Investigating the Enthalpy of Different Organic Fuels

Introduction

Fuels are an integral part of our life as many functions rely on some sort of energy source. Without any type of fuels, the majority of operations will cease to exist. The most prevalent are fossil fuels, but they are also environmentally damaging sources of energy. Fossil fuels are vital in our daily lives due to their versatile nature and usage such as feedstock for chemicals, heating, cooking and as fuel for all kinds of vehicles. However, what makes fossil fuels so harmful and the fact that they are a non-renewable source of energy and is depleting at a rapid rate. Over time, there have been many substitutes considered for fossil fuels such as geothermal, tidal, wind, and solar energy. However, these substitutes did not provide the same amount of energy and other limitations.

As an aspiring chemical engineer, the topics of energetics and organic chemistry have been of my primary interests. Both topics are consisting of basic fundamentals and delve deeper into complex sub-topics which churn my brain all night. However, what excites me the most about organic chemistry and energetics is their relationship with each other and their practical applications in the petrochemical sector and towards sustainable and renewable energy. The internal assessment gives me the opportunity to investigate different organic compounds (based on physical and chemical properties) and then calculate the enthalpy change of combustion. Finally, I can then observe and state whether they contribute towards improving the environment.

Research Question

As the current energy sources such as fossil fuels (coal, natural gas, and petroleum) are depleting at a very rapid rate, it is necessary to look for alternative sources of energy which can be substituted for fossil fuels.

Thus, the following research question: ***Out of all methanol, ethanol, and hexane, which organic chemical compound releases the most energy in a non-controlled (practical) environment?***

Background

In this section, I will discuss the various characteristics of each fuel. The characteristics include their constituents, the energy output, the cost of the fuel, the environmental effects. I have chosen to investigate ethanol, methanol, and hexane because these compounds are easily found in a lab environment and so can be investigated accordingly to determine whether they can replace the current fossil fuels. Also, all three organic compounds are liquid at room temperature so comparisons can appropriately be made.

Methanol

Methanol is also an alcohol with a hydrogen atom replaced by a hydroxyl group (–OH) in methane. Methanol can be produced from natural gas, coal and renewable sources such as municipal waste, biomass and recycled carbon dioxide. Methanol is a non-pollutant because there are no nitrogen and sulphur oxide impurities present which means that the combustion of methanol does not ameliorate the formation of acid rain or greenhouse gases. Methanol has low production costs compared to other alternative fuels. Methanol also has a lower risk of flammability compared to gasoline which improves its safety and usage. Methanol can be manufactured from a variety of carbon-based feedstocks, such as natural gas and coal. Its use could help reduce fuel use while advancing domestic fuels.

Ethanol

Like methanol, ethanol is a renewable, transportation fuel. Ethanol is a grain alcohol, which means it is produced from the fermentation of carbohydrates that have been converted into simple sugars. Ethanol can also be obtained from sugar, root crops and the hydration of ethene. Ethanol is part of the chemical compounds which contain a hydroxyl group (–OH). Ethanol does not conduct electricity because no mobile ions are present. Ethanol is a very volatile liquid and burns immediately when ignited. Compared to gasoline, ethanol is slightly more expensive as it requires more energy to produce for consumer usage. However, ethanol's octane rating is greater than which prevents knocking in a vehicle's engine and provides increased power and performance. Lastly, ethanol has a lower emission rate of greenhouse gases and nitrogen oxides in the atmosphere.

Hexane

Hexane is an alkane hydrocarbon with the chemical formula C_6H_{14}. Hexane's five isomers are predominantly unreactive in organic reactions, so hexane commonly behaves as an inert solvent because it is non-polar and thus does not dissolve in water; for example, it is frequently used in chromatography. Hexane is widely used in glues to manufacture shoes and leather products, as well as in gasoline. Moreover, it is added to cleansing agents in shoes, solvents for extracting all types of cooking oil, and found in textile and furniture manufacturing. Although hexane is a mild anaesthetic, its level of toxicity is regarded as fairly low. The production cost hexane is relatively expensive due to the fact that it is obtained from refining crude oil.

Hypothesis

For each fuel, I hypothesize the following:

For ethanol, it is expected to burn quickly without creating pollutants. It is also expected to raise the temperature of the water the most due to its high enthalpy of combustion.

For methanol, it also expected to burn quickly and without creating any pollutants just like ethanol. However, it should not raise the temperature of the water by the same amount as it has a lower enthalpy of combustion due to its shorter carbon chain.

