 119.6 \times 4.5)$$

$$18.5 \times C_{p \text{ metal}} \times 59.5 = -1103.31$$

$$18.5 \times C_{p \text{ metal}} = \frac{-1103.31}{59.5}$$

$$18.5 \times C_{p \text{ metal}} = 18.54$$

$$C_{p \text{ metal}} = \frac{18.54}{18.5}$$

$$C_{p \text{ metal}} = 1.002\text{J/g}^{\circ}\text{C}$$

This is about 0.1 J/g °C from being correct according to online literature, discussed below. If the specific heat value of the calorimeter was reduced to 1.20 J/g°C [6], then the result changes to 0.895 J/g °C , (amended calculations below), putting the result accurate to 0.005 J/g °C , suggesting an extremely accurate result for an extremely cheap and basic test.

$$18.5 * C_{pmetal} = -\frac{984.91}{59.5}$$

$$C_{pmetal} = \frac{16.55}{18.5}$$

$$C_{pmetal} = 0.895 \text{ J/g } ^\circ\text{C}$$

DISCUSSION

The key findings of the experiments is that the Specific Heat Capacity of the Aluminium mass obtained was 1.002J/g Celsius. Comparing this to the 'the purest out of all the commercial aluminium grades' [2], Aluminium 1000, which have a Specific Heat Capacity of [1] '0.900 - 0.904 J/g-°C', this result is accurate to a 10% margin, which shows a degree of error. However, this is expected for ease and basic nature of the calorimetry undertaken, where if much more expensive equipment and precise instrumentation alongside a confined environment where to be used and implemented, then a more accurate result may be obtained.

A variant of calorimetry, Heat Flow Calorimetry (HFC) is used within the world of OME for the testing of Nitrocellulose based propellants, which is standardised by NATO within STANAG 4582 [3] 'This STANAG describes a method for establishing the chemical stability of SB, DB and TB propellants for a minimum of 10 years when stored at 25°C or to an equivalent degree'. Heat flow calorimeters uses a thermopile 'to continuously measure the temperature difference between the reaction vessel and an outer jacket acting as a constant-temperature heat sink. The heat transfer takes place mostly through the thermocouple wires, and to a high degree of accuracy is proportional to the temperature difference integrated over time. This is the best method for an extremely slow reaction, and it can also be used for rapid reactions.' [4] This method is good for testing propellants and relevant explosive compounds due to the reactive nature of the materials used, so a slow reaction is required as well as precise result, rather than a very fast one which could provoke a reaction.

HFC testing is used both to quality test ammunition before coming into service, ensuring that the propellant will last for 10 years at room temperature, by artificially aging the propellant using a calorimeter for a certain number of days, for example 28 days at 70 degrees, to ensure that the propellant meets the required safety and performance specifications agreed. It is also used in, in service surveillance (ISS), which is testing completed after the ammunition in question has reached the end of its qualified life, which is generally 10 years after ammunition has been in storage. ISS is then done again, which involves HFC testing alongside other tests, to test the propellant to see how long the subject ammunition can be safely stored for or last. As per the STANAG, the propellant is tested to be stored for '10 years when stored at 25°C'. However, this is a guide and not a yes/no test, so it is left to the organisation conducting the test to decide whether to endorse an additional life extension, which is based on multiple factors, which included previous Inservice incidents that have occurred and in-depth result analysis which also reviews how close the results achieved are to the acceptable limits.

Bomb Calorimeters are used to measure the 'heats of combustion' [5] of explosives such as bombs, as well as non OME related 'applications such as calculating the calorific value of foods and fuels.' [5]. This is achieved by enclosing the 'bomb' into a metal sealed enclosure, where the internal reactants are encouraged to react 'under constant volume conditions' [5]. In which it is ignited by an electrical current and built to withstand extreme pressures so that it can measure the heat released and temperature change when ignited.

Within the experiment there are a variety of limitations and sources of error including:

- The Calorimeter:
 - The effectiveness of Styrofoam as an insulator, leading to unrecorded heat loss. This could be solved by using an even better insulator, in a controlled environment. Not in a warm class lab.
 - The heat capacity of the cup being high, leading to more margin for error within calculations.
 - Mixing of the water being human led, leading to poor mixing and not being consistent over the duration of the test. This can be solved by using a machine-controlled stirrer to set a specific speed throughout the test.
- The thermometer may have been slightly inaccurate, which can be rectified by ensuring it is calibrated and using a more precise instrument.

