International Baccalaureate

# Extended essay cover

*Candidates must complete this page and then give this cover and their final version of the extended essay to their supervisor.*

| | | | |
|---|---|---|---|
| Candidate session number | | | |
| Candidate name | | | |
| School number | | | |
| School Name | | | |
| Examination session (May or November) | MAY | Year | 2013 |

Diploma Programme subject in which this extended essay is registered: CHEMISTRY

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: An investigation into the effect of concentration of primary alcohols and Hexane and the effect of the amount of Carbon atoms within the alcohol to the Enthalpy of Combustion of the mixture

**Candidate's declaration**

*If this declaration is not signed by the candidate the extended essay will not be assessed.*

I confirm that this work is my own work and is the final version. I have acknowledged each use of the words or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

Candidate's signature:

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## Supervisor's report

*The supervisor should complete the report below and then give this cover, enclosing the final version of the extended essay, to the Diploma Programme coordinator. The supervisor must sign this report; otherwise the extended essay will not be assessed and may be returned to the school.*

Name of supervisor (CAPITAL letters)

## Comments

*If appropriate, please comment on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome. These comments can help the examiner award a level for criterion H. Do not comment on any adverse personal circumstances that may have affected the candidate.*

chose this because he is interested in fuels, particularly alternative fuels. He would like to study Chemical Engineering at university and so a chemistry ee was a priority. would have liked to research hydrogen as a fuel, but realised that wasn't practical.

found out that as the number of carbon atoms increases, $\Delta H_c$ increases. Problems during the experiments included heat loss to the surroundings & incomplete combustion (especially for butan-1-ol).

The highlight of the process was getting to do a practical designed by himself. found the calculations & propagation of errors difficult.

If were to do this again, he would organise his time better and listen more carefully to advice given.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent 25. hours with the candidate discussing the progress of the extended essay.

Supervisor's signature:

Date:

| | |
|---|---|
| A | 2/2 |
| B | 2/2 |
| C | 2/4 |
| D | 1/4 |
| E | 2/4 |
| F | 2/4 |
| G | 1/4 |
| H | 1/2 |
| I | 2/4 |
| J | 1/2 |
| K | 2/4 |
| Total | 18/36 |

# Chemistry Extended Essay

## An Investigation Into The Effect of Concentration of Primary Alcohols and Hexane and the effect of the amount of Carbon atoms within the alcohol to the Enthalpy of Combustion of the Mixture

**3/7/2013**

Word Count: 3960 Words

# CONTENTS

# Abstract

The experiment was aimed at the investigation of properties of the combustion of primary alcohols when mixed with Hexane to emulate gasoline. 4 different primary alcohols and 4 different alcohol concentrations were considered which could show a correlation as to how concentration of alcohol as well as carbon chains affects the enthalpy of combustion. Thus the research question of this experiment was the following:

**At what concentration of alcohol in a hexane-alcohol mixture will produce the most amount of energy and therefore could be a viable alternative against commercial diesel in the fuel market?**

In order to investigate this, it was necessary to collect experimental data: enthalpy of combustion through calorimetry. To collect this, different variables were taken, including: Mass of Water being burned in Calorimeter, Temperature Change and the moles of Alcohol.

$$Enthalpy_{Combustion} = \frac{m_{H_2O} \times c \times \Delta T_{H_2O}}{M_{Fuel}}$$

In addition experimental data in the form of Alcohol type and Alcohol concentration were also taken to be analyzed for the evaluation of which Alcohol-Hexane composition would exert the most energy per unit mass.

The results showed that for most of the alcohols, as the concentration tends towards 50% from 40% the enthalpy of combustion reaches a peak. It is enough to assume that incomplete combustion may have been less frequent at these concentrations.

Also, the results revealed that the amount of carbon atoms within the alcohol molecule may be related to its enthalpy of combustion. Although Butan-1-ol's average concentrations were lower than propan-1-ol, there was still an increasing trend of average enthalpy of combustions from methanol to propan-1-ol. It can be assumed that because of the prominent sources of error within the experimental process, this may have affected the values of butan-1-ol. However, experimental it can also be assumed that butan-1-ol mixtures do exhibit a larger incomplete combustion frequency than other alcohols.

Word Count: 299 Words

# 1. Introduction

In the modern world, cars have become an integral mode of transportation. Transportation of people and merchandise has allowed the world to run faster and as a result, the productivity of an average day has increased, however as a result, fossil fuel reserves are being burned everyday by combustion engines of cars. This has a negative effect not only on the environment but also on the economy. Because of depleting fuel reserves, the supply of everyday diesel petrol cannot cater for the increasing demand, in turn forcing the petroleum industries and governments to increase the price of petrol. In addition, the petroleum created from fractional distillation creates problems for the environment as the resultant combustion products aids the global warming process. Thus, a lot of today's scientific research is going towards the development of alternative fuels.

Alcohol fuel, in particular, has been used in many countries, most notably in Brazil where the development of Ethanol Fuel has been attributed to its 37 year old ethanol fuel program of the cultivation of sugar cane as the main source of ethanol[1]. This brings about not only a seemingly cleaner combustion but also has a competitive edge in terms of cost of production in the market. Due to the wide availability of ethanol in forms of crops (sugarcane in Brazil, Corn in United States), it seems more widely available and less costly to switch to the production of alcohol fuels but the question still remains of whether it is a viable source of energy that the international economy and world's chemical engineers should invest their time and money into.

The most common form of alcohol fuel is an ethanol fuel variant – E85 – and is the most commercially available[2]. There has been study as to the effect of the varying number of carbon atoms in an alcohol on the enthalpy of combustion of that alcohol. From experimental data, in most cases of lower carbon number alcohols, the enthalpy of combustion of higher number carbon atom alcohols have produced a higher enthalpy of combustion. The combustion of a methanol fuel[3] has also been widely considered along with the existence of Butanol[4][5] and Propanol substances brings to mind the effect of alcohol type and concentration in an alcohol fuel mixture on the enthalpy of combustion of the fuels. As well as gasohols[6] there has been extensive research in alternative sources of fuel for vehicles. One prominent possibility is the Hydrogen fuel being researched in universities such as the University of Birmingham[7]. Although it can be domestically produced the main

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[1] http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil Ethanol Fuel in Brazil

[2] http://en.wikipedia.org/wiki/Alcohol_fuel Alcohol Fuel

[3] http://www.afdc.energy.gov/fuels/emerging_methanol.html Emerging Methanol

[4] http://www.afdc.energy.gov/fuels/emerging_biobutanol.html Emerging Bio-butanol

[5] Life-Cycle Assessment of Corn-Based Butanol as a Potential Transportation Fuel by M. Wu, M. Wang, J. Liu

[6] http://www.oilgae.com/ref/glos/gasohol.html Gasohol

[7] http://www.birmingham.ac.uk/news/latest/2008/04/14Apr-Hydrogen.aspx Hydrogen Fuel

problem with Hydrogen fuel is that it does not exert enough energy per unit volume and thus this creates problems with storage space[8]. Like Hydrogen fuel, gasohols have the problem of needing a larger volume of the fuel to suffice a specific power output.

