IBDP Group 4: Chemistry (HL)
Internal Assessment

Comparing the enthalpies of combustion of alcohols (Methanol, Ethanol, Propan-1-ol, Butan-1-ol, Pentan-1-ol) and fatty acid methyl ester (FAME) generated from cooking oil

IB candidate code: kbx007

1: Introduction

1.1: Motivation

Energy is always around us and I was always curious about the concept of energy. In everyday life, we are using a lot of energy such as the use of vehicles. However, the use of fossil fuels is one of the major problems in the world. Fossil fuel is mostly used for generating electricity or energy for vehicles, and they serve about 80 % of our use of energy[1]. However, the combustion of fossil fuels produces much CO2, which is one of the greenhouse gases that trap the heat inside the Earth's atmosphere and acts as one of the causes of global warming. According to the U.S. Energy Information Administration, fossil fuel combustion accounted for 73% of U.S. greenhouse gas emissions and 92% of U.S. CO2 emissions in 2020[2]. In addition, fossil fuels are non-renewable resources, and there is a limit to the amount of fossil fuel that we can use because the formation of fossil fuels (coal, oil, gas) takes millions of years. It is estimated that fossil fuel runs out decades later[3]. Therefore, we need to find an alternative energy source and fuel that can generate clean and renewable, sustainable energy. When I was thinking about that, I found an article about biodiesel, SeQuential's "The Biodiesel Process: Making Fuel From Waste" (2020). From this article, I learned about biodiesel and fatty acid methyl acid (FAME). FAME can be made from used cooking oil, which means they are renewable and reduce waste. In addition, they are clean and not harmful to the environment, and easy to produce. However, the efficiency of combustion is also an important factor as a fuel. Using this opportunity to conduct an investigation, I decided to do an experiment and evaluate the efficiency of combustion of FAME by comparing the enthalpies of the combustion of alcohols and FAME. According to this aim of the investigation, I set the research question: **Does fatty acid methyl ester (FAME) generated from cooking oil have a higher enthalpy of combustion than alcohols (methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol)?**

1.2: Research question

Does fatty acid methyl ester (FAME) generated from cooking oil have a higher enthalpy of combustion than alcohols (methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol)?

2: Background

2.1: Alcohols

Alcohols are a type of organic compound in which one or more of the hydroxyl functional group (-OH) is bonded to a carbon atom in an alkyl group and have the general formula of $C_nH_{2n+1}OH$. Mostly, ethanol is commonly known as alcohol. Depending on the kind of alcohol, the position where the hydroxyl functional group is bonded to the carbon is different, and the number of carbon differs. And the boiling points of alcohols are proportional to the number of carbon atoms[4]. However, the boiling point of alcohols is quite low and they are liquid at room temperature. In addition to the low boiling point, they

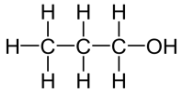
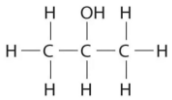
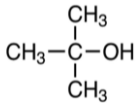
[1] U.S. Energy Information Administration. (n.d.). U.S. energy facts explained. https://www.eia.gov/energyexplained/us-energy-facts/.

[2] U.S. Energy Information Administration. (n.d.). Energy and the environment explained: Where greenhouse gases come from. https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php.

[3] Gioietta Kuo. (2019, May). When Fossil Fuels Run Out, What Then?. https://mahb.stanford.edu/library-item/fossil-fuels-run/.

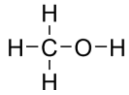
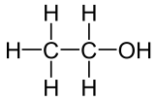
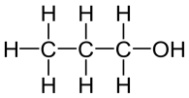
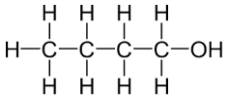
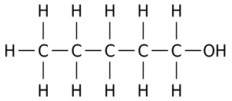
[4] Chemistry LibreTexts. (2020, May 31). 13.3: Physical Properties of Alcohols. https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Map%3A_Organic_Chemistry_(Wade)/13%3A_Structure_and_Synthesis_of_Alcohols/13.03%3A_Physical_Properties_of_Alcohols.

are soluble in water and the solubility of alcohols is inversely proportional[5]. Alcohols are classified into 3 groups, primary, secondary and tertiary. In primary alcohols, carbon bonded to the hydroxyl group is bonded to one alkyl group. In secondary alcohols, carbon bonded to the hydroxyl group is bonded to two alkyl groups. In tertiary alcohols, carbon bonded to the hydroxyl group is bonded to three alkyl groups[6].