CONCLUSIONS

The main findings within this basic calorimetry test were the specific heat capacity of the calorimeter as well as the aluminium subject material. The findings support the hypothesis as the specific heat capacity of the metal was found to be accurate to 10%, which for an extremely basic set up, is a good result. Which as proven, if the Specific Heat Capacity of the cup was accurately recorded, would've been accurate to an extremely impressive 1%. Using this information, you can learn more about the properties of the metal and potential future applications which require specific thermal properties.

Future research could be done to achieve a more improved result using an improved set up involving a more complex calorimeter and environment, as well as using an unknown material and using this method for material identification. Redoing the test, aiming to achieve a more accurate value for the calorimeter, as well as taking the result further and conducting material thermal analysis and suggesting a use based on the thermal properties of a subject material.

REFERENCES

- [1] "Mat Web - The Online Materials Information Resource," www.matweb.com.
<https://www.matweb.com/search/datasheet.aspx?matguid=38e1c167c7ea4dfefb80778b29ae71cf>
- [2] "Aluminium Grades Overview | 1st Choice Metals," 1st Choice Metals, 2011.
<https://www.1stchoicemetals.co.uk/aluminium/grades-guide/>
- [3] "STANAG 4582 JAS (EDITION 1)- EXPLOSIVES, NITROCELLULOSE BASED PROPELLANTS, STABILITY TEST PROCEDURE AND REQUIREMENTS USING HEAT FLOW CALORIMETRY ," STANAG 4582 , no. 1, Mar. 2007.
- [4] Chemistry LibreTexts, "7.3: Heats of Reactions and Calorimetry," Chemistry LibreTexts, Jun. 03, 2019.
[https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_\(Petrucchi_et_al.\)/07%3A_Thermochemistry/7.3%3A_Heats_of_Reactions_and_Calorimetry](https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_(Petrucchi_et_al.)/07%3A_Thermochemistry/7.3%3A_Heats_of_Reactions_and_Calorimetry)
- [5] ScienceDirect, "Bomb Calorimeter - an overview | ScienceDirect Topics," Sciencedirect.com, 2011.
<https://www.sciencedirect.com/topics/engineering/bomb-calorimeter>
- [6] P. Dave Explains, "Heat Capacity, Specific Heat, and Calorimetry," [www.youtube.com](https://www.youtube.com/watch?v=yhNHJ7WdT8A&t=135s), Nov. 26, 2015.
<https://www.youtube.com/watch?v=yhNHJ7WdT8A&t=135s> (accessed Apr. 25, 2024).

APPENDIX A: MATERIALS & METHODS

Materials & Equipment used:

- 2 stacked Styrofoam Cups
- Sealed Cup Lid
- Thermometer
- Wooden stirring rod
- Stand
- Clamp
- Beaker
- Bunsen Burner
- Tongs
- Lab Coat
- Safety Goggles
- Disposable Latex Gloves

1. Method to measure the specific heat capacity of the calorimeter:

1. Place 50ml of water into the Styrofoam cups.
2. Seal with lid with stirrer and thermometer inserted and measure the temperature of the water as T_{Cold}
3. Heat 50ml of water in a beaker to 80 °C.
4. Turn of gas at 80 degrees and allow the water to cool to 60°C before recording it as T_{Hot}
5. Pour the 60°C water into the calorimeter and mix thoroughly
6. Record the maximum equilibrium temperature as T_{Max}
7. Calculate the heat capacity of the water using the T_{values} taken.

Method to measure the specific heat capacity of the metal:

1. Weigh the subject metal and record its mass as M_{Metal}
2. Heat a water bath until boiling, before putting the metal into it.
3. Boil for 5 minutes, before closing the gas and leaving it for 2 minutes to allow for the temperature of the metal to match the water temperature.
4. During step 3, fill the calorimeter with 30ml of water and record the temperature of the water as T_{Cold}
5. Now measure the temperature of the water bath as T_{hot} and quickly move the metal into calorimeter using tongs.
6. Stir the water at a constant, steady rate, measuring the temperature and filling in table 1 every 10 seconds.
7. Continue this until the water has reached a maximum temperature and reduced by about 2
8. Record the maximum temperature of the water as T_{Max}
9. Calculate the specific heat of the metal as $C_{p \text{ metal}}$ using the equations within this report. Noting that $C_{p \text{ water}} = 4.186 \text{ J/(g}^\circ\text{C)}$,

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