The subject being explored in the extended essay is how different compositions of Alcohols in the gasohol solutions can affect how much energy output a gasohol could create per unit volume. The topic presents some value for investigation as it explores alternative fuels to commercial diesel and with a portion of the world worrying about the depleting reserves of fossil fuels that are transmuted to fuels for cars, airplanes and boats it seems fitting that a probable replacement in gasohol is explored. For instance, perhaps a trend in concentration of alcohol within a gasohol as well as the number of carbon atoms in the alcohol mixed could point towards an optimum mixture of alcohol to gasoline mixture that produces an optimum ratio between energy outputs to volume of gasohol. Although it could be argued that perhaps alcohol may not be the heavily determining factor in production of gasohol, it is safe to say that with a rapidly depleting reserve of oil that has served for more than a century it is smart to find the most favorable mixture as in the long run, it could mean the sustenance of gasohol ingredient reserves.

The testing of viable sources of fuel would normally be investigated under complex scientific investigations such as an Adiabatic Bomb Process[9] but since schools do not generally possess such advanced equipment, a simple calorimeter experiment was decided to test out the energy output of different gasohol compositions since it involved readily available equipment that would be found in a school lab. The problem that this runs against is that it may be incredibly unreliable as the burning of fuels will definitely incur incomplete combustion and thus will create soot underneath the copper calorimeter which could tamper with the reliability of the results as the incomplete combustion may mean that the combustion is not reaching its actual potential energy output. There is also the risk of an ever changing open system taking the heat from the calorimeter and the fuel burner. In addition, since conventional gasoline mixture is too hazardous to burn in a school lab, it has been replaced by Hexane.

For this investigation, 4 different alcohols were added to Hexane at 4 different concentrations each and burned to a temperature below the boiling point of water. Although all the alcohols being tested are miscible in Hexane (with the exception of methanol)[10] each mixture is going to be shaken to emulate a well-mixed solution as close as

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[8] http://www.fueleconomy.gov/feg/hydrogen.shtml Hydrogen Fuel

[9] http://www.docbrown.info/page07/delta1Hc.htm Calorimeters

[10] http://www.sigmaaldrich.com/chemistry/solvents/hexane-center/miscibility-immiscibility.html Miscibility of Hexane

possible. Also, the basis behind the choice of hexane as a gasoline-mixture stand-in is that firstly, gasoline is highly carcinogenic and the burning of such in school premises would be a fire hazard. Thus, as hydrocarbons are constituents in the production of gasoline for cars and it is not as much of a fire hazard to combust; it seemed like a feasible choice.

## 2. Hypothesis

The main factor that affects the Enthalpy of Combustion of the Alcohols is the amount of Carbon-Carbon Chains the Alcohol has. I predict that the more carbon atoms in the alcohol, the larger its enthalpy and therefore I predict that a Butan-1-ol mixture would have the largest enthalpy value as compared to other alcohols.

Since alcohols generally exhibit larger enthalpy of combustion, I think that a mixture with a high concentration of alcohol will have a high enthalpy of combustion. One source of hindrance for energy output for a fuel is incomplete combustion. The incomplete combustion of an Alcohol will result in Carbon Monoxide and Water Vapor to form. On the other hand an incomplete combustion of Hexane will result in Carbon Dioxide, Carbon Monoxide, Water and Carbon to form. Moreover, the presence of Carbon in the form of soot may hinder the calorimeter heating process as it may insulate the copper. Perhaps if an even concentration of both Alcohol and Ethanol were to be mixed, this could result in a higher enthalpy of combustion because either there will be less incomplete combustion of either Alcohol or Hexane or perhaps Carbon from the Alkane's incomplete reaction and Carbon Monoxide from the Alcohol's incomplete combustion will react together to form Carbon Dioxide, thus avoiding much interference from soot.

## 3. Methodology for Data Collection

Since there are two dependent variables being explored and evaluated in this investigation, in order to collect relevant data there needs to be 16 different calorimetry experiments[4] run with 3 repeats each to account for uncertainty in the results. Moreover, since each mixture will be used only to burn a small amount of water (100.00cm$^3$±0.10cm$^3$) it seems efficient to only use a small amount of mock gasohol solution: 20.00 ml.

Due to it being only a 20ml mixture, the enthalpy of combustion will be miniscule in change as concentration changes. Therefore the graphing of results will have very miniscule scales to be able to find a trend. In addition, because there are only 4 concentrations being tested per alcohol, it will be difficult to distinguish whether there is a linear, exponential or logarithmic correlation to the concentration graph. Therefore, it will be assumed via excel that each relationship will be linear. The gradients will be compared per alcohol and evaluated on how much the alcohol affects and determines the solution. Because of the different specific Gravities of Alcohol and Hexane it is assumed that they aren't completely miscible and thus they are shaken to mix them.

To measure the Enthalpy of Combustion of Gasohol Solution I used the standard equation of an enthalpy of combustion of a fuel:

$$Enthalpy_{Combustion} = \frac{m_{H_2O} \times c \times \Delta T_{H_2O}}{M_{Alcohol \times [Alcohol] \cdot C_6H_{14} \times [C_6H_{14}]}}$$

The value for specific heat capacity of water will be taken as 4.18 as all values will be rounded to 2 decimal points. The mass of the water was measured using a mass balance that measures up to 2 decimal points of grams. This was done by putting the calorimeter on the mass balance and was synced back to zero before water was added. Water was added and was as close as possible added till 100.00cm$^3$.