Primary	Secondary	Tertiary
 Propan-1-ol	 Propan-2-ol	 2-Methylpropane-2-ol

Alcohols mainly serve as an ingredient in alcoholic beverages. However, it is also widely used as a solvent. Ethanol can dissolve organic compounds which are not soluble in water and this property is used in the cosmetic industry. In the chemical industry, alcohols are used to produce other compounds such as methanal, ethanoic acid, and methyl esters[7]. In addition, Alcohol can be used as fuel for vehicles and is blended with petrol to improve combustion[8]. In countries with no access to fossil fuels but ideal conditions for sugar cane, fermentation is done to produce alcohol to use as fuel[9]. The use of the produced fuel has little impact on the environment, and the fuel is renewable because the sugar cane can be grown again.

In this experiment, only primary alcohols are used. Here are the used alcohols in this experiment:

Alcohol	Methanol	Ethanol	Propan-1-ol	Butan-1-ol	Pentan-1-ol
Formula	CH_3OH	C_2H_5OH	C_3H_7OH	C_4H_9OH	$C_5H_{11}OH$
Structure					

Cited structure image from wikipedia.org

[5] Chemistry LibreTexts. (2020, May 31). 13.3: Physical Properties of Alcohols. https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Map%3A_Organic_Chemistry_(Wade)/13%3A_Structure_and_Synthesis_of_Alcohols/13.03%3A_Physical_Properties_of_Alcohols.

[6] Chemistry LibreTexts. (2020, May 31). 13.2: Classification of Alcohols. https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Map%3A_Organic_Chemistry_(Wade)/13%3A_Structure_and_Synthesis_of_Alcohols/13.02%3A_Classification_of_Alcohols.

[7] Jim Clark. (2022, Aug 27). Uses of Alcohols. https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Supplemental_Modules_(Organic_Chemistry)/Alcohols/Properties_of_Alcohols/Uses_of_Alcohols

[8] ChemicalSafetyFacts. (n.d.). Methanol. https://www.chemicalsafetyfacts.org/methanol/#:~:text=Solvent,%2C%20streptomycin%2C%20vitamins%20and%20hormones..

[9] Pass my exams. (n.d.). Uses of Alcohols. http://www.passmyexams.co.uk/GCSE/chemistry/uses-of-alcohols.html#:~:text=Ethanol%20is%20used%20as%20a,micro%2Dorganisms%20(germs)..

2.2: Fatty acid methyl ester (FAME)

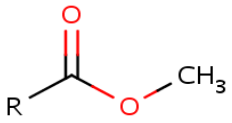
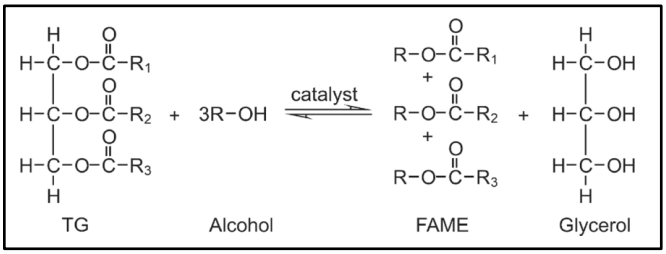
Fatty acid methyl ester (FAME)	$CH_3(CH_2)_nCOOCH_3$ (R is a fatty acid)	

Image from; ChEBI. (n.d.). CHEBI:4986: fatty acid methyl ester. https://www.ebi.ac.uk/chebi/searchId.do?chebiId=4986.



