

# Effect of Methanol Concentration on Biodiesel Production

## Introduction

As a huge fan of Formula 1 racing, I have always loved the thrill of watching the speedy race. However, Formula 1 has announced a change to a new fuel which is a mixture of biofuel and conventional fossil fuel (Szymkowski, 2021). They are moving on from gasoline due to its detrimental effects on the environment. Combusting gasoline produces toxic gases such as carbon monoxide, nitrogen oxides, and hydrocarbons, but most importantly, it produces a large amount of carbon dioxide (CO<sub>2</sub>). As more CO<sub>2</sub> accumulates in the atmosphere, it causes an enhanced greenhouse effect which can lead to climate change and global warming (*Gasoline*, 2020). Although biofuels also produce CO<sub>2</sub>, it is considered carbon neutral since plants used for biodiesel production offset the CO<sub>2</sub> that forms during combustion as they absorb CO<sub>2</sub> for photosynthesis (EIA, 2020).

According to the 2022 F1 regulation, F1 cars must use mixed fuel with 5.75% of biofuel (Szymkowski, 2021). Although many experts quoted that the use of new fuel does not influence fuel efficiency, I have always been skeptical about biofuels as many F1 fans were, with the perception that they are not as energy-efficient as the conventional ones. Hence, I will aim to investigate how production of biodiesel affects energy produced and what factor can be changed to increase energy produced when the biodiesel is combusted.

## Research Question

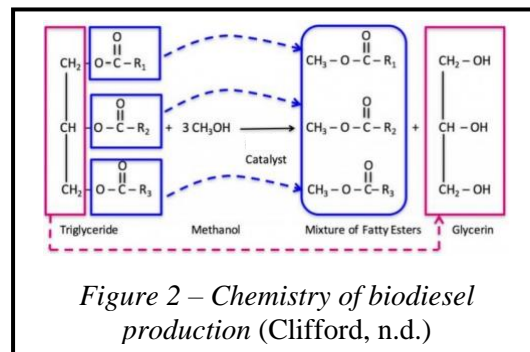
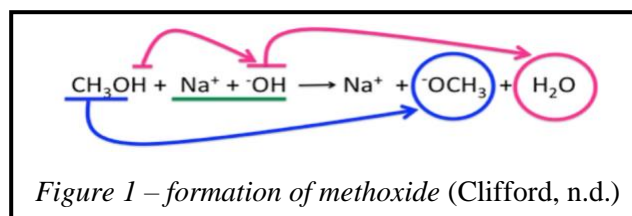
How does increasing methanol concentration from 20% to 100% (20%, 40%, 60%, 80%, 100% v/v) affect the heat energy per gram (kJ/g) transferred to 100cm<sup>3</sup> of water which is released by biodiesel made from canola oil using methanol and sodium hydroxide at 65°C?

## Scientific Background

Transesterification is a chemical conversion process of triglycerides with alcohol into alkyl esters using catalysts (Thangarasu, 2019). It is commonly used to make biodiesels using methanol because of its low cost and availability (Baskar, 2019). Transesterification is carried out in two ways: catalytic or non-catalytic (Baskar, 2019). Catalytic transesterification is used more commonly than the non-catalytic process since non-catalytic process requires high temperature and pressure which results in high cost (Baskar, 2019).

The first step of catalytic transesterification is mixing methanol with a base such as sodium hydroxide (NaOH) to prepare the catalyst. The NaOH dissociates into Na<sup>+</sup> and OH<sup>-</sup> ions, and OH<sup>-</sup> reacts with H<sup>+</sup> from methanol to form water while leaving methoxide (CH<sub>3</sub>O<sup>-</sup>) to react with fatty acid (FA) (Clifford, n.d.) (figure 1). The methoxide ion is the active catalyst as it reacts with triglyceride to produce methyl ester, but is regenerated from excess methanol when hydrogen ion is removed from methanol creating a methoxide ion (Gerpen, 2019).

Once the catalyst is prepared, the triglyceride will be reacted with excess methanol (approximately 3 moles) to ensure the complete reaction of the triglyceride. The glycerol group will react with the OH groups from methanol to form glycerin which is a waste product (Clifford, n.d.) (figure 2). The remaining CH<sub>3</sub> groups will react with three fatty acids, forming a fatty acid methyl ester (FAME) which is the biodiesel (Clifford, n.d.) (figure 2).



For the transesterification process to work well, it is important to minimize the water concentration. This is because the presence of water reduces the conversion of triglycerides to biodiesel. Water molecules cause soap formation when it reacts with fatty acids and consume catalyst which reduces the effectiveness (Kusdiana, 2004). The

conversion rate of triglyceride to fatty acids decreased by 6% when 5% of water is added to the reaction (Atadashi, 2012). As a result, reduced conversion by transesterification will lead to a slower rate of reaction, reduced yield of biodiesel, and a decrease in heat of combustion (Atadashi, 2012).

In chemistry, heat is “a form of energy that flows from something at a higher temperature to something at a lower temperature” (Owen, 2014). When the biodiesel is combusted, the reaction is called exothermic because heat energy is transferred from the system to the surroundings. To measure this energy, enthalpy change ( $\Delta H$ ) is used which is “the amount of heat energy taken in or given out in a chemical change” (Owen, 2014). Since the heat energy leaves the system, the enthalpy change for an exothermic reaction is negative (figure 3) (Owen, 2014).