In order for the experiment to be as fair as possible, I needed to make sure that there is not much difference in the apparatus that was used for each trial and therefore I used the same calorimeter if possible but brush off the carbon from the calorimeter from the combustion before each test and repeat. In addition, before each trial, I allowed the thermometer to cool off with a beaker of tap water. I also did each repeat at the same station with the same protective screen as draught shields in the same place so that there is not much difference in the system when I do each trial.

### 3.1 Apparatus List:

- Copper Calorimeter
- Hexane
- Ethanol
- Methanol
- Propan-1-ol
- Butan-1-ol
- Spirit Burners (w/ 5mm thick wicks)
- Gloves
- Protective Screen (Draughts Shields)
- Insulation Cards
- Thermometer
- Standing Clamps
- 10ml Pipette
- Mass Balance (2.dp)
- Paint Brush

### 3.2 Variables

| *Variable Type* | *Variable* | *Method of Control* |
|---|---|---|
| *Independent* | *Concentration of Alcohol and Hexane in solution (Fuel make-up)* | *Use the same Spirit Burner with same fuel composition for each repeat of a fuel composition. Use a different Spirit Burner for each fuel composition. Same apparatus used to transfer same substances into fuel burner.* |
| | *Mass of Water* | *Water added:* $100.00cm^3$ ±$0.10cm^3$ |
| *Control* | *Height from burner to Calorimeter* | *Stable object (bottle) used as a seat for calorimeter before clamped on onto standing clamp.* |
| | *System interference* | *Draught Shields and insulation cards used to contain heat and emulate a quasi-closed system. Practical done at the corner of a lab, away from windows and any high activity.* |
| | *Conductivity of Calorimeter* | *Use the same Calorimeter for each trial. After each trial, cool with water in preparation for the next trial. Any soot on the calorimeter is brushed with a paint brush.* |
| *Dependent* | *Temperature of Water* | *Use the same Thermometer each trial. After each trial, cooled to base level with separate can of water. "Temperature Before" is read after 30 seconds of thermometer immersion. "Temperature After" read immediately as fuel burner is put out.* |
| | *Mass of Fuel* | *Use the same Spirit Burner for each repeat of a fuel composition.* |

### 3.3 Method

1. Set up Protective screens as draught shields from most possible sources of interference (i.e. windows, doors and bystanders)
2. Using a pipette, measure and transfer an amount of alcohol (dependent on concentration being measured) into a spirit burner.
3. With a different pipette, measure and transfer an amount of hexane into the spirit burner, corresponding with the concentration of alcohol present in the spirit burner.
4. Place wick through Spirit burner and seal off.
5. Shake burner in order for the alcohol and hexane to properly mix (they have separate gravities).
6. Measure the mass of the fuel with the burner mixture before the combustion and record it on a table.
7. Put copper calorimeter on mass balance and "zero" the units on the mass balance.
8. Carefully add water into the balance. Get as close to 100.00 $cm^3$. Record this mass on table.
9. Clamp the calorimeter a fixed distance from the work surface and place wick under it (make sure to have a heat proof mat under the burner for safety precautions)
10. Place insulating card on top of copper calorimeter and through the hole, place the thermometer. Take starting temperature and record it on table.
11. Light burner wick.
12. Wait until temperature reaches a sufficient amount but avoid boiling point 100 degrees Celsius. Blow out wick and quickly put the spirit burner on the mass balance. Record temperature and Mass of the Fuel after combustion.
13. Repeat process 3 times for each concentration of each alcohol.

### 3.4 Safety Precautions

There are some safety precautions that must be taken when doing this experiment. Firstly, when handling hexane, it is necessary to wear gloves because it is a volatile, flammable solvent with labels "Harmful" and "Dangerous". In addition, it was imperative that I wear goggles at all times near the experiment. In the event that chemicals come in contact with skin, affected area must be immediately washed thoroughly with water. If eye contact is made, a rubber tube is attached to the tap and water blown into the affected eye. Because this experiment involves combustion, any burns must be treated with cold water. Secondly, the matches must be struck away from the person in order to avoid burning clothing or the person. However, matches must be struck away from flammable objects such as the alcohols and hexane. Finally, tongs must be used when handling hot calorimeters.

## 4. Raw Data Collection

Methanol

| Trial | Mass of Water (g) ±0.02g | Mass of Fuel Before (g) ±0.01g | Mass of Fuel After (g) ±0.01g | ΔMass of Fuel (g) ±0.02g | Temperature Before (c) ±0.5°C | Temperature After (c) ±0.5°C | ΔTemperature of Water ±1°C | Concentration of Alcohol (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 100.06 | 175.68 | 174.46 | 1.22 | 21.00 | 80.00 | 59.00 | 20 |
| 2 | 100.04 | 174.35 | 173.11 | 1.24 | 21.00 | 85.00 | 64.00 | |
| 3 | 100.04 | 173.09 | 171.86 | 1.23 | 22.00 | 86.00 | 64.00 | |
| 1 | 100.02 | 176.35 | 174.97 | 1.38 | 21.00 | 65.00 | 44.00 | 40 |
| 2 | 100.07 | 174.96 | 173.97 | 0.99 | 21.00 | 53.00 | 32.00 | |
| 3 | 100.04 | 173.55 | 172.65 | 0.90 | 21.00 | 50.00 | 29.00 | |
| 1 | 100.00 | 182.09 | 181.22 | 0.87 | 21.00 | 37.00 | 16.00 | 60 |
| 2 | 100.04 | 181.61 | 180.76 | 0.85 | 21.00 | 36.00 | 15.00 | |
| 3 | 100.05 | 180.72 | 179.96 | 0.76 | 21.00 | 40.00 | 19.00 | |
| 1 | 100.05 | 179.21 | 176.58 | 2.63 | 21.00 | 85.00 | 64.00 | 80 |
| 2 | 100.05 | 176.50 | 174.97 | 1.53 | 20.00 | 60.00 | 40.00 | |
| 3 | 100.07 | 174.89 | 173.17 | 1.72 | 20.00 | 76.00 | 56.00 | |