Transesterification of triglyceride image from: CC BY. (n.d.). Transesterification of triglycerides. researchgate.net/figure/Transesterification-of-triglycerides_fig1_338962681

The fatty acid methyl ester is a type of fatty acid ester, produced through transesterification of fatty acids and methanol, and they also can be generated from oils and fats. Oils and fats are composed of triglycerides. Through transesterification with methanol, triglyceride is divided into glycerol and fatty acid methyl ester with a catalyst. In transesterification, glycerol-backbone of triglyceride and methyl group of methanol are exchanged and forms glycerol and fatty acid methyl ester under the presence of a catalyst (ex. NaOH)[10]. Mostly, fatty acid methyl ester is used as fuel for vehicles and blended into fossil fuels. Diesel fuel including up to 7 % of FAME is allowed to use without any modifications in vehicles by European diesel standards. In Sweden, most diesels at filling stations contain 5-7% of FAME[11]. However, FAME is sensitive to cold climates, and the grades of the FAME change depending on the condition of the climate.

2.3: Enthalpy of combustion

Enthalpy change (ΔH) is the amount of heat absorbed or released in a chemical reaction. And the enthalpy of combustion means the enthalpy change which occurs when one mole of the compound is completely combusted with enough oxygen. Since combustion is an exothermal reaction, the enthalpy of combustion always has a negative value.

The enthalpy of combustion is calculated using the formula:

$$E\ (kJ/mol) = \frac{mc\Delta T}{n} \div 1000$$

where E is the enthalpy of combustion, m is the mass of the water, c is the heat capacity, ΔT is the temperature rise, and n is the mole of the combusted compound. Through the calculation of $mc\Delta T$, the total amount of heat released is calculated, which is $q\ (J)$. Then, to calculate the enthalpy change just for one mole, $mc\Delta T$ is divided by the mole of the combusted compound. And to convert the unit to kJ, the calculated value is divided by 1000. Through these steps, the enthalpy of combustion is calculated.

3: Method

3.1: Variables

Independent variable: Type of compound (methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol, tatty acid methyl ester (FAME))

[10] f [3] centre . (2017, June 28). FAME, Fatty acid methyl esters. https://f3centre.se/en/fact-sheets/fame-fatty-acid-methyl-esters/.

[11] f [3] centre . (2017, June 28). FAME, Fatty acid methyl esters. https://f3centre.se/en/fact-sheets/fame-fatty-acid-methyl-esters/.

Dependent variable: Lost mass of the compound (±0.02g) and temperature rise of the heated water (±1℃). The mass of the compound (with the spirit burner), and the temperature of the water were measured before and after the combustion of every trial, using a scale (±0.01g) and a thermometer (±0.5℃). Then, the enthalpy of combustion of each compound was calculated using the differences between the initial mass/temperature and the final mass/temperature.

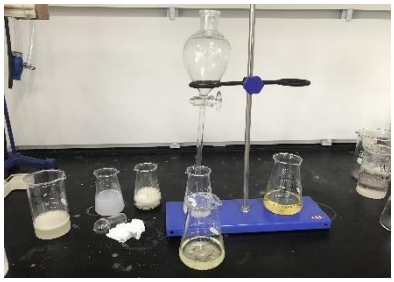
Controlled variables:

Variable	method/set value	Justification
The volume of water in the bottle	500ml (±2.5ml)	The volume of used water affects temperature change and the calculations of the enthalpies of combustion.
The distance between the wick and the bottle.	5cm (±0.05cm)	It can affect the temperature change of water.
Height of the wick.	1cm (±0.05cm)	As the height of the wick changes, the amount of compound permeated into the wick would change. Then it can affect the fire intensity.
The same source of water.	I used tap water from the sink	Water from different sources can have slightly different heat capacities.
The same person operated	-	Because of the possibility of differences in operation between different individuals
The same bottle	I used a 500ml aluminum bottle	Different types of bottles could have different heat conductivity.

