

Comparing the changes of combustion of different alcohols

Aim

The aim is to find the enthalpy change of combustion of a number of alcohols' so that you can investigate how and why the enthalpy change is affected by the molecular structure of the alcohol.

Background Knowledge

Combustion is principally the oxidation of carbon compounds by oxygen in air to form CO_2 if there is a sufficient amount of oxygen. The hydrogen in a compound forms H_2O . Combustion produces heat as well as carbon dioxide and water. The enthalpy change of combustion is the enthalpy change that occurs when 1 mole of a fuel is burned completely in oxygen. I can use an enthalpy cycle to work the combustion value out only if you have the right information. The energy contained in the bonds of the products is less than the energy contained in the bonds of the reactants. The difference in energy is released as heat. Energy releasing reactions are called exothermic reactions. Calorimetry is a way to determine the amount of heat produced in a reaction. Calorimeters are devices to measure heat released by a reaction. The temperature of the calorimeter increases as heat is released by the reaction.

For any reaction to take place bonds must be broken and made. Bond breaking requires energy whilst bond making releases energy. Bonds between different atoms require or release different amounts of energy when broken or made because they are different in strength. Chemical bonding is the electrical attraction between atoms or ions. When you break a bond you have to do work in order to overcome these attractive forces. To break the bond completely you need (theoretically) to separate the atoms or ions so they are an infinite distance apart. The quantity of energy needed to break a particular bond in a molecule is called the bond enthalpy. Breaking bonds is endothermic- needs energy. Making bonds energy is given out- exothermic. When the fuels are burnt the reaction involves both making and breaking new bonds. In these combustion reactions the energy taken in during the bond breaking steps is less than the energy given out in the bond making steps so the overall reaction is exothermic. I have drawn up the theoretical values at what the standard enthalpy of combustion for a mole of each of the alcohol's is and written equations to show what the reactants and products are in each of the experiments.

Alcohol's:	Standard Enthalpy of Combustion (Kj mol ⁻¹)
Methanol $\text{CH}_3\text{OH} + 1\frac{1}{2}\text{O}_2 \equiv \text{CO}_2 + 2\text{H}_2\text{O}$	-726
Ethanol $\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \equiv 2\text{CO}_2 + 3\text{H}_2\text{O}$	-1367
Propan-1-ol $\text{C}_3\text{H}_7\text{OH} + 4\frac{1}{2}\text{O}_2 \equiv 3\text{CO}_2 + 4\text{H}_2\text{O}$	-2021
Butan-1-ol $\text{C}_4\text{H}_9\text{OH} + 6\text{O}_2 \equiv 4\text{CO}_2 + 5\text{H}_2\text{O}$	-2676

This information was obtained from a data book done under standard conditions (1 atm, 298K).

The following equation is helps to work out the enthalpy change of combustion:

Energy transferred to water by burning fuel (Kj mol^{-1})= (mass of water (g) x temperature rise ($^{\circ}\text{C}$) x 4.2 (J))

Prediction

From my background knowledge I can form a prediction about my results. I am predicting that the alcohol's with a greater number of carbon atoms within the molecule to have a higher enthalpy change of combustion than the ones with less. This means as the number of carbon's increase so does the enthalpy change of combustion. This means that butan-1-ol will have the highest enthalpy change of combustion and methanol will have the lowest.

For any reaction to take place bonds must be broken and made, bond breaking requires energy while bond making releases energy. Bonds between different atoms require or release different amounts of energy when broken or made because they are different in strength. There are much more bonds to make and break in bigger alcohol's this therefore means that bigger alcohol's will have a high bond breaking enthalpy and therefore will have a very high bond making enthalpy. This in turn means that they will have a high enthalpy change of combustion. It is also due to an increase in the number of carbon atoms and hydrogen atoms.