Ethanol

| Trial | Mass of Water (g) ±0.02g | Mass of Fuel Before (g) ±0.01g | Mass of Fuel After (g) ±0.01g | ΔMass of Fuel (g) ±0.02g | Temperature Before (c) ±0.5°C | Temperature After (c) ±0.5°C | ΔTemperature of Water ±1°C | Concentration of Alcohol (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 100.06 | 179.48 | 177.66 | 1.82 | 21.00 | 88.00 | 67.00 | 20 |
| 2 | 99.99 | 176.34 | 174.19 | 2.15 | 22.00 | 93.00 | 71.00 | |
| 3 | 100.00 | 173.89 | 172.32 | 1.57 | 22.00 | 86.00 | 64.00 | |
| 1 | 100.03 | 173.93 | 172.22 | 1.71 | 23.00 | 89.00 | 66.00 | 40 |
| 2 | 100.01 | 177.33 | 175.99 | 1.34 | 22.00 | 85.00 | 63.00 | |
| 3 | 100.03 | 175.78 | 174.00 | 1.78 | 22.00 | 90.00 | 68.00 | |
| 1 | 100.02 | 181.10 | 179.58 | 1.52 | 20.00 | 84.00 | 64.00 | 60 |
| 2 | 100.04 | 179.52 | 178.09 | 1.43 | 21.00 | 85.00 | 64.00 | |
| 3 | 100.04 | 178.03 | 176.50 | 1.53 | 21.00 | 87.00 | 66.00 | |
| 1 | 100.06 | 177.75 | 175.40 | 2.35 | 19.00 | 100.00 | 81.00 | 80 |
| 2 | 100.01 | 175.33 | 173.65 | 1.68 | 20.00 | 85.00 | 65.00 | |
| 3 | 100.10 | 173.43 | 171.96 | 1.47 | 21.00 | 85.00 | 64.00 | |

Propan-1-ol

| Trial | Mass of Water (g) ±0.02g | Mass of Fuel Before (g) ±0.01g | Mass of Fuel After (g) ±0.01g | ΔMass of Fuel (g) ±0.02g | Temperature Before (c) ±0.5°C | Temperature After (c) ±0.5°C | ΔTemperature of Water ±1°C | Concentration of Alcohol (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 100.09 | 175.55 | 174.08 | 1.47 | 21.00 | 85.00 | 64.00 | 20 |
| 2 | 100.05 | 172.42 | 170.80 | 1.62 | 20.00 | 80.00 | 60.00 | |
| 3 | 100.07 | 170.78 | 168.85 | 1.93 | 20.00 | 82.00 | 62.00 | |
| 1 | 100.06 | 177.01 | 175.51 | 1.50 | 21.00 | 90.00 | 69.00 | 40 |
| 2 | 100.06 | 175.50 | 174.07 | 1.43 | 21.00 | 85.00 | 64.00 | |
| 3 | 100.08 | 172.66 | 170.65 | 2.01 | 21.00 | 95.00 | 74.00 | |
| 1 | 100.07 | 177.30 | 175.79 | 1.51 | 21.00 | 90.00 | 69.00 | 60 |
| 2 | 100.06 | 175.60 | 173.83 | 1.77 | 21.00 | 93.00 | 72.00 | |
| 3 | 100.06 | 173.67 | 171.73 | 1.94 | 21.00 | 98.00 | 77.00 | |
| 1 | 100.02 | 178.09 | 176.59 | 1.50 | 24.00 | 80.00 | 56.00 | 80 |
| 2 | 100.06 | 175.82 | 173.79 | 2.03 | 21.00 | 88.00 | 67.00 | |
| 3 | 100.06 | 173.27 | 171.24 | 2.03 | 21.00 | 88.00 | 67.00 | |