For hexane, it is expected to burn not as quickly as methanol and ethanol, but it is expected to produce relatively highest energy because of its long and straight carbon chains. The combustion of hexane will also produce smog due to the presence of impurities such as nitrogen and Sulphur oxides.

Materials

- Ethanol — 30ml
- Methanol — 30ml
- Paraffin — 30ml
- Hexane — 30ml
- Distilled water — 200 ml

Apparatus and Uncertainties

Instrument	Uncertainty	Volume	Quantity
Thermometer	± 0.1°C	—	1
Stopwatch (Digital)	± 0.01s	—	1
Graduated Cylinder	± 0.25ml	50ml	2
Tripod Stand	—	—	1
Spirit Burner	—	—	1
Safety Goggles	—	—	1
Wire Gauze	—	—	1
Bunsen Burner	—	—	1
Gas Lighter	—	—	1
Beaker	—	100ml	4
Graduated Pipette	± 0.05	10ml	1

Variables

Type of Variable	Name (unit)	Controlling Mechanisms of the Variables
Independent	The fuel being used: Ethanol, Methanol, and Hexane	By conducting the investigation with each fuel mentioned and taking equal trials of each fuel. The chosen fuels depend on the environment and appropriateness of where the investigation is taking place.
Dependent	The enthalpy change, ΔH, of water when it is heated by the burning fuel. (kJ)	By measuring the temperature change and then using the formula $Q = mc\Delta T$ to calculate the enthalpy of each fuel to determine which fuel releases the most amount of energy.
Controlled	Volume of fuel used (ml)	By measuring out the same amount of each fuel per trial with a beaker. If equal volumes of fuels are not used, then the enthalpy changes will not be accurate.
	The distance between the crucible and the beaker.	By maintaining the same experimental setup with the same apparatus so that the spirit burner is the same distance below the beaker. Thus, approximately the same amount of heat will escape every time.
	Dimensions of the wick.	By using the same type of wick of constant length and thickness.
	Quality of water being used.	In this investigation, distilled water from the same source was used. Different qualities of water can have different types of impurities and thus may require more or less energy to heat.

Procedure

1. Set up the tripod stand, spirit burner, and the wire gauze the way shown in diagram 1.
2. Using a measuring cylinder, measure out 50ml of water and transfer the water into a beaker. Place that beaker on the tripod stand.
3. Measure 5ml of ethanol by using a graduated pipette and pour it in the spirit burner.
4. Place the spirit burner under the tripod stand.
5. Measure the temperature of the water in the beaker and record the value.
6. Take a wooden splint, and light it from the Bunsen burner and then light the ethanol in the spirit burner. Note that the ethanol will immediately catch fire so take safety precautions.
7. Take the stopwatch and start it. Record the temperature of water every 30 second intervals.
8. Record the temperature until all the ethanol has burned.
9. Repeat steps 1-9 four more times.
10. Repeat steps 1-10 for methanol and hexane.

Ethical and Safety Considerations

Hazard	Harm	Precaution
Alcohols are flammable	May cause fires or burns.	Make sure that spirit burner has the lid in place. Clean up any spillages quickly.
Beaker will get hot	May cause burns.	Let apparatus cool down before dismantling.