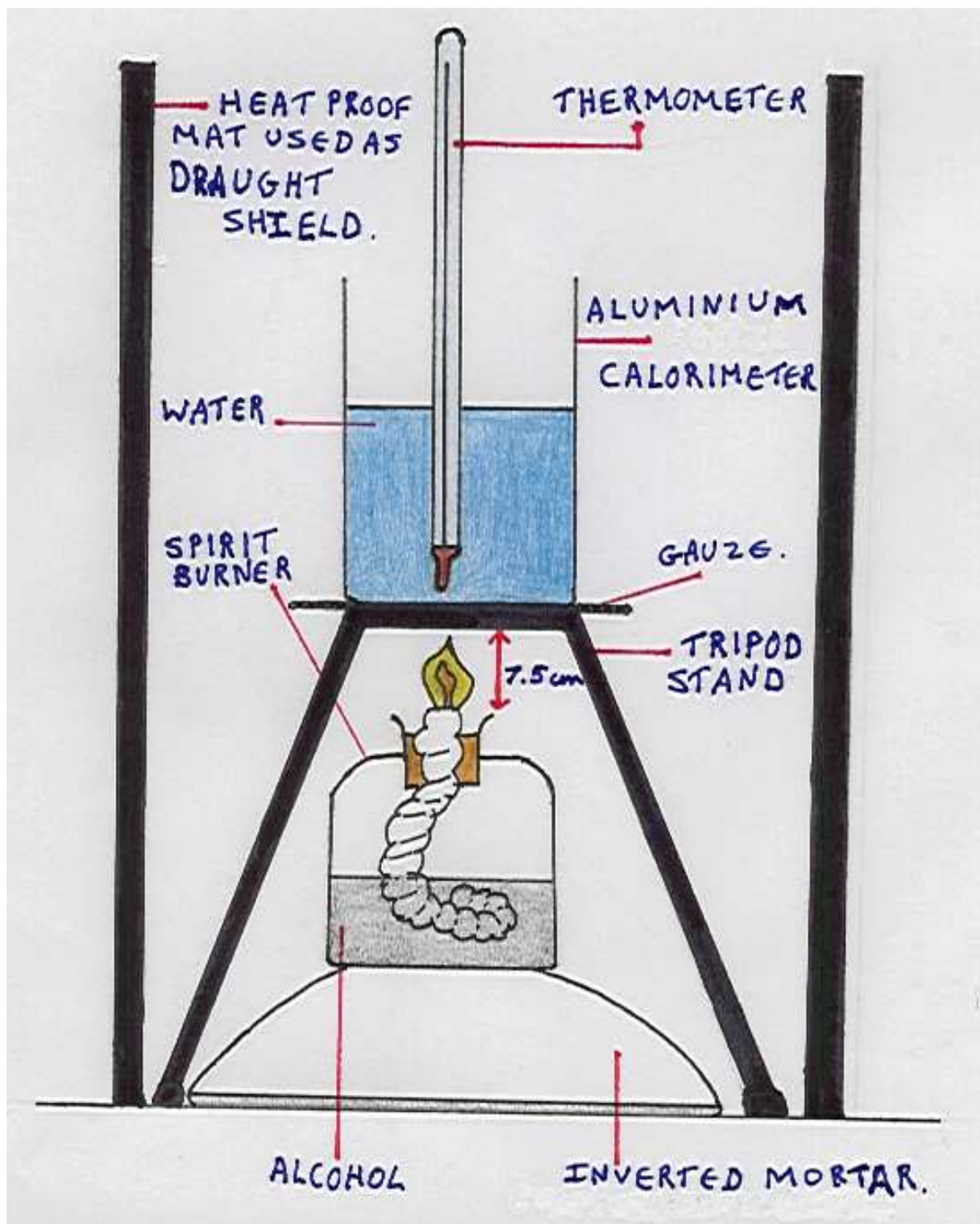
Plan

I am going to write a plan on how to find the enthalpy changes of combustion of alcohol's so that I can draw conclusions about how these values are affected by their molecular structure. I will work out the enthalpy change of combustion by using the fact that 4.2J of energy is required to raise the temperature of 1g of water by 1°C .

Apparatus: -

- Spirit burner to burn the alcohol
 - (a) Methanol
 - (b) Ethanol
 - (c) Propan-1-ol
 - (d) Butan-1-ol
- Aluminium calorimeter (is highly thermal conductive)
- Tripod stand to balance the aluminium can on it
- Electronic balance to 2 decimal places, I used this type of balance as this gives me enough detail to be accurate but not so much that it would be difficult to handle the result detail.
- 4-heat proof mats to act as draught/heat shields to reduce energy/heat loss.
- Goggles used for safety to prevent damage to the eye.
- 250 cm³ measuring cylinder to keep results more accurate.
- Thermometer set to 1⁰c intervals, this is being used to keep my results accurate but not confusing
- 200 ml of water this is because it gives a reasonable temperature rise.
- Matches to light the wick
- Mortar (used for, see diagram)
- Gauze (used for, see diagram)

Diagram: -



Note - the heatproof mats cover all 4 sides of the equipment. No heat mat covers the top of the experiment (for safety reasons).

Preliminary work and results: -

I carried out the practical to work out the enthalpy combustion of ethanol. I repeated the experiment twice.

Spirit Burner	Mass of spirit burner + lid + fuel before (g)	Mass of spirit burner + lid + fuel after (g)	Temperature of water before ($^{\circ}\text{C}$)	Temperature of water after ($^{\circ}\text{C}$)
Ethanol Trial 1	212.50	210.44	16	36
Ethanol Trial 2	210.41	208.44	17	37

I used 150 ml of water.

I am going to show how to work out the enthalpy of combustion of ethanol trial 1:

$$\text{Energy transferred} = 150 \times 4.2 \times (36 - 16) = -12600 \text{ J}$$

$$\text{Moles of fuel used} \text{ ----- } \text{Mole} = \text{Mass (g)} / \text{RMM g mol}^{-1}$$

$$\begin{aligned} \text{RMM of Ethanol (C}_2\text{H}_5\text{OH)} &= (12 \times 2) + (1 \times 6) + (1 \times 16) \\ &= 46 \end{aligned}$$

$$\text{Mass} = 212.50 - 210.44 = 2.06 \text{ g}$$

$$\text{Moles} = 2.06 / 46 = 0.0448 \text{ moles (to 3 s.f.)}$$

Amount of energy released per mole of fuel burned/ Enthalpy of combustion -----

$$(1/0.0448) \times 12600 = -281250 \text{ J}$$

$$- 281250/1000 = 281.25 \text{ kJ mol}^{-1}$$

I repeated the same steps for working out the enthalpy for ethanol trial 2.