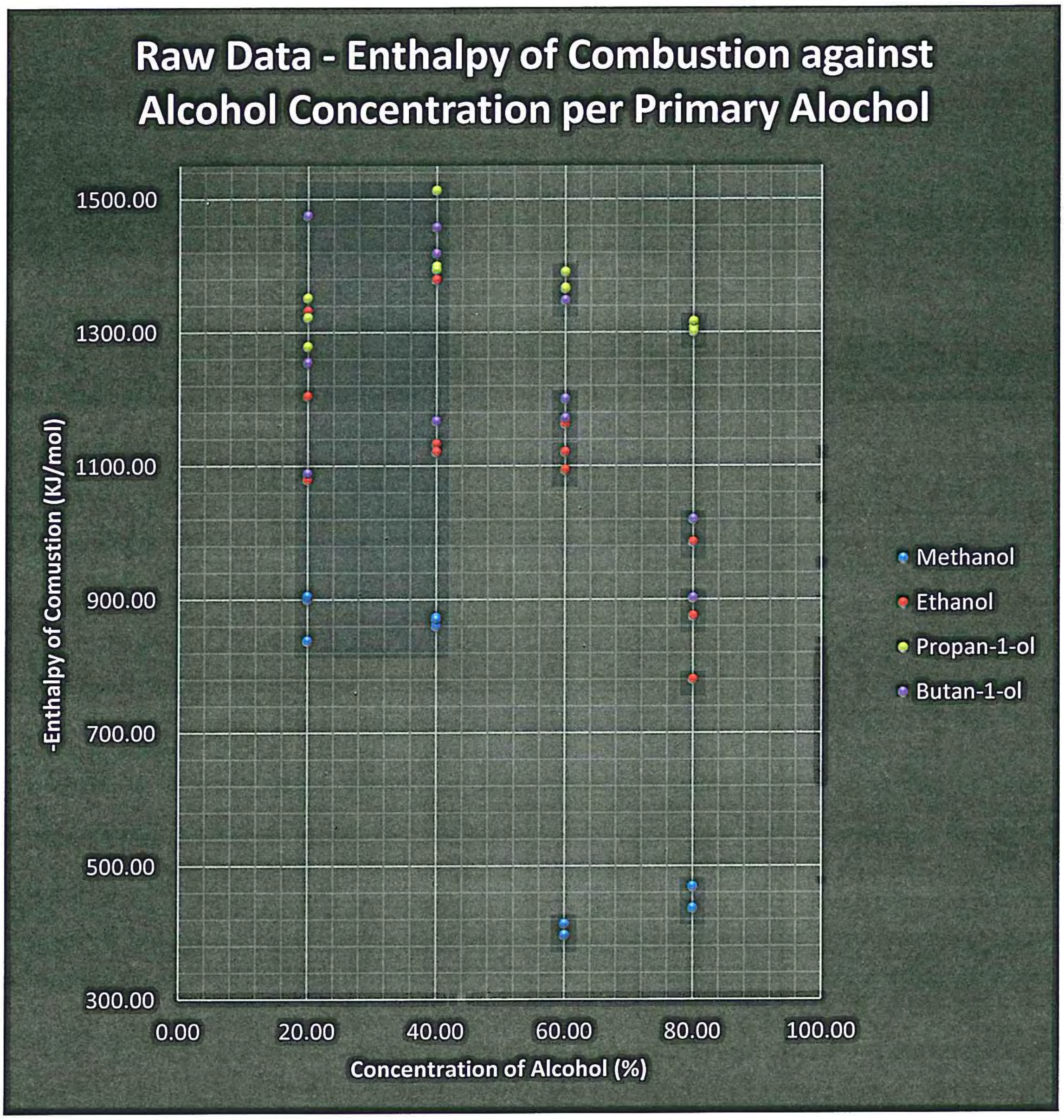
Butan-1-ol

| Trial | Mass of Water (g) ±0.02g | Mass of Fuel Before (g) ±0.01g | Mass of Fuel After (g) ±0.01g | ΔMass of Fuel (g) ±0.02g | Temperature Before (c) ±0.5°C | Temperature After (c) ±0.5°C | ΔTemperature of Water ±1°C | Concentration of Alcohol (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 100.03 | 179.32 | 177.21 | 2.11 | 23.00 | 100.00 | 77.00 | 20 |
| 2 | 100.06 | 177.13 | 175.46 | 1.67 | 22.00 | 85.00 | 63.00 | |
| 3 | 100.07 | 175.75 | 174.22 | 1.53 | 21.00 | 80.00 | 59.00 | |
| 1 | 100.08 | 175.35 | 173.89 | 1.46 | 20.00 | 80.00 | 60.00 | 40 |
| 2 | 100.06 | 173.86 | 172.42 | 1.44 | 21.00 | 85.00 | 64.00 | |
| 3 | 100.04 | 172.49 | 171.05 | 1.44 | 21.00 | 80.00 | 59.00 | |
| 1 | 100.06 | 181.05 | 179.60 | 1.45 | 21.00 | 81.00 | 60.00 | 60 |
| 2 | 100.06 | 179.46 | 177.96 | 1.50 | 21.00 | 83.00 | 62.00 | |
| 3 | 100.04 | 177.94 | 176.42 | 1.52 | 21.00 | 85.00 | 64.00 | |
| 1 | 100.05 | 182.32 | 180.95 | 1.37 | 20.00 | 80.00 | 60.00 | 80 |
| 2 | 100.05 | 180.90 | 179.44 | 1.46 | 20.00 | 80.00 | 60.00 | |
| 3 | 100.07 | 179.34 | 177.74 | 1.60 | 20.00 | 85.00 | 65.00 | |

During the experiment, there were inconsistencies in results that arose which could be attributed to the unreliability of data collection through the standard calorimeter experiment. This affected the spread of results in repeats and consequently none of the repeats for at least one mixture were even concordant of each other to 100KJ/mol.

The combustion of fuel seemed incomplete from the heavy soot, black smoke and the red tinged flames of the fuel, especially observed with the Methanol-Hexane mixture. One result (Concentration Methanol 80%: Trial 3) was considered an anomaly as it wasn't concordant of the other results to more than 10000KJ/mol. An observation of this exact trial reveals that there was a considerable larger flame on this trial and also the insulation card was set on fire by this flame thus the additional heat energy from the card as a fuel resulted in the temperature of the water not only being affected by the burning fuel and otherwise colder system, there I now also additional burning fuel from the card.

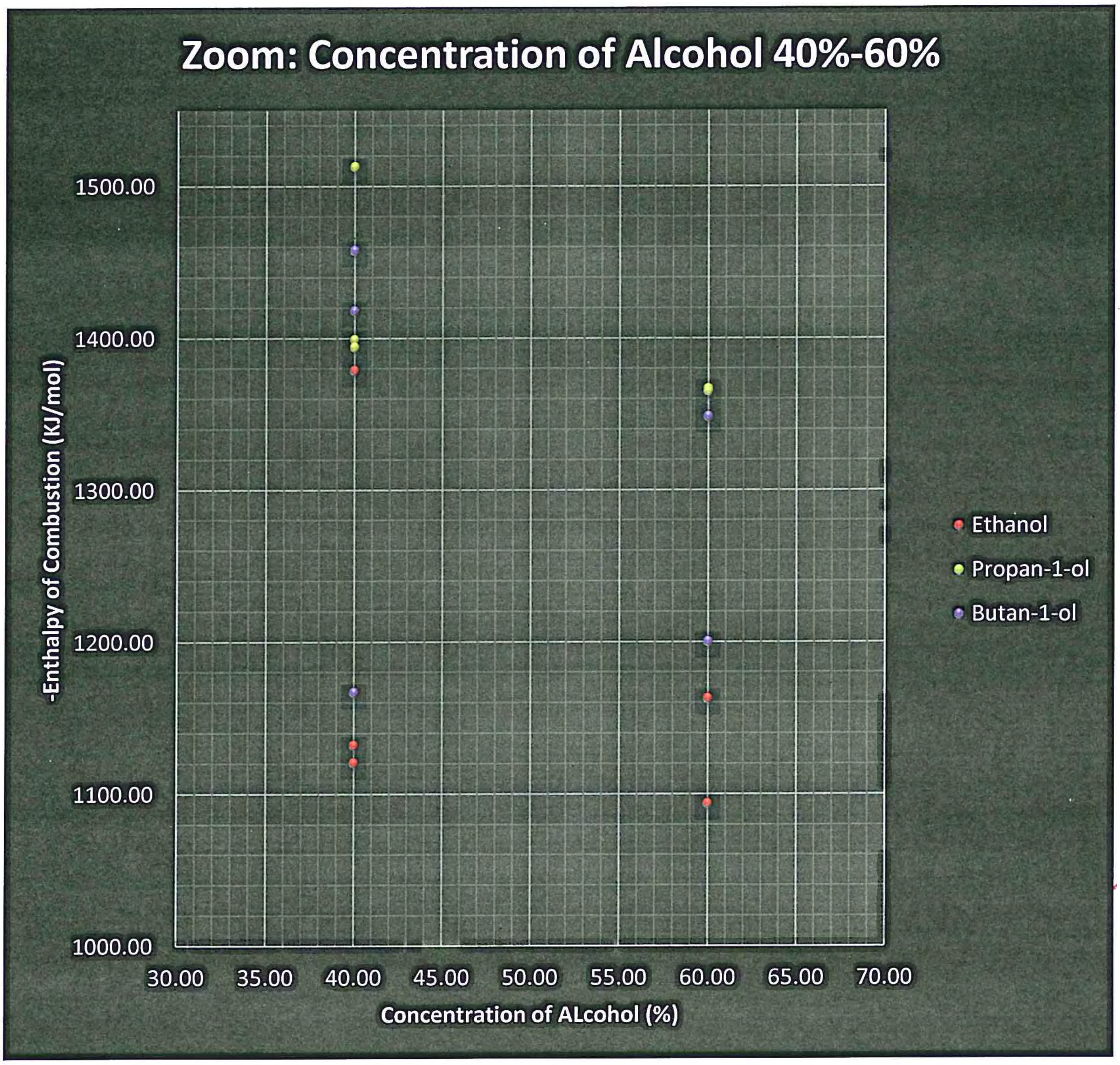
Once the Enthalpy of Combustion was calculated for each trial it can be displayed on the graph.