Data

Qualitative Data

Ethanol

TIME (± 0.01s)	Temperature (±0.1°C)					
	T1	T2	T3	T4	T5	Average
0	26.6	26.7	26.7	26.6	26.7	26.7
30	26.6	26.7	26.7	26.6	26.7	26.7
60	26.6	26.7	26.7	26.6	26.7	26.7
90	28.0	27.8	28.9	28.3	28.4	28.3
120	31.5	31.3	30.8	31.0	30.7	31.1
150	35.7	35.6	34.9	34.7	35.4	35.3
180	39.5	39.6	39.0	38.5	39.2	39.2
210	42.9	42.7	43.8	42.6	43.4	41.1
240	46.0	46.1	45.1	45.4	45.7	45.7
270	49.0	49.2	48.3	48.5	48.8	48.8
300	51.7	51.7	52.2	51.9	52.1	51.9
330	54.5	54.6	55.6	54.8	55.1	54.9
360	57.2	57.3	56.3	56.5	57.3	56.9
390	59.5	59.4	60.5	59.6	60.1	59.8
420	61.8	61.6	62.7	62.3	62.5	62.0
450	64.3	64.1	65.3	64.5	65.2	64.6
480	65.9	65.7	64.8	65.3	65.8	65.5
510	67.8	67.7	66.9	67.4	67.6	67.5
540	69.6	69.9	68.8	69.1	69.4	69.4
570	71.2	71.3	71.9	71.2	71.8	71.5
600	72.9	72.8	73.7	72.9	73.2	73.1
630	74.2	74.2	74.4	74.1	74.6	74.3
660	75.4	75.3	75.2	75.0	75.7	75.3
690	76.5	76.7	76.7	76.6	76.7	76.6
720	77.7	77.6	77.6	77.6	77.7	77.6
750	78.7	78.9	78.9	78.8	79.3	78.9
780	79.8	79.9	79.8	79.9	80.4	80.0
810	80.4	80.3	80.3	80.6	81.1	80.5
840	81.2	81.4	81.4	81.3	81.8	81.4
870	82.1	82.2	81.9	82.2	82.7	82.1
900	82.9	82.8	82.8	83.0	83.5	83.0
930	83.7	83.5	83.2	83.6	84.1	83.6
960	83.7	83.8	84.6	83.8	84.3	84.0
990	84.2	84.3	85.3	84.3	83.8	84.4
1020	84.4	84.5	84.5	84.5	85.0	84.6
1050	84.6	84.7	84.7	84.7	85.2	84.8
1080	84.9	85.1	85.0	85.0	85.3	85.0
1110	85.1	85.3	85.2	85.2	85.5	85.3
1140	85.3	85.5	85.4	85.4	85.7	85.5
1170	85.5	85.7	85.6	85.6	85.9	85.7
1200	85.7	85.9	85.8	85.8	86.0	85.9
1230	85.7	86.1	85.9	85.8	86.0	85.9
1260	85.6	86.2	85.9	85.9	86.1	85.9
1290	85.9	86.4	86.1	85.9	86.3	86.1
1320	85.9	86.5	86.2	86.0	86.5	86.2
1350	85.9	86.5	86.2	86.0	86.5	86.2
1380	85.9	86.5	86.2	86.0	86.5	86.2