3.2: Material/Apparatus

Material	Quantity	Material/Apparatus	Quantity	Apparatus	Quantity
Methanol	50ml	500ml graduated cylinder (±2.5ml)	1	spirit burner	6
Ethanol	50ml	Scale (±0.01g)	1	lighter	1
Propan-1-ol	50ml	Thermometer (±0.5℃)	1	stand with a clamp	1
Butan-1-ol	50ml	Timer (±0.1s)	1	towel	1
Pentan-1-ol	50ml	tap water	30L	goggles	1 set
Fatty acid methyl ester (FAME)	50ml	aluminum bottle (500ml)	1	Inflammable glove	1 pair

The FAME that I used in this experiment is generated from cooking oil according to Bautista's "Optimisation of FAME production from waste cooking oil for biodiesel use" (2009).



3.3: Procedure

1. Measure 500ml of tap water with the 500ml graduated cylinder, and pour the water into the aluminum bottle. I chose the bottle made of aluminum so that the heat can be conducted to the water inside. And I decided to use tap water since the amount of necessary water is quite a lot, and I considered that the effect of the contained chemical in water, on the heat capacity of water, is small.
2. Wrap a towel around the bottle to keep the heat of the water inside. I wetted the towel with water so that the flame won't spread to the towel.
3. Insert the top of the bottle into the clamp of the stand, then adjust the angle so that the bottom of the bottle faces the ground and the distance between the wick and the bottom of the bottle becomes 5cm.

4. Pour a compound into a spirit burner.
5. Record the initial mass of the compound including the spirit burner and the cap using a scale.
6. Stir the water in the bottle and record the temperature.
7. Take the cap of the spirit burner off and place the spirit burner below the bottle. Then, light the wick with a lighter and start a timer for 3 minutes.
8. Wait for 3 minutes, stirring the water in the bottle, to allow heat to spread throughout the water. At this time, AC was stopped and windows are closed to prevent winds so that the flame won't burn out nor weaken, the direction of the fire is at the bottom of the bottle.

9. When the timer rings, put the cap on the spirit burner and extinguished the flame, then record the water temperature in the bottle.
10. Record the final mass of the compound including the spirit burner and the cap using a scale.
11. Repeat the procedure 10 times for each compound, to obtain enough data.

3.4: Risk assessment

Because of the fire and to ensure safety, I proceeded to the experiment wearing goggles and inflammable gloves. Since the flame is small and clean[12] [13], there are scarcely any safety risks or environmental issues. In addition, there are no ethical issues in this experiment.

[12] Colsen FIRE PIT. (n.d.). Alcohol as a Fuel Source. https://colsenfirepits.com/pages/alcohol-as-a-fuel-source-v02.

[13] ETIP Bioenergy. (n.d.). Fatty Acid Methyl Esters (FAME) Fact Sheet. https://www.etipbioenergy.eu/fact-sheets/fatty-acid-methyl-esters-fame-fact-sheet.

4: Results

4.1: Raw Data

The initial and final temperature of the water in the bottle (℃) (±0.5℃)											
Compound	Trial	1	2	3	4	5	6	7	8	9	10
Methanol	Initial temp.	23.5	23.1	23.0	23.2	23.1	23.2	23.3	22.3	22.5	22.6
	Final temp.	35.4	35.1	36.2	35.6	34.9	36.1	36.3	34.4	32.9	33.0
Ethanol	Initial temp.	21.0	21.0	21.3	21.1	21.9	23.0	23.0	23.3	23.2	23.5
	Final temp.	32.0	31.0	31.9	32.5	33.8	36.2	35.9	36.4	36.5	37.0
Propan-1-ol	Initial temp.	23.0	23.0	22.9	22.5	23.0	23.0	23.0	21.0	21.0	21.1
	Final temp.	37.0	37.3	36.9	37.5	38.0	37.8	37.4	34.5	34.0	33.0
Butan-1-ol	Initial temp.	20.9	21.0	20.9	20.8	20.8	20.5	21.0	21.0	21.3	21.9
	Final temp.	35.5	34.0	34.5	33.5	32.0	31.0	31.8	31.8	32.0	33.0
Pentan-1-ol	Initial temp.	21.1	21.4	21.3	21.4	21.2	21.9	21.6	22.0	21.4	21.5
	Final temp.	30.9	30.5	31.1	31.0	32.0	32.6	32.2	33.0	30.5	30.1
FAME	Initial temp.	23.0	23.0	24.0	24.1	24.3	23.9	23.7	22.9	23.4	23.9
	Final temp.	31.2	30.5	31.0	32.5	31.0	30.0	30.2	29.4	32.0	29.6