$$\text{Ethanol trial 2 standard enthalpy of combustion} = -294.39 \text{ kJ mol}^{-1}$$

$$\begin{aligned} \text{The average for these 2 results is} &= (-294.39 + -281.25)/2 \\ &= - 287.82 \text{ kJ mol}^{-1} \end{aligned}$$

% Error in the form of heat loss is very high. The average enthalpy change of combustion for ethanol is very low compared to the value given in the databook, which is $-1367 \text{ kJ mol}^{-1}$.

$$\begin{aligned} \% \text{ Error} &= (1367 - 287.82) = - 1079.18 \\ &= (1079.18/1367) \times 100 = 78.9\% \end{aligned}$$

From this preliminary work I know how I am going to change my plan to make there be less errors in the experiment and to make my results more accurate. I will do this in a number of ways that will be explained in more detail later on but some examples are to use draught shields to prevent heat loss. Keeping the amount of water the same and preventing soot build up by putting the wick closer to the calorimeter.

Method: -

I plan to measure the enthalpy change by burning the alcohol, using a spirit burner, I will then use the heat produced during the combustion of the alcohol to heat 200 cm^3 of water that will be situated in a aluminium calorimeter directly above the burning alcohol. The calorimeter is made of aluminium as aluminium has a high thermal conduction value, this basically means that it is a good conductor of heat so a lot of the heat the aluminium receives will be passed on to the water which I am then able to measure.

During the experiment I will be taking a number of measurements, I will firstly take the initial temperature of the water and initial mass of the alcohol I will then burn the alcohol until an increase in temperature of 20°C has occurred in the water I will then reweigh the alcohol.

The measurements

- * Mass of alcohol burned (g)
- * Temperature increase ($^\circ\text{C}$)

This will tell me what mass of alcohol is used during combustion to cause the temperature increase of 20°C in the water, I can then work out the energy released per mole and compare these values and see which has the highest enthalpy of combustion. I will need to repeat my experiment a number of times and take an average so I am sure of an accurate result.

1. Measure out 200 cm^3 of cold water using measuring cylinder, pour into aluminium beaker, this poses no safety risk but must be done carefully as to keep it a fair test.

2. Place the heatproof mat, spirit burner, tripod stand, thermometer, mortar and gauze as shown in the diagram above.
3. Weigh the spirit burner with the lid and the alcohol and record the mass.
4. Place the spirit burner back to its position and check that the distance between the top of the spirit burner and evaporation dish is 7.5 cm because from my preliminary work this was the distance I worked out which had less incomplete combustion.
5. Place the thermometer in the water and leave in for 2mins then record the starting temperature.
6. Leaving the thermometer in place remove the lid of the spirit burner and light the wick with matches.
7. Use the thermometer to stir the water until the water temperature has risen by 20°C , make sure the thermometer doesn't touch the bottom of the copper can as this is the hottest part of the can and this would be unfair.
8. Replace the spirit burner lid; this will extinguish the flame and stop any evaporation. Keep stirring the water and record the highest temperature reached by the water.
9. Weigh the spirit burner with the lid on and record the mass of alcohol that has been burned.

10. Record the information into a table like this one below.

Spirit burner/ name of alcohol	Mass of water used (g)	Initial weight of spirit burner + lid + alcohol (g)	Final weight of spirit burner + lid + alcohol (g)	Overall mass loss of fuel (g) = initial-final weight of spirit burner + lid + alcohol	Initial temperature of the water (°C)	Final temperature of the water (°C)	Overall temperature change (°C) = final - initial water temperature
Methanol							
Ethanol							
Propan-1-ol							
Butan-1-ol							

11. Clean all equipment. Clean Aluminium can thoroughly and check for carbon deposits -on the bottom of the can especially. If there are carbon deposits it is likely to be due to incomplete combustion.

12. Repeat steps 1-11 for each of the different alcohol's listed and do 3 repeats for each individual alcohol.

13. Using all this information you can work out the enthalpy of combustion for the alcohol's.

The reason for the choice of the first four alcohol's is that they have no or very few isomers, which will lead to more accurate results. For my investigation I am going to use propan-1-ol and butan-1-ol as representatives of propanol and butanol. propanol and butanol are large enough molecules to form isomers

etc, I have decided to use propan-1-ol and butan-1-ol because they have the closest structural arrangement to the other alcohol's that I am going to be testing. Using butan-1-ol and propan-1-ol means all the alcohol's that I am comparing have their OH group joined onto an end carbon and they are all straight chain alcohol's. I need to keep as many of the factors in my experiments as I can the same, only changing what I have to, the variables, so that I get as accurate results as possible showing the correct pattern. I don't know how or whether the positions of the OH group on the alcohol, and whether branching within the molecule effects the enthalpy change. I need to use alcohol's with as similar structure as possible, with the only difference being the number of carbon atoms within the molecule as this is what I am investigating.

Fair Test: -

There are many variables that could affect the validity of my experiment. Therefore to ensure I conduct a fair test I am going to put some precautions in place. Every time I repeat my experiment I am going to ensure that I use the same equipment each time. This is because different equipment varies in shape and size and it would effectively mean that there would be room open for inaccuracy, which is simply not acceptable. Following this I think that the environment surrounding the equipment should be monitored. Notably draughts could have a catastrophic effect on the factor of efficient heat transfer and could be detrimental to the outcome of the results. This is why I have placed 4 heat mats around the experiment.