Because of the amount of data in the graph, no vertical errors were added in order to avoid confusion caused by overlapped error bars.

The graph shows that there is a clear trend on how concentration of alcohol affects the enthalpy of combustion in a mock gasohol mixture. It seems as if when there amount of an alcohol to gasoline tends towards even, there seems to be a higher enthalpy of combustion for Ethanol, Propan-1-ol, Butan-1-ol and 40% concentration of Methanol.

In addition it seems that higher carbon chains in alcohol have also become a factor on the enthalpy of combustion of the mock gasohol mixture.



Upon closer examination it seems as though that ethanol (although widely used in the world) shows the smallest values for enthalpy of combustion between Ethanol, Propan-1-ol and Butan-1-ol. Although Butan-1-ol has a larger carbon to carbon chain, Propan-1-ol mixtures seem to perform much better and at a much more consistent rate.

On the other hand, the methanol mixtures did not manage to create a value of significance as there is a large gap between its values and the rest. This can be attributed by the lack of energy within the molecule of methanol.

## 5. Raw Data Processing

Methanol

| *Trial* | *Average Enthalpy of Combustion (KJ/mol)* | *Total Positive Error* | *Total Negative Error* | *Concentration of Alcohol (%)* |
|---|---|---|---|---|
| *1* | *880.94* | *+57.48* | *-56.98* | ***20*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *867.53* | *+63.74* | *-60.57* | ***40*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *404.62* | *+47.64* | *-45.37* | ***60*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *452.61* | *+35.50* | *-34.92* | ***80*** |
| *2* | | | | |
| *3* | | | | |

**Ethanol**

| *Trial* | *Average Enthalpy of Combustion* | *Total Positive Error* | *Total Negative Error* | *Concentration of Alcohol (%)* |
|---|---|---|---|---|
| *1* | *1204.93* | *±166.11* | *-165.05* | ***20*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *1210.49* | *±172.64* | *-171.27* | ***40*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *1125.70* | *±70.87* | *-69.77* | ***60*** |
| *2* | | | | |
| *3* | | | | |
| *1* | *880.22* | *±133.59* | *-132.71* | ***80*** |
| *2* | | | | |
| *3* | | | | |