The initial and final mass of compounds (g) (±0.01ml)											
Compound	Trial	1	2	3	4	5	6	7	8	9	10
Methanol	Initial mass	196.24	194.10	191.85	189.59	187.25	184.92	181.97	185.48	183.35	181.08
	Final mass	194.10	191.85	189.59	187.25	184.92	182.47	179.84	183.35	181.08	178.92
Ethanol	Initial mass	230.82	228.91	226.88	224.84	222.88	219.49	217.55	215.57	213.54	211.51
	Final mass	228.91	226.88	224.84	222.88	220.91	217.55	215.57	213.54	211.51	209.50
Propan-1-ol	Initial mass	210.76	208.57	206.15	203.65	201.11	198.59	196.03	190.93	188.79	186.59
	Final mass	208.57	206.15	203.65	201.11	198.59	196.03	193.53	188.79	186.59	184.36
Butan-1-ol	Initial mass	192.22	190.11	187.99	185.88	184.11	204.54	203.28	202.09	200.77	199.36
	Final mass	190.11	187.99	185.88	184.11	182.45	203.33	202.09	200.77	199.36	197.86
Pentan-1-ol	Initial mass	204.69	203.42	202.27	201.06	199.87	198.64	196.55	195.35	194.02	192.97
	Final mass	203.42	202.27	201.06	199.87	198.64	197.47	195.35	194.16	192.98	191.95
FAME	Initial mass	209.77	208.75	207.84	206.94	206.03	205.10	204.21	203.36	202.16	201.38
	Final mass	208.75	207.84	206.94	206.02	205.10	204.23	203.34	202.57	201.38	200.53

4.2: Qualitative data

All kinds of compounds caught fire easily and burned with an orange flame of the same sizes. However, flames with FAME were a bit slow to grow and were slightly smaller than the flames with alcohol. Flames of butan-1-ol, pentan-1-ol, and FAME produced smoke sometimes, which means incomplete combustion occurred.

4.3: Calculation

Calculation of temperature rise: Final (±0.5℃) - Initial (±0.5℃) = temperature rise (±1℃)

Ex. For trial 1 for methanol, 35.4℃ (±0.5℃) - 23.5℃ (±0.5℃) = 11.9℃ (±1℃)

Uncertainty of the temperature rise is ±1℃ because the sum of the uncertainty of the initial temperature, ±0.5℃, and the uncertainty of the final temperature ±0.5℃ is ±1℃.

Calculation of the lost mass of the compounds:
Initial (±0.01g) - Final (±0.01g) = lost mass of the compound (±0.02g)

Ex. For trial 1 for methanol, 196.24g (±0.01g) - 194.10g (±0.01g) = 2.14g (±0.02g)

Uncertainty for the lost mass of the compounds is ±0.02g because the sum of the uncertainty of the initial mass, ±0.01g, and the uncertainty of the final mass, ±0.01g is ±0.02g.

Calculation of the averages of the temperature rises and the lost mass of the compounds:

$$\frac{trial\ 1 + trial\ 2 + trial\ 3 + \cdots + trial\ n}{total\ number\ of\ trials} = average$$

Ex. For the temperature rises of methanol,

$$\frac{11.9 + 12.0 + 13.2 + 12.4 + 11.8 + 12.9 + 13.0 + 12.1 + 10.4 + 10.4}{10} = 12.0℃\ (\pm 1℃)$$

Since these are just a calculation for the averages for lost mass (±0.02g) and temperature rises (±1℃), absolute uncertainties won't change.

Calculation of the percentage uncertainty:

$$\frac{Absolute\ uncertainty}{measured\ value} \times 100 = Percentage\ uncertainty\ (\%)$$

Since percentage uncertainty is needed to derive the uncertainty of the enthalpies of combustion later, percentage uncertainty of the average temperature rises and the average lost mass of each compound was calculated.