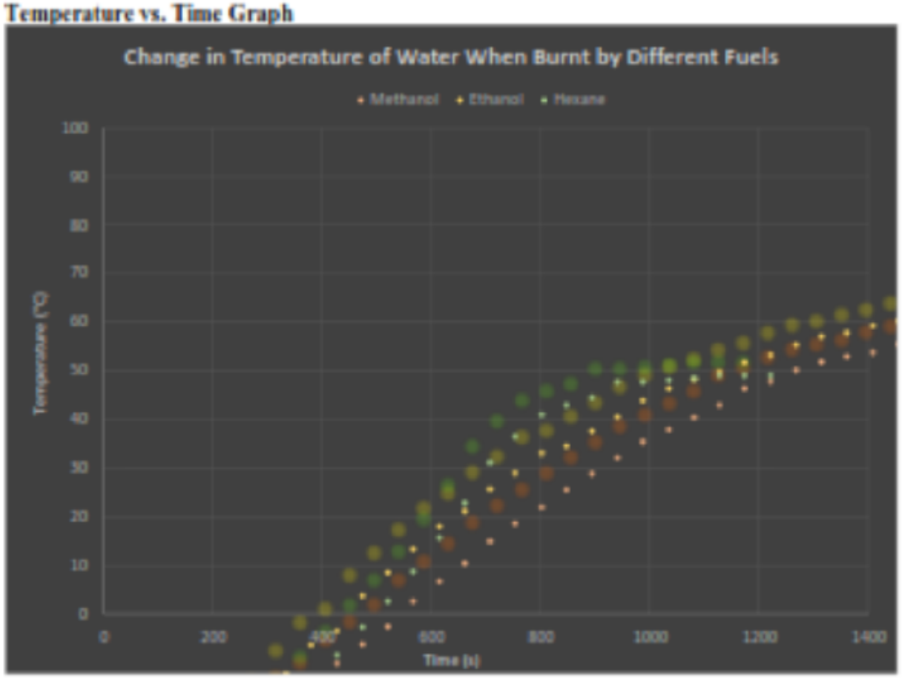
Methanol

TIME (± 0.01s)	Temperature (± 0.1°C)					
	T1	T2	T3	T4	T5	Average
0	26.5	26.3	26.2	26.3	26.4	26.3
30	26.5	26.3	26.2	26.3	26.4	26.3
60	26.5	26.3	26.2	26.3	26.4	26.3
90	27.5	27.4	27.4	27.5	27.3	27.4
120	29.4	28.8	29.2	28.9	28.7	29.0
150	32.0	31.6	31.7	31.8	31.6	31.7
180	34.6	33.2	34.2	33.5	33.3	33.7
210	37.3	36.5	36.8	36.8	36.6	36.8
240	39.9	38.9	39.4	39.2	39.0	39.3
270	42.6	41.1	42.1	41.3	41.2	41.7
300	45.4	44.7	44.9	45.0	44.8	45.0
330	48.0	47.3	47.5	47.6	47.4	47.6
360	50.5	49.8	50.0	51.1	49.9	50.0
390	53.2	52.8	52.7	53.1	52.9	52.9
420	55.5	55.2	55.0	55.5	55.3	55.3
450	57.8	57.1	57.3	57.4	57.2	57.4
480	60.1	59.4	59.6	59.7	59.5	59.7
510	62.3	61.6	61.8	61.9	61.7	61.9
540	64.3	63.7	63.8	64.0	63.8	63.9
570	66.5	65.8	66.0	66.1	65.9	66.1
600	68.1	67.4	67.6	67.7	67.5	67.7
630	69.8	69.0	69.3	69.3	69.1	69.3
660	71.3	70.7	70.8	71.0	70.8	70.9
690	73.3	72.7	73.8	73.0	72.8	73.1
720	74.5	73.9	74.0	74.2	74.0	74.1
750	75.9	75.3	75.4	75.6	75.4	75.6
780	77.0	76.4	76.5	76.7	76.5	76.7
810	77.8	77.2	77.3	77.5	77.3	77.4
840	78.9	78.3	75.4	78.6	78.4	78.0
870	79.5	78.7	79.0	79.0	78.8	79.0
900	80.2	79.6	79.7	79.9	79.7	79.8
930	81.1	80.5	80.6	80.8	80.6	80.7
960	81.8	81.2	81.3	81.5	81.3	81.4
990	82.3	81.7	81.8	82.0	81.8	81.9
1020	82.8	82.2	82.3	82.5	82.3	82.4
1050	83.0	82.4	82.5	82.7	82.5	82.6
1080	83.0	82.4	82.5	82.7	82.5	82.6
1110	83.0	82.4	82.5	82.7	82.5	82.6

Hexane

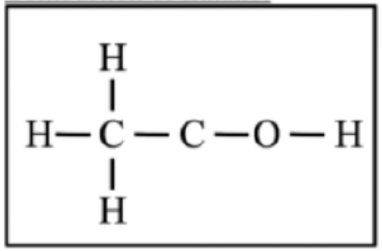
TIME (± 0.01s)	Temperature (± 0.1°C)					
	T1	T2	T3	T4	T5	Average
0	25.0	25.1	25.0	25.0	25.2	25.0
30	25.0	25.1	25.0	25.0	25.2	25.0
60	25.0	25.1	25.0	25.0	25.2	25.0
90	25.4	25.3	25.4	25.2	25.5	25.4
120	28.2	28.0	27.8	28.1	27.9	28.0
150	31.5	31.2	31.1	31.3	31.2	31.3
180	35.0	34.7	34.6	34.9	34.7	34.5
210	38.1	37.8	37.7	37.9	37.8	37.9
240	41.8	41.5	41.4	41.6	41.5	41.6
270	45.3	45.0	44.9	45.1	44.9	45.0
300	49.2	48.9	48.8	49.0	48.9	49.0
330	53.6	53.3	53.3	53.4	53.3	53.4
360	58.3	57.9	57.8	58.0	57.9	58.0
390	63.6	63.3	63.2	63.4	63.3	63.4
420	67.0	66.7	66.6	66.8	66.7	66.8
450	69.9	69.6	69.5	69.7	69.6	69.7
480	71.1	70.8	70.7	70.9	70.8	70.9
510	72.1	71.8	71.7	71.9	71.8	71.9
540	73.8	73.5	73.4	73.6	73.5	73.6
570	74.2	73.9	73.8	74.0	73.9	74.0
600	74.4	74.1	74.0	74.2	74.1	74.2
630	74.8	74.5	78.4	74.8	78.5	76.2
660	75.1	74.8	74.7	75.0	74.8	74.9
690	75.1	74.8	74.7	75.0	74.8	74.9
720	75.1	74.8	74.7	75.0	74.8	74.9

Temperature vs. Time Graph



Analysis

Combustion of Ethanol



$$C_2H_5OH(aq) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

$$\Delta H = -143\ kJmol^{-1}$$

There was complete combustion, and no soot was produced, nor pollutants were observed. There was a high flame, but it was lower than that of methanol. At the end when the temperature became constant, the flame was dim, but present because the wick was still wet with ethanol. The average temperature rise of water was 59.5°C. After doing the necessary calculations (shown below), the enthalpy of combustion for ethanol was 142.81 $kJmol^{-1}$. This is was surprising because it is significantly lower than the literature value (found from the IB chemistry data booklet). The increase in temperature was initially the fastest but at around 400 seconds, it started to slow down. Despite a decrease in its rate of temperature, ethanol burnt very steadily throughout its time and consistent temperature increases were observed at the 30 second intervals.