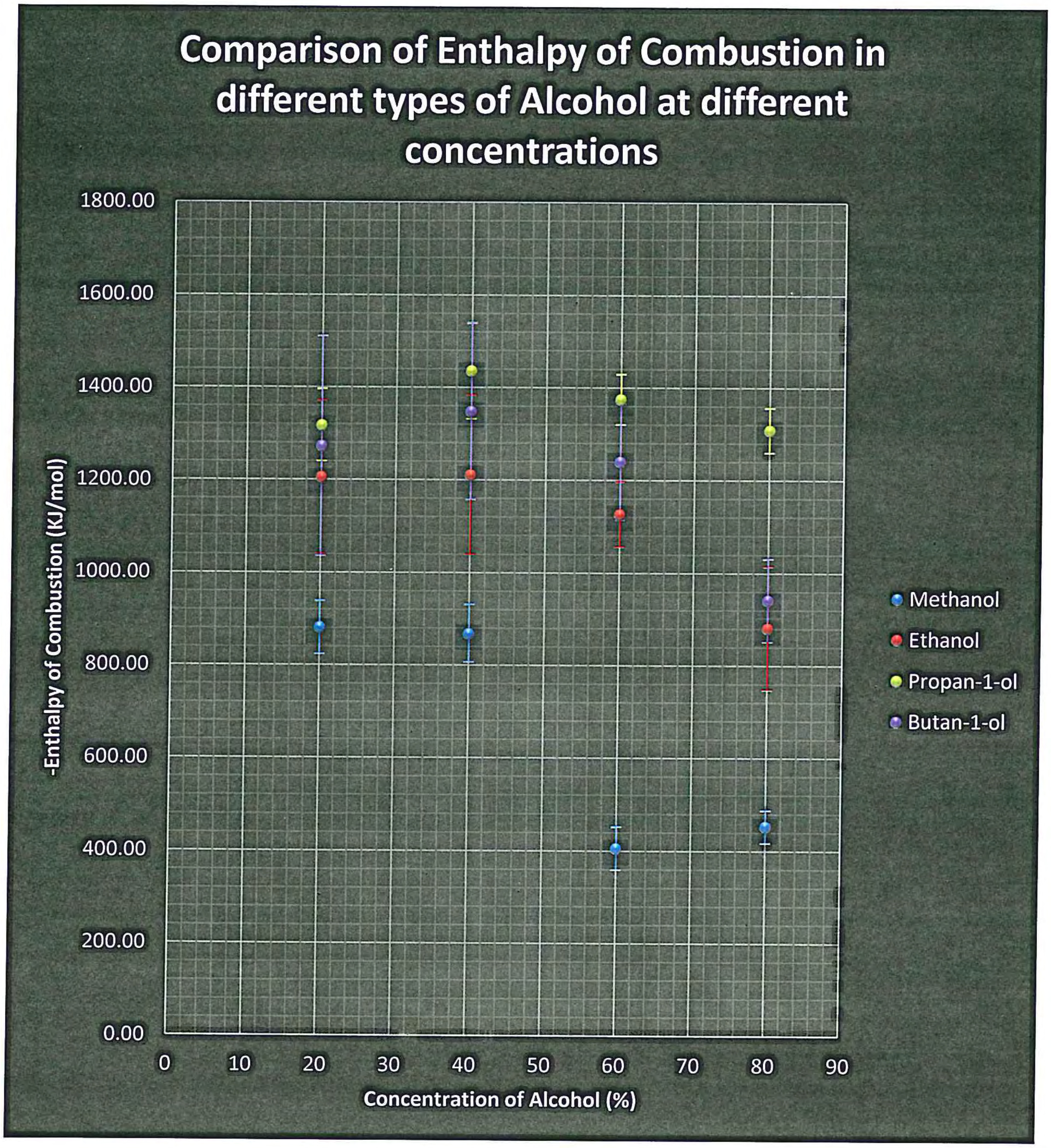
**Propan-1-ol**

| Trial | Average Enthalpy of Combustion | Total Positive Error | Total Negative Error | Concentration of Alcohol (%) |
|---|---|---|---|---|
| 1 | 1317.35 | +78.71 | -77.60 | **20** |
| 2 | | | | |
| 3 | | | | |
| 1 | 1435.31 | +104.74 | -103.47 | **40** |
| 2 | | | | |
| 3 | | | | |
| 1 | 1374.02 | +55.00 | -53.83 | **60** |
| 2 | | | | |
| 3 | | | | |
| 1 | 1307.75 | +48.75 | -47.61 | **80** |
| 2 | | | | |
| 3 | | | | |

**BUtan-1-ol**

| Trial | Average Enthalpy of Combustion | Total Positive Error | Total Negative Error | Concentration of Alcohol (%) |
|---|---|---|---|---|
| 1 | 1272.54 | +238.05 | -236.81 | **20** |
| 2 | | | | |
| 3 | | | | |
| 1 | 1347.58 | +190.98 | -189.66 | **40** |
| 2 | | | | |
| 3 | | | | |
| 1 | 1239.92 | +126.68 | -125.66 | **60** |
| 2 | | | | |
| 3 | | | | |
| 1 | 941.10 | +90.04 | -89.22 | **80** |
| 2 | | | | |
| 3 | | | | |

Errors are calculated through the method in the Appendix.



The error bars in the graph are considerably large but this is to be expected as the experimental process involved a method that it is very inefficient. Though there are overlaps in error bars for the majority of data, it is clear that methanol mixtures do not have higher Enthalpy of Combustion than any other alcohols. This can be seen in the graph as there is no overlap in errors for any methanol mixtures over any other alcohol mixtures. The main observations from this graph is that although there is a persistent trend within concentrations between alcohols, there is an inconsistency with this observation as methanol's mixtures did not hold up: most notably, methanol 60%.

# 6. Evaluation

There are two main sources of error within the experiment. The first is heat loss or gain from the surrounding system. Although Protective screens that were uses as Draught Shields were in place, this did not stop the open system tampering with the copper calorimeter and thus, as well as heating the copper calorimeter, the fuel was in fact heating the system as well as heat from the fuel transferred to the calorimeter and then to the system. However, since the laboratory was large and not a closed system, the heat from the fuel from each fuel mixture experienced heating both the calorimeter and the system. Moreover, because the laboratory was a considerably large size, and due to thermal equilibrium, fuel added heat amounts to negligible change to the system over time.

The second source of error is that because this is combustion of hydrocarbons and alcohol, there will almost always certainly be incomplete combustion and this will tamper with the amount of energy that the fuel puts out as the production of soot and carbon monoxide hinders the energy output.

If this experiment was to be repeated, in order to get more accurate results, it would be more efficient to use an Adiabatic Bomb Calorimetry test[9] as it does not lose heat as much as an ordinary Copper Calorimeter test. In addition if this test was to be carried out once more it should be at a lab without much system interference as compared to a school laboratory as some heat loss and gain may have come from the changing temperature of the classroom as well as the body heat of people within the classroom when this was carried out.

In terms of the propagation of errors, because of the amount of independent errors, it would be difficult to use percentage errors as the repeats. In addition, the use of percentage uncertainty assumes that the value of the positive error and negative errors are almost equal. However, there is still scope for its usage.

The amount of repetitions that were done presented a large amount of error for values. If perhaps, a bigger amount of repetitions were made, this could perhaps highlight any anomalies that were taken into account because of the spread of data (notably on Ethanol mixtures) and thus error values may have been smaller. Due to time management, it was suitable to only do three repeats for each mixtures because of how many combinations of concentration and type of mixtures that are possible to trial.

# 7. Conclusion

The first initial observation that I made during the experiments when comparing alcohols was that as the number of carbon atoms in the molecular make up the alcohol increased, so did the vigor of the flame. However, it could also be noted that all ethanol mixtures burned uniformly whereas the flames of butan-1-ol and propan-1-ol fluctuated from time to time in shape. One major observation I made is that the flame from all 4 methanol mixtures were not only small most of the time compared to the rest of the other mixtures but it fluctuated in shape at a more rapid rate. Conversely though, when methanol's concentration was at 60% and 80% of the mixture, it burned with a considerably large flame, enough to burn the insulation card.

At times, it had seemed as if the flame from a couple of ethanol mixtures did in fact "burn out" and there was no visible flame on the wick besides the wick itself giving off a red glow and thus the trials had to be redone. Because of how quickly methanol had burned out, it was decided that it would only burn to a smaller temperature as the other mixtures were allowed to burn and as there was no time parameter within the experiments, it did not matter when calculating the enthalpy of combustion values. On the other hand, it could be argued that this could have had an effect on the values of enthalpy as it would have taken perhaps a "start up" thermal energy to increase the kinetic energy of methanol molecules and thus conversion into thermal energy.

The fluctuations in the shape of the flame, I believe derive from incomplete combustion of the fuel and thus ethanol seems the most efficient alcohol as it burned uniformly. The experimental, however, data disagrees with how much energy output it creates but if this is contemplated as a possible alternative fuel it must be looked upon from the perspective of a possible producer. Although, there may be a market for alternative fuels in the future the production of gasohols with Butanol and Propanol are considered to be tricky to create as the fermentation of both alcohols can create an unpleasant smell which brings up the dilemma of setting up fermentation plants. The limited locations that this could be created also limit how much of these alcohols the world's economy could produce. The essence of this investigation was to find out fuel viability of alcohols in a mock gasohol solution but it did not center on the production of these alcohols.