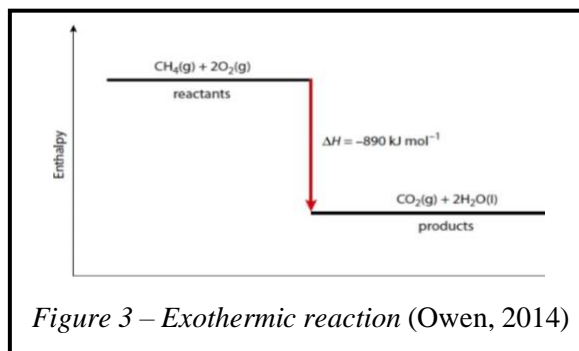


Figure 3 – Exothermic reaction (Owen, 2014)

Calorimetry is one of the multiple ways to measure heat energy. It uses the idea that heat released from the reaction is used to heat the surroundings. To measure the heat energy released from the reaction, apparatus called a calorimeter is used. Typically, calorimeters measure the enthalpy change by measuring the temperature change of water. The water act as the surrounding and absorbs the heat released from the system which increases the temperature. To express the heat energy in terms of joules (J), a specific formula is used.

$$q = mc\Delta T$$

In this investigation,  $q$  represents the heat energy in joules,  $m$  represents the mass of water, and  $\Delta T$  represents the temperature change.  $c$  represents the specific heat capacity of the water which is the “energy required to raise the temperature of 1g of substance by 1K” ( $4.18 \text{ JK}^{-1}\text{g}^{-1}$ ) (Owen, 2014).

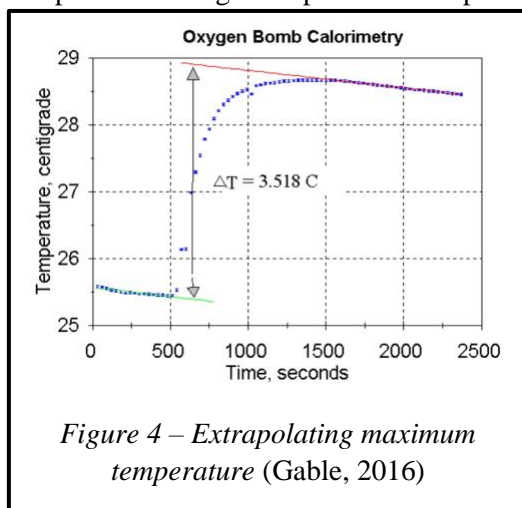
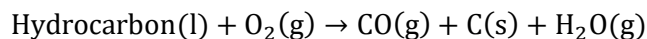


Figure 4 – Extrapolating maximum temperature (Gable, 2016)

However, the temperature change measured using a calorimeter will not be accurate due to incomplete combustion and heat loss. Instead of producing  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , oxygen supply will be low and combustion of FAME will produce carbon monoxide, carbon soot, water, and less heat energy (BBC, n.d.).



The calorimetry is also continuously losing heat to the environment. Hence, the cooling curve before combustion and after combustion should be used to extrapolate the maximum temperature (Gable, 2016). To extrapolate, a linear regression line will be drawn and an equation for the best fit line will be used to extrapolate it to when the time equals 0 (Ford, 2021) (figure 4).

## Hypothesis

As the concentration of methanol increases from 20% v/v to 100% v/v, the heat energy (kJ/g) produced by the combustion of biodiesel would increase since there will be fewer water molecules hindering the transesterification process by consuming base catalyst and forming soap with fatty acids.

## Variables

Independent	Method	Impacts
Concentration of Methanol	<p>To make methanol with various concentrations, pure methanol will be used. To make methanol with a lower concentration, distilled water will be added for dilution. To control the volume of water added, the equation below will be used.</p> $\text{concentration (\%v/v)} = \frac{\text{methanol volume}}{\text{total volume}}$	As the concentration of methanol increases, the heat energy produced by the biodiesel (kJ/g) would increase.
Dependent	Method	Significance to the research question
<p>Heat Energy Per Mass (kJ/g)</p> <p>Trials: 5×3</p>	<p>To measure the heat energy released from biodiesel, a calorimeter will be created using a coffee can. Inside the coffee can, there will be 100cm<sup>3</sup> of water and a thermometer will be put inside to measure the temperature change. Using this temperature change, heat energy will be calculated using the equation below.</p> $q = mc\Delta T$ <p>In this experiment, <i>m</i> will be 100g as water has a density of water is 1g/cm<sup>3</sup>. <i>c</i> will be 4.18 J/g/k as water's specific heat capacity is 4.18 J/g/k. Then the <i>q</i> will be divided by 1000 to make the make unit kJ. Finally, the energy value will be divided by the mass of biodiesel combusted.</p>	The heat energy (kJ/g) produced by each biodiesel will show the efficiency of the fuel. The more heat energy is produced for each gram of biodiesel, the more efficient it is.

Controlled	Method	Significance
The Volume of Oil (100cm <sup>3</sup> )	Using a graduated cylinder and pipette, 100cm <sup>3</sup> of canola oil will be used to make biodiesel.	Since the total volume of the oil available was limited (700cm <sup>3</sup> ), 100cm <sup>3</sup> of oil will be used to make each biodiesel and minimize wastage.
Water Bath Temperature (65°C)	The temperature of the water bath will be set at 65 °C degrees.	The optimal temperature for transesterification reaction is approximately 60°C, and the rate of reaction increases with the increasing temperature (