1. Calculating the Enthalpy change

$Q = mc\Delta T$

Q: energy (Joules)
m: mass of water (kg)
c: specific heat capacity (4,200 J/kg°C)
ΔT = change in temperature (°C)

2. Calculating the mass of water:

density = mass /volume
Density of water: 1000kg/m^3
Volume of water: 50mL or $5\text{x}10^{-5}$ m^3

Mass of water = (density)(volume)
Mass of water = (1000) (0.00005)
Mass of water = 0.05 kg

3. Plugging in all the values and calculating

m = 0.05kg
c = 4200 J/kg°C
ΔT = 86.2 – 26.7 = 59.5°C (Calculated by using average temperature from data table)

Plugging the values in the equation:
Q = mcΔT
Q = (0.05kg) (4200 J/kg°C) (86.2°C – 26.7°C)
Q = 12495J = 12.5 ± 0.2 kJ

4. Calculating the moles of ethanol

Calculating the mass of ethanol:
mass = (density)(volume)
mass = (789 kg/m^3) (0.000005m^3)
Mass = 3.9450 ± 0.0004 kg

Finding the moles of ethanol:
Moles = mass/molecular mass
Moles = 3.945g/45.07gmol^{-1}
Moles: 0.08753

5. Propagating uncertainties

(a) For mass of water:

$$\frac{\Delta m}{m} = \frac{\Delta \rho}{\rho} + \frac{\Delta v}{v}$$

$$\frac{\Delta m}{0.05} = 0 + \frac{2.5 \times 10^{-7}}{3 \times 10^{-5}}$$

$$\Delta m = \frac{2.5 \times 10^{-7}}{3 \times 10^{-5}} \times 0.05 = \pm 0.0004 \text{ kg}$$

(b) For Enthalpy change

$$\frac{\Delta Q}{Q} = \frac{\Delta m}{m} + \frac{\Delta c}{c} + \frac{\Delta T}{T} \qquad [{}^1\Delta T = \frac{T_f - T_i}{2} = \frac{59.8 - 59.3}{2} = 0.3]$$

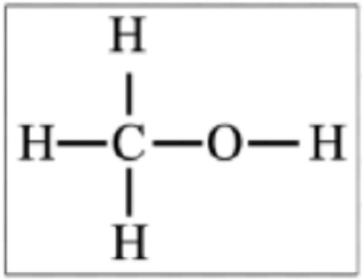
$$\frac{\Delta Q}{12.495} = \frac{0.0004}{0.05} + 0 + \frac{0.3}{59.5} = \pm 0.2 \text{ kJ}$$

Now calculating the enthalpy change per mole:

ΔH = 12.5kJ/0.08753mol = 142.81 ± 0.2 kJmol^{-1}
Literature value for enthalpy of combustion for ethanol = -1367kJmol^{-1}

Efficiency: (142.81/1367) (100) = 10.4%
Percentage Error: (1367 – 142.81)/1367 = 89.6 %

Combustion of Methanol



$$\mathrm{H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-O-H}$$

$$\mathbf{2CH_3OH(aq) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)}$$

$$\mathbf{\Delta H = -95.5\ kJmol^{-1}}$$

Like ethanol, methanol also burned very easily and quickly. Methanol's flame was stronger than of ethanol's but due to methanol being combusted very easily, it may have run out much faster than ethanol. Methanol had a lower enthalpy of combustion due to its shorter chain. From 150 seconds to 480 seconds on the graph above, a constant increase in temperature can be noted, which is supported by the data because it initially takes time for the heat to be absorbed from the glass beaker to the water. Once a steady flow is in place, then heat flows at a constant rate till all the fuel is depleted in the spirit burner. From the data, the average change in temperature was 56.3°C. After calculating the enthalpy change, the combustion of methanol calculated was 95.5 kJ mol^{-1}