Loss of the alcohol itself due to evaporation has also been carefully considered. I have decided to ensure that the lid remains on at all possible times, in-between weighing and after the experiment has finished. In regarding the position of certain equipment. I have already stated that the calorimeter should be

placed at 7.5 cm above the flame at all times to ensure accurate heat transfer. This may also prevent incomplete combustion. The size and shape of the spirit burners is essential. The wick especially needs to have a constant length, width and surface area, so that the same amount of alcohol is in contact with the air and wick to react at all times. I am making sure that the amount of water is the same all the time so there will be no difference in my measurements due to volume. This would affect the experiment, as the energy that will be measured is heat energy transferred to the water and with a larger volume of water you would need more energy to heat it and therefore resulting in the end with a different value for the enthalpy of combustion. The measuring cylinders are to be used to measure the water for a more precise degree of accuracy.

I have chosen to use a Aluminium calorimeter because Aluminium has a high thermal conduction value, which means that it is a good conductor of heat so the heat transferred in the reaction will all be transferred to the water and will enable me to measure the amount of energy transferred to the water more accurately. The mercury thermometer is very accurate, as it will enable me to read to temperature to the nearest degree. It is to be left stationary for 2 minutes in the water to get the true initial temperature and to minimise error.

I have also decided that the distance the thermometer is suspended in the calorimeter should remain constant as an extra precaution to stirring. The temperature of the water may differ at the top to that at the bottom of the can because heat rises so I have decided to suspend the thermometer at an equal distance of half way up in the center of the can to ensure fairness. Insulation has been another priority of mine to minimise heat loss. I have put 4 heat mat around the sides of the experiment to minimise heat loss by radiation and insulated the sides of the Aluminium can heat loss by conduction and convection. I am also

going to make sure that all the equipment is cleaned after each experiment to prevent cross contamination and ensure more valid results. Also make sure all soot which is caused by incomplete combustion is clear after each experiment to ensure that there is no invalid results.

% Errors/accuracy: -

Measurements must be made as accurately as possible, because inaccuracy always develops due to human inaccuracy. Every effort must be made to ensure readings are taken to as precise detail as possible using the equipment. When doing the experiment there are going to be very slight errors when measuring due to the instruments. In actual fact there is 3 instruments, which could have slight errors, this is the electronic balance, thermometer and measuring cylinder. I am going to show how to work out the percentage error, which we are going to use later when we collect our results. It will help minimise the amount of error in the experiment.

% Error:

Electronic Balance

It is set to 2 decimal places and therefore reads to the nearest 0.01g.

This means that 0.01 max and min point is ± 0.005 . It is accurate to 0.005g.

% Error = $(0.005/\text{your change in mass}) \times 100$

E.g. 1.0g of $\text{C}_2\text{H}_5\text{OH}$ calculated as $(0.005/1.00) \times 100 = 0.5\%$

Thermometer

It is set to the nearest 1°C and is accurate to $\pm 0.5^\circ\text{C}$.

$$\% \text{ Error} = (0.5/\text{Change in temperature}) \times 100$$

E.g. Temperature change of H_2O is 20°C calculated as
 $(0.5/20) \times 100 = 2.5\%$

Measuring Cylinder

Measures up to 250cm^3 and is accurate to $\pm 0.5\text{cm}^3$

$$\% \text{ Error} = (0.5/\text{Volume}) \times 100$$

E.g. Water is measured to 200 cm^3 is calculated as $(0.5/200) \times 100 = 0.25\%$

Heat Loss Error

This is going to be the highest source of error in the experiment.

$$\% \text{ Error} = (\text{The difference in enthalpy of combustion between the actual experimental value and data book value} / \text{databook value}) \times 100$$

E.g. Actual = -500 KJ mol^{-1}
Databook = -1367 KJ mol^{-1}

$$(867/1367) \times 100 = 63.4\%$$

This shows a very high heat loss error.

Risk Assessment: -

There are risks within the experiment and it is essential that I have everything under control when dealing with potential hazards.

Methanol and Ethanol

It is highly flammable and harmful. The vapours will catch fire at temperatures above 13°C. The narcotic effect of ethanol/methanol is well known and may result from inhalation of the vapour. Methanol and ethanol are toxic by inhalation, if swallowed and by skin absorption. There is a danger of very serious irreversible effects though inhalation, in contact with the skin and if swallowed.

If swallowed: Wash out mouth and give a glass or two of water. Seek medical attention if victim shows drunken symptoms.

If vapour inhaled: Remove victim to fresh air to rest. Keep warm.

If liquid splashed in eyes: Flood the eye with gently running tap water for 10 minutes. Seek medical attention.

If split on skin or clothes: Remove contaminated clothing. Wash affected area thoroughly with cold water. Soak contaminated clothing to reduce fire risk if more than 10 ml.

If spilt in laboratory: Shut off all sources of ignition. Open all windows and apply mineral absorbent to the spill. Scoop up into a bucket and add water.

Store: As a Flammable liquid (FL).
Handle it with care

Heating- Wear eye protection. Never use an open flame to heat ethanol or methanol. If alcohol catches fire then cover with a heatproof mat to starve of oxygen.

Propanol and Higher Alcohol's

It is highly flammable, irritant and is harmful.

Vapours may cause drowsiness or dizziness and maybe headaches. Irritating to the skin and harmful if swallowed. There is a risk of serious damage to the eyes. This alcohol's are irritant to the respiratory system.