Ex. for the temperature rises of methanol,

$$\frac{\pm 1℃}{12.0℃} \times 100 = 8.33\%$$

Temperature rises (℃) (±1℃)												
Compound	1	2	3	4	5	6	7	8	9	10	Average	% uncertainty
Methanol	11.9	12.0	13.2	12.4	11.8	12.9	13.0	12.1	10.4	10.4	12.0	8.33%
Ethanol	11.0	10.0	10.6	11.4	11.9	13.2	12.9	13.1	13.3	13.5	12.1	8.27%
Propan-1-ol	14.0	14.3	14.0	15.0	15.0	14.8	14.4	13.5	13.0	11.9	14.0	7.15%
Butan-1-ol	14.6	13.0	13.6	12.7	11.2	10.5	10.8	10.8	10.7	11.1	11.9	8.40%
Pentan-1-ol	9.8	9.1	9.8	9.6	10.8	10.7	10.6	11.0	9.1	8.6	9.9	10.09%
FAME	8.2	7.5	7.0	8.4	6.7	6.1	6.5	6.5	8.6	5.7	7.1	14.04%

Lost mass of the compounds (g) (±0.02g)												
Compound	1	2	3	4	5	6	7	8	9	10	Average	% uncertainty
Methanol	2.14	2.25	2.26	2.34	2.33	2.45	2.13	2.13	2.27	2.16	2.25	0.89%
Ethanol	1.91	2.03	2.04	1.96	1.97	1.94	1.98	2.03	2.03	2.01	1.99	1.01%
Propan-1-ol	2.19	2.42	2.50	2.54	2.52	2.56	2.50	2.14	2.20	2.23	2.38	0.84%
Butan-1-ol	2.11	2.12	2.11	1.77	1.66	1.21	1.19	1.32	1.41	1.50	1.64	1.22%
Pentan-1-ol	1.27	1.15	1.21	1.19	1.23	1.17	1.20	1.19	1.04	1.02	1.17	1.71%
FAME	1.02	0.91	0.90	0.92	0.93	0.87	0.87	0.79	0.78	0.85	0.88	2.26%

Calculation of the lost amount of the compounds in mole:

To calculate the enthalpy of combustion, conversion of the units (gram to mole) is needed.

$$\frac{m\ (g)}{M\ (g/mol)} = n\ (mol)$$

Ex. For the mass of methanol,

$$\frac{2.25\ g}{32.042\ g/mol} = 0.0702\ mol$$

Please note that I assumed that the molar mass of the used FAME is 296.513 g/mol (which is the molar mass of Methyl oleate (oleic acid methyl ester)[14]. Oleic acid accounts for the large composition of the cooking oil[15].).

[14] PubChem. (n.d.). Methyl oleate. https://pubchem.ncbi.nlm.nih.gov/compound/Methyl-oleate.

[15] Bautista, L.F. (2009). Optimisation of FAME production from waste cooking oil for biodiesel use, P864.

Lost amount of the compounds in mole (mol)			
Compound	Average Lost mass (g)	Molar mass (g/mol)	Mole
Methanol	2.25	32.042	0.0702
Ethanol	1.99	46.069	0.0432
Propan-1-ol	2.38	60.096	0.0396
Butan-1-ol	1.64	74.121	0.0221
Pentan-1-ol	1.17	88.15	0.0133
FAME	0.88	296.513	0.0030

The average mole of each compound has the same percentage uncertainty as the lost mass of the compound.

Calculation of the enthalpy of combustion

Using the values of temperature rises and the lost amount of the compounds in mol, calculate the enthalpy of combustion of each compound.