There seems to be an overall pattern to my results. Firstly, the concentration of alcohol to hexane in the mixture produced the highest enthalpy of combustion at 40% to 60% with a few inconsistencies (notably methanol at 20% and methanol at 60%). Overall my hypothesis was met considerably in that the more carbon atoms in the alcohol the larger the enthalpy of combustion. However, one inconsistency was Butan-1-ol, which gave figures that were mostly under in value by the enthalpy of combustion of Propan-1-ol mixtures. The comparative graph produced could visually be improved because the overlapping errors by changing the format to place the points side by side.

Even though methanol mixtures produced a smaller enthalpy of combustions as compared to the other mixtures, its gasohol is still more widely produced in the world as compared to butyl and propyl alcohol-gasoline fuels because, although it is more toxic to burn, it is still a lot cheaper to produce. Perhaps if in the future it is possible to get around the problems of the production of butyl and propyl alcohol and the world's economy were to invest into the production of such, it would be possible to find much more effective and thus viable alternatives to commercial gasoline. As for the demands of fuel for the modern world's transportation, commercial gasoline is still the prominent choice for fuelling cars. It is the hope of chemical engineers, world leaders and other stakeholders of the earth that perhaps an alternative such as the mixtures that this investigation attempts to emulate can hinder the commercial gasoline market and thus reduce the emissions of greenhouse gases onto the ozone layer.

If the opportunity to repeat the experiment arose using the same methodology of data collection, I would make the concentrations being contemplated to a smaller degree (for example adding 5% or even 2% each trial) within the region of 40% concentration and 60% concentration. The apparatus would also need alteration in order to get more accurate results. If the experiment had been conducted with real draught shields, it would perhaps prevent much error from heat loss. Furthermore, if the experiment was conducted in a system with minimal interference, this would also prevent much error from heat loss from the open system.

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## Appendix 1: Propagation of Uncertainties

Since the error in measurement of amount of alcohol and hexane put into the fuel burner does not directly affect the mass of fuel burned as the value burned was significantly smaller (estimated at around one tenth of the fuel originally added) it shall be ignored. In order to propagate this I need to consider the whole equation in terms of constants and measured value:

$$\Delta H_c^{\emptyset} = \frac{m_{H_2O} \times c \times \Delta T_{H_2O}}{M_{Alcohol \times [Alcohol] \cdot C_6H_{14} \times [C_6H_{14}]}}$$

There are no error values for the specific heat capacity of water as it was taken from an external source thus this leaves the equation at:

$$Uncertainty\ in\ \Delta H_c^{\emptyset} = Uncertainty\ in(\frac{m_{H_2O} \times \Delta T_{H_2O}}{M_{Alcohol \times [Alcohol] \cdot C_6H_{14} \times [C_6H_{14}]}})$$

There is still a problem with the denominator in that the unit in the equation is in Moles but the measured unit is in Mass and also that there are two substances in the mixture at different concentrations thus using the mass to mole equation, I am going to convert the mass uncertainty into a mole uncertainty. In addition, in order to get around the problem of having one mole of two different substances at different concentrations, each substance will each have an error value and the summation of both taken to present a maximum and minimum error value.

$$\left(\frac{m_{alcohol}}{Mr_{alcohol}} \times concentration\right) + \left(\frac{m_{hexane}}{Mr_{hexane}} \times concentration\right)$$

This assumes that the ratio of alcohol to hexane of the fuel burnt is the same as the intended concentration ratio.

The equation contemplated for the errors is:

$$\Delta H_c^{\emptyset} = \left(\frac{m_{H_2O} \times \Delta T_{H_2O}}{\left(\frac{m_{alcohol}}{Mr_{alcohol}} \times concentration\right) + \left(\frac{m_{hexane}}{Mr_{hexane}} \times concentration\right)}\right)$$

Once all errors are found, in order to propagate errors a maximum value and a minimum value should be found, this can be done by formulating the error values in such a way that it will bring about either the largest value for Enthalpy of Combustion or the smallest value for Enthalpy of Combustion.

For the maximum value, the numerator of the errors must be added to the numerator values in order to increase the value of enthalpy. On the contrary, the denominator error must be deduced from the denominator values in order to increase the value of enthalpy. For the maximum value, the numerator of the errors must be deduced from the numerator values in order to decrease the value of enthalpy. On the contrary, the denominator error must be added to the denominator values in order to decrease the value of enthalpy. From this the absolute Uncertainty can be deduced by deducting the minimum value from the calculated experimental value or by deducting the calculated experimental value from the maximum value.

Each of these was found for each trial and then had a random error for each uncertainty taken and added to that error as well as the random error from the enthalpy of combustion. For example for Methanol 20%, the maximum enthalpy, minimum enthalpy and enthalpy of combustion was calculated. From this the absolute uncertainties were taken:

| Trial | Maximum Enthalpy of Combustion (KJ/mol) | Minimum Enthalpy of Combustion (KJ/mol) | Enthalpy of Combustion (KJ/mol) |
|---|---|---|---|
| 1 | 861.23 | 814.84 | 837.79 |
| 2 | 924.40 | 877.08 | 900.49 |
| 3 | 928.59 | 880.98 | 904.53 |

| Absolute Uncertainty Maximum | Absolut Uncertainty Minimum |
|---|---|
| 23.45 | 22.95 |
| 23.91 | 23.41 |
| 24.06 | 23.55 |

Averages and Random Errors were taken for Enthalpy of Combustion, Maximum Enthalpy of Combustion Uncertainty and Minimum Enthalpy of Combustion Uncertainty:

| Average Enthalpy of Combustion | Absolute Uncertainty (max) | Absolute Uncertainty (min) | Random error Enthalpy of Combustion | Random error Max Enthalpy of Combustion | Random error Min Enthalpy of Combustion |
|---|---|---|---|---|---|
| 880.94 | 23.80 | 23.30 | 33.37 | 0.31 | 0.30 |

Thus errors for the positive were taken by adding Absolute Uncertainty (max) with Random Error Enthalpy of Combustion and Random Error Max Enthalpy of combustion. Whereas negative errors were taken by adding Absolute Uncertainty (min) with Random Error Enthalpy of Combustion and Random Error Min Enthalpy of combustion.