If swallowed: wash out mouth and give a glass or two of water. Seek medical attention.

If vapour inhaled: Remove victim to fresh air to rest. Keep warm.

If liquid splashed in eyes: Flood the eye with gently running tap water for 10 minutes. Seek medical attention.

If split on skin or clothes: Remove contaminated clothing. Wash affected area thoroughly with cold water. Soak contaminated clothing to reduce fire risk if more than 10 ml.

If spilt in laboratory: Shut off all sources of ignition. Open all windows. Cover with mineral absorbent and clear up into a bucket. Rinse area with a cloth. Wash the absorbent with dispersing agent and pour liquid down the foul-water drain.

Store: As Flammable Liquids (FL).

Handle it with care. Wear eye protection. The room should be well ventilated, but draughts may affect experimental work. Put alcohol's in spirit burners. The experiment can be shortened if smaller temperature changes are required and smaller volumes of water are heated.

Goggles should be worn at all times. Alcohol's are flammable and need to be handled with care. Therefore spillages should be avoided and the alcohol's should be used out of the way of other naked flames.

The experiment itself produces heat, which causes the apparatus heat up. I suggest that it should be handled with care

during and after experiment has taken place. Make sure the room is well ventilated.

Reliability of results and plan: -

The plan I have devised is likely to provide precise and reliable results as I have carried out the experiment myself and written down a step by step procedure of what I did when I carried out the experiment myself for preliminary work. My preliminary results were fairly accurate and this is why I improved my plan a lot, so this is why it is very good. The points are easy and clear to understand, so that any student would be able to follow them. The results will be very reliable and accurate because I have done a number of things to ensure that errors are left to the minimum. These are all explained in the fair test section and % accuracy section.

The sources I have used to devise my plan are:

- Hazard cards
- Chemical ideas - Salters advanced chemistry
- Chemical storyline - Salters advanced chemistry
- Worksheet DF1.2
- Teacher
- My own notes
- Practical I did in GCSE's
- The Internet

Analysis & Conclusion of Results

The Table shows the results from the combustion of four alcohols that I used

Spirit burner/ name of alcohol	Mass of water used (g)	Initial weight of spirit burner + lid + alcohol (g)	Final weight of spirit burner + lid + alcohol (g)	Overall mass loss of fuel (g) = initial-final weight of spirit burner + lid + alcohol	Initial temperature of the water (°C)	Final temperature of the water (°C)	Overall temperature change (°C) = final - initial water temperature
Methanol Trial 1	200	213.12	209.74	3.38	16	36	20
Methanol Trial 2	200	209.72	206.35	3.37	16	36	20
Methanol Trial 3	200	213.14	210.15	2.99	16	36	20
Ethanol Trial 1	200	166.26	163.94	2.32	16	36	20
Ethanol Trial 2	200	177.22	174.89	2.33	17	37	20
Ethanol Trial 3	200	172.22	169.14	3.08	17.5	37.5	20
Propan-1-ol Trial 1	200	213.27	211.21	2.06	17	37	20
Propan-1-ol Trial 2	200	206.50	204.40	2.10	16	36	20
Propan-1-ol Trial 3	200	204.20	201.77	2.43	16	36	20
Butan-1-ol Trial 1	200	189.87	188.34	1.53	17.5	37.5	20
Butan-1-ol Trial 2	200	124.45	121.46	2.99	17.5	37.5	20
Butan-1-ol Trial 3	200	211.39	209.63	1.76	16	36	20

I am going to use the following formula to work out how much energy in form of heat was transferred to the water in each experiment:

Energy transferred to water by burning fuel (KJ mol^{-1}) = (mass of water (g) \times temperature rise ($^{\circ}\text{C}$) \times 4.2 (J))

From this above formula the enthalpy change of combustion can be worked out for each experiment by finding out the amount of moles of fuel burnt, using this formula:

Moles = (Mass/Relative Molecular Mass)

The table shows information about the four alcohols I chose to use in this experiment

Alcohol	Number of carbon atoms	Relative Molecular Mass
Methanol	1	32
Ethanol	2	46
Propan - 1 - ol	3	60
Butan - 1 - ol	4	74

Using all the above data I worked out for each experiment the enthalpy change of combustion and the average enthalpy change of combustion from one mole of fuel burnt.

The table shows sums up the results for the enthalpy change of combustion

Spirit burner/ name of alcohol	Amount of heat absorbed by the water (KJ)	Moles of fuel burnt(m)	Enthalpy Change of Combustion (KJ mol ⁻¹)
Methanol (1)	16.8	0.105625	159.05
Methanol (1)	16.8	0.1053125	159.53
Methanol (1)	16.8	0.0934375	179.80
Ethanol (1)	16.8	0.050434782	333.10
Ethanol (2)	16.8	0.050652173	331.67
Ethanol (3)	16.8	0.066956521	250.91
Propan-1-ol (1)	16.8	0.034333333	489.32
Propan-1-ol (2)	16.8	0.035	480.00
Propan-1-ol (3)	16.8	0.0405	414.81
Butan-1-ol (1)	16.8	0.020675675	812.55
Butan-1-ol (2)	16.8	0.040405405	415.79
Butan-1-ol (3)	16.8	0.023783783	706.36

The table shows the average enthalpy change of combustion

Name of Alcohol	Average mass of fuel used (g)	Average moles of fuel burnt (m)	Average enthalpy change of combustion (Kj mol ⁻¹)
Methanol	3.25	0.1015625	165.58
Ethanol	2.58	0.056086956	299.92
Propan-1- ol	2.20	0.036611111	458.88
Butan-1-ol	2.09	0.028243243	593.89

Note: Graphs are at the end of the coursework.