$E\ (kJ/mol) = \frac{mc\Delta T}{n} \div 1000$	m = mass of the water in the bottle (500ml) c = heat capacity of water (4.18) ΔT = temperature rise n = lost amount of the compounds in mol (mol)

Ex. For methanol,

$$\frac{500\ ml\ (\pm 0.5\%) \times 4.18 \times 12.0\ ℃\ (\pm 8.33\%)}{0.0702\ mol\ (\pm 0.89\%)} \div 1000 = 373\ kJ/mol\ (\pm 9.72\%)$$

The percentage uncertainty of the enthalpy of combustion can be calculated by adding the percentage uncertainty of the mass of water used, the temperature rises, and the lost amount of the compounds in mol. The percentage uncertainty of the mass of the water is 2.5/500*100=0.5%. After the percentage uncertainty of the enthalpy of combustion of each compound was calculated, the percentage uncertainty was converted to the absolute uncertainty.

Calculation of the absolute uncertainty:

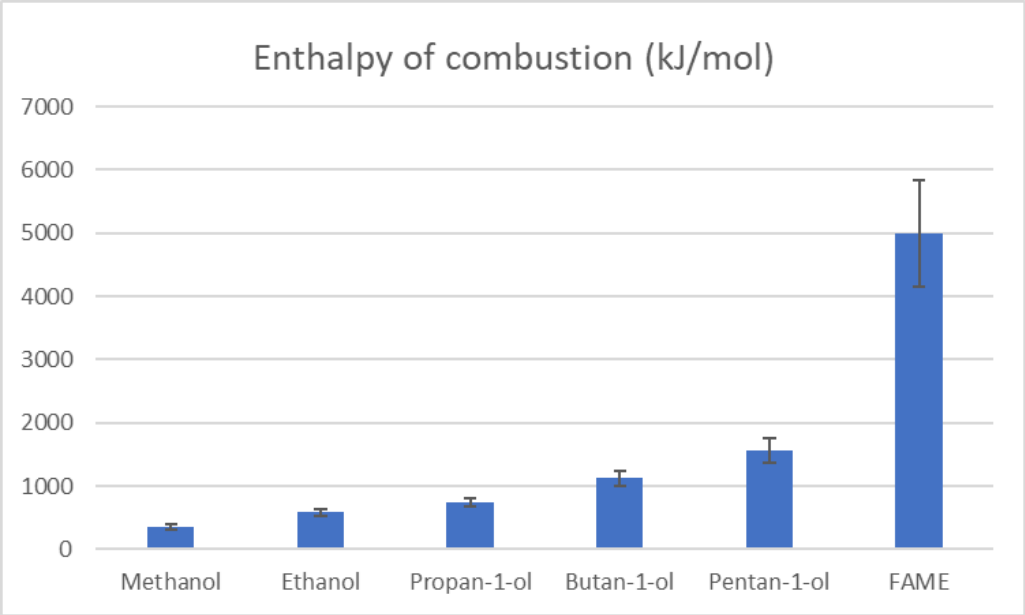
$$\frac{Percentage\ uncertainty}{100} \times measured\ value = Absolute\ uncertainty$$

Ex. For methanol,

$$\frac{9.72\ \%}{100} \times 357\ kJ/mol = 34.7\ kJ/mol$$

Enthalpy of combustion (kJ/mol)			
Compound	Enthalpy of combustion	Percentage uncertainty	Absolute uncertainty
Methanol	357	9.72%	34.7
Ethanol	585	9.78%	57.3
Propan-1-ol	739	8.49%	62.7
Butan-1-ol	1124	10.12%	113.8
Pentan-1-ol	1559	12.30%	191.7
FAME	5000	16.80%	840.0

From these processed data, the graph below was drawn.



5: Conclusion

As you can see from the graph, the FAME has the highest enthalpy of combustion, even with the consideration of the presence of wide uncertainty. The uncertainty is indeed large, however, the difference between the enthalpies of combustion of alcohols and FAME is still big, even if the high enthalpy of combustion of the FAME is caused by the uncertainty of the data. In conclusion, this result shows that FAME releases more energy than alcohols when one mole of the molecules is combusted, and has a quite high efficiency as a fuel. Through this investigation, it is found that the FAME has a higher enthalpy of combustion than alcohols, however, it is also still needed to compare the efficiency with other fuels to find the most suitable fuel for our use.