From looking and analysing at both my graphs and my results I have identified some trends. From my graph devised from the table above, it shows clearly that as the molecular structure/hydrocarbon chain increases so does the alcohol enthalpy change of combustion. For example, the enthalpy change of combustion for methanol is ' $165.58 \text{ KJ mol}^{-1}$ ' but for ethanol it is ' $299.92 \text{ KJ mol}^{-1}$ '. Ethanol has a bigger molecular structure than methanol. The reason for the higher enthalpy value is because the bigger the molecular structure the more bonds that are needed to be broken and made. Butan-1-ol has the highest enthalpy change of combustion, which is ' $593.89 \text{ KJ mol}^{-1}$ ' on the other hand methanol has the lowest. All of this matches with my prediction which proves somewhat that my experiment was a success.

There is some further evidence that can explain these findings. There is a certain amount of energy required to break a specific bond, which is related to the bond enthalpy. For example, the average bond enthalpy for O-H is ' $+464 \text{ KJ mol}^{-1}$ ' but for C-C is ' $+347 \text{ KJ mol}^{-1}$ '. This shows that different bonds have different enthalpy values. This means if there are more bonds present in a molecule, there is a greater need for energy to break and make these bonds. Breaking bonds take in energy on the other hand making of bonds release energy. This explains why more energy is released in the combustion of bigger molecules. For example Butan-1-ol releases more energy than Propan-1-ol which means more CO_2 and H_2O are formed.

I have also identified another trend from my results. I have noticed that as the molecular structure of the alcohol increases the moles of fuel burnt decreases. An example is the average moles of fuel burnt for ethanol is 0.056086956 moles but for Propan-1-ol it is 0.036611111 moles of fuel burnt. The reason for this is because the bigger the molecular structure the less volatile the molecule is. Before a reaction can take place in

the experiment, the alcohol has to go against gravity and travel up to the top of the wick where the reaction can occur to break and make bonds. This explains why the moles of fuel burnt for ethanol, which has an RMM of 46 was greater than propan-1-ol which has an RMM of 60.

From analysing graph number 1 it clearly shows that as the number of carbon atoms increase so does the enthalpy change of combustion. Even though my results don't show these two things being directly proportional to each other it does show a very high positive correlation. This is because as the hydrocarbon chain of successive alcohols increases, only by an extra CH_2 bond. This means there is a fixed increase in the amount of bonds that are broken and made for successive alcohols. The findings from my experiment support this fact because for the successive alcohols the enthalpy change of combustion does roughly increase by the same value. From my table you can see that the enthalpy change of combustion from methanol to ethanol increases by ' $134.34 \text{ KJ mol}^{-1}$ ' and from ethanol to propan-1-ol is ' $158.96 \text{ KJ mol}^{-1}$ '. This shows the increase in enthalpy is roughly the same meaning that as the number of carbon atoms increase so does the enthalpy change of combustion. So in conclusion my results and findings match my prediction and I did get a kind of proportional relationship between the number of bonds being made and broken and enthalpy values.

Evaluation

Evaluating the Procedure/Experiment: -

In my opinion the experiment was very good because the results were as expected and matched my prediction. Nevertheless there were still errors in the experiment, which may mean that the results were not completely accurate.

Below is a table to show the percentage errors for instrumentation:

Instrument	Accuracy	Point/degree of Accuracy	Percentage error (%)
Electronic Balance	0.01g	$\pm 0.005\text{g}$	0.20 = Average (%) error
Thermometer	1 ⁰ C	$\pm 0.5^{\circ}\text{C}$	2.5
Measuring cylinder	250 cm ³	$\pm 0.5 \text{ cm}^3$	0.25

This table shows that the percentage errors for the instruments are very small. This means that my results were fairly accurate and reliable because the percentage errors have a low impact on my results. Also the fact that there were no anomalous results proves that my experiment went well.

Even though the percentage error was so low, there were still other sources of errors in my experiment/procedure. The main source of error is heat loss. Looking at graph number 2, you can see that the data book value which is the actual value for the enthalpy change of combustion is very different from the value I got from my experiment. The reason for this could be heat loss.

The table shows the percentage error from heat loss for each alcohol I tested

Name of alcohol	Data book enthalpy change of combustion value (KJmol ⁻¹)	Enthalpy change of combustion value obtained (KJ mol ⁻¹)	Percentage Error (%)
Methanol	726	165.58	77.2
Ethanol	1367	299.92	78.1
Propan-1-ol	2021	458.88	77.3
Butan-1-ol	2676	593.89	77.8

This table clearly shows that heat loss was the main source of error. The average percentage heat loss for my experiment was 77.6%, which is a very high value and probably is the main reason for the results in graph 2. Therefore it means I need to question the accuracy and reliability of my results because the heat loss error to the surrounding was so high. This could mean that the water in the calorimeter did not absorb a lot of the heat energy emitted from the alcohol/fuel. So this will affect my results for the enthalpy change of combustion because all the fuel was not transferred to the water.

There were aspects of my procedure that were used to try and combat these errors to ensure as accurate and reliable results as possible. An example is that in my experiment I used a temperature rise of 20°C to reduce the amount of heat loss. This is because if the temperature rise was a high value it will increase the amount of heat loss due to there being more time available for heat loss to occur. I could improve this further by choosing to use 10°C intervals this means there is less time for heat loss to occur.

A human error that may have contributed to heat loss is way I stirred the water because it could have caused hot spots to develop in the water causing all the energy from the fuel not to be transferred to the water. I could improve this by using a bomb calorimeter. These have a stirring system, which is done automatically ensuring uniform heat flow, which means it reduces the amount of heat loss. A bomb calorimeter can give a very accurate and reliable result for the enthalpy change of combustion. Another way to stop heat loss is to use a flame or food calorimeter where heat is directly connected to the water through copper tube in an enclosed system with a tube for oxygen. Also use a calorimeter that conducts heat more efficiently.

Another major error in my experiment is incomplete combustion of the fuel. It produces soot and CO, therefore resulting in the release of less energy to the water and therefore decreasing the enthalpy of combustion value. This occurred in the experiment by the fact that soot collected on the bottom surface of the gauze and the aluminium calorimeter. This meant that not all the heat energy from the burning fuel got transferred to the water because the soot would act as an insulator and prevent this process occurring. The reason for this could be due to the inconsistencies in measuring the wick which is due to human error thus meaning that the distance from the top of the wick to the bottom of the calorimeter that I chose which was 7.5cm was not maintained. This meant there was a limiting supply of oxygen resulting in incomplete combustion.

Since the wick was used it meant that it also combusted and the burning of the wick creates extra energy. Thus causing a reaction to occur where bonds are broken and made. This meant that the energy released from bonds being formed may have added to the total amount of heat transferred to the water from the fuel causing inaccurate enthalpy change of combustion to be worked out because the burning of the wick will increase the enthalpy value. Another reason could be that the draught exclusion system, which prevents heat loss, may have prevented more oxygen from reaching the alcohol causing incomplete combustion, which could have decreased the enthalpy values.

To improve and to reduce incomplete combustion you could use a bomb calorimeter, which does not involve the use of a wick and gauze. Therefore it would prevent differences to occur in the measuring of the wick length, prevent combustion of the wick, prevent soot collection on the gauze because the wick and gauze are not used in a bomb calorimeter. This would result in more complete combustion because heat energy from the fuel would transfer to the water meaning that my results would be more

accurate and the enthalpy change of combustion value will be more accurate. An alternate thing you could do is use a non-burning wick that can only deliver the alcohol but does not burn itself. Another thing you could do is to provide an alternate oxygen supply to the flame so all the alcohol burns. This would result in more complete combustion and more reliable results.

Evaluating the Results and Equipment: -

As I have mentioned before I think that my results are very good to an extent because they match my predictions. There were also no anomalous results, which meant that my results are very reliable and fairly precise. Nevertheless there were still errors in my experiment, which may have meant that I didn't get the most precise results possible.

The electronic balance was not that accurate which could have resulted in less accurate results. To improve this I should use a more accurate weighing instrument to measure the alcohol in the spirit burner before and after the experiment. This would have meant that a more accurate enthalpy change of combustion value to be worked out.

The measuring cylinder I used could have contributed to the errors because the degree of accuracy is only 0.5cm^3 . To improve my accuracy of my results I could use a burette instead, which is more accurate. This would mean that it would improve the value achieved for the amount of heat absorbed by the water in joules, meaning it will improve the accuracy of the enthalpy change of combustion values.