6: Evaluation:

In this section, the evaluation of the strengths and limitations of the methodology of this experiment is taken to examine the credibility of the results.

6.1: Strengths

Strength	Significance
Use of an aluminum bottle	Since aluminum conducts the heat of the flame so well, the heat energy of the flame of each compound can be accurately measured by the temperature rises of water.
Wrapping the bottle with a towel	To prevent heat to escape, the bottle was wrapped with a towel, which doesn't conduct heat. To accurately measure the heat energy of the flame, heat should be preserved as much as possible.
Prevention of wind from outside and AC to the flame	Winds might put out or weaken the flame, and diffuse the heat into the surroundings. To accurately measure the heat energy of the flame, winds should be prevented.

6.2: Limitations

Limitation	How it affects	How to improve
Heat loss from the bottle and water	The used bottle is made of aluminum which has high heat conductivity and easily releases heat. The bottle was wrapped with a towel to prevent heat to escape, however, a towel doesn't have highly effective thermal insulation and can't completely prevent heat loss. And also, the heat can escape through the spout of the bottle, because the cap was taken from the bottle to make it easy to stir and measure the temperature. As the effect of heat loss, the values of temperature rises can be inaccurate and recorded as lower than the actual value.	- Insulate the bottle - close the bottle with a cap that has a small hole at the center to pass a thermometer
Heat loss from the flame into the surrounding	Some heat was released into the surroundings and some amount of combusted compound is not related to the temperature rise of water. This causes inaccuracy in the values of the lost mass of compounds, and the recorded values might be higher than the actual value.	Use a draught shield
Absorption of heat by the bottle	There is a possibility that the heat was absorbed by the bottle from the water. As the effect of heat loss from water, the values of temperature rises can be inaccurate and recorded as lower than the actual value.	-Use a bottle whose sides are insulated. However, the bottom of the bottle should be able to conduct heat because the bottle needs to conduct heat from the flame through the bottom.

Unequal distribution of the heat of water	The heat is distributed in the water, and the measured temperature can be slightly lower or higher than the average temperature of the water.	-Stir the water -Repetition
Inaccuracy of the measuring instruments (thermometer, scale, cylinder)	Inaccuracies of each value can lead to deviations in data and inaccuracy of the results. As the effects of the uncertainties of the measuring instruments, the uncertainty of the enthalpy of combustion increases and causes the inaccuracy of the results.	-Use more accurate instruments - Use a digital thermometer. The thermometer was a great source of error. (Uncertainty of about ±10%) - Repetition
Use of tap water	Tap water contains a few chemicals (ex. chlorine), and it might slightly affect the heat capacity of water.	Use distilled water
Experiment over a few weeks	This experiment took a few weeks to finish, and the air temperature is different depending on the day. And there is a possibility that the heat loss from the flame into the surroundings changes depending on the day. For example, if the air temperature is low, the heat from the flame would be more absorbed into the air.	-keep the temperature of the room constant -finish the experiment within a day
The unknown molar mass of the FAME	The FAME used in this experiment was a mix of several kinds of FAME because the FAME was generated from cooking oil. Therefore, the actual molar mass of the FAME is unknown and I used the molar mass of oleic acid methyl ester. This would cause inaccuracy and the low validity/credibility of the calculated enthalpy of combustion of the FAME.	Use the pure FAME composed of only one kind of FAME

6.3: Suggestions for further experiment

Here are some suggestions for extensive investigations.

- **Comparison of the enthalpy of combustion of FAME and other fuel.** - Through this investigation, it is found that FAME is more efficient than alcohols, however other fuels might be way more efficient and it is significant to pursue what the most suitable energy source and fuel for our use is.
- **Does the structure of FAME affect its enthalpy of combustion?** - The FAME used in the experiment was a mix of several kinds of FAME. However, each FAME has its enthalpy of combustion. Through the investigation of this question, it is possible to find how the length and the structure (saturated/unsaturated) of fatty acid affect the enthalpy of combustion of FAME, and which kind of FAME has the highest enthalpy of combustion and efficiency as a fuel.

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