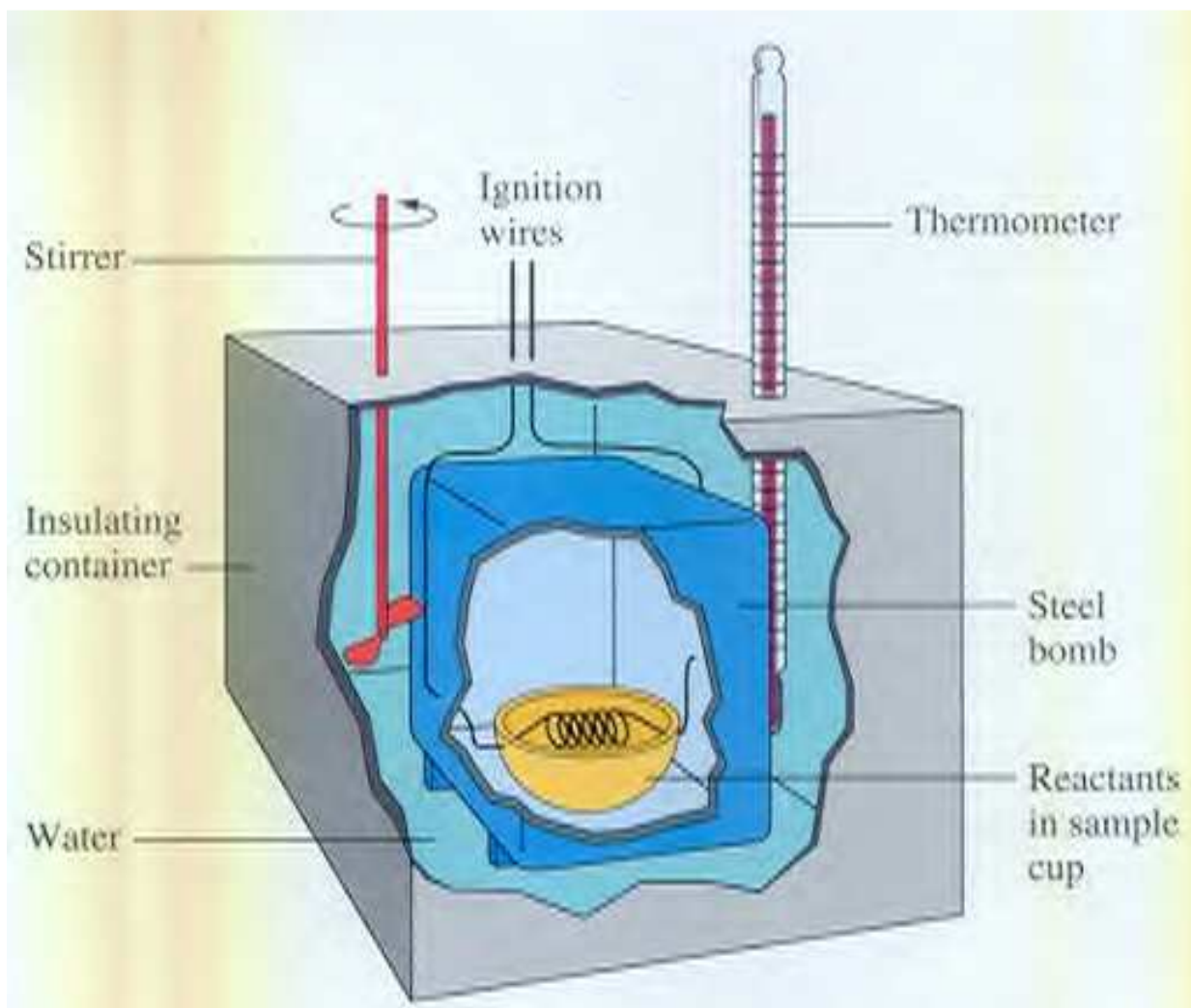
The thermometer may have contributed to the errors because its degree of accuracy was 0.5°C . This may have affected my results by making a lower reading for the enthalpy change of combustion value. To improve this I could have used a more accurate thermometer, which is measured to the nearest

0.1°C and leave it in the water for 5 minutes to get a true initial temperature and to minimise error. This would improve the value for both the enthalpy change of combustion and the amount of heat absorbed by the water in kilo joules.

Using the aluminium calorimeter may have contributed to % heat loss error. This is because it was not well ventilated so it allowed heat to escape to the surrounding causing an affect on the accuracy of my results. The calorimeter did not have a lid on it, which may have caused water to evaporate from it. This in turn reduces the mass of water and affects the value for the amount of water absorbed by the water, which then has an impact on the enthalpy change of combustion value, worked out.

I could have improved this error by using a more sophisticated calorimeter called a bomb calorimeter, as shown below in the diagram. The bomb calorimeter is a device used for making accurate measurements of energy changes. The fuel is ignited electrically and burns in oxygen inside the pressurised vessel. Energy is transferred to the surrounding water, whose temperature rise is measured by the thermometer. The 'bomb' is where reactants are put in and then the 'bomb' is sealed. The reactant enter the 'bomb' from the valve e.g. oxygen in the case of the combustion of fuel. The bomb is surrounded by water, which absorbs the heat from the reaction. The stirrer makes sure that the water is at constant temperature. All of this improves the accuracy of the enthalpy change of combustion values. Since the experiment is done in a closed container with a sealed vessel and lid and also done at constant volume means there is much less chance of heat escaping. Also the fact that an insulation chamber surrounds it means a less chance of heat escaping. This means my results will be more accurate and reliable.

A Diagram showing a Bomb Calorimeter



Another way to reduce heat loss is by using an insulation chamber to minimise heat loss. Insulation is a good way of minimising heat loss. I can silver the sides of the calorimeter to minimise heat loss by radiation, insulate the sides of the calorimeter and the insulation chamber to minimise heat loss by conduction and convection. This will ensure that the end enthalpy change of combustion value will be very accurate.

To improve the experiment to achieve more accurate results I can choose to use the distilled water as opposed to tap water

because tap water contains a variety of minerals and ions and the concentration of these may vary in view of repetition of the experiment also impurities in the water (may change the specific heat capacity of the water). This particular precaution is in aid of maintaining a fair experiment and limiting the inaccuracy of the experiment.

To improve the accuracy and reliability of my results even further I could repeat the experiment a greater number of times. I would do the experiment six times for each alcohol and use a wider range of alcohol's e.g. I could use alcohol's up to hexan-1-ol instead of butan-1-ol. This would improve the accuracy and reliability of my results.

A major way of improving the experiment is to do everything under standard conditions, which is 1 atmosphere pressure and 298K. This would produce the best results, which were the most accurate and reliable.

Bibliography: -

The other sources that I have used for information on this investigation are:

- Salter's Chemical Ideas Book
- The internet
- Work done at GCSE and practical done at GCSE
- Teachers help
- Work done in class on combustion
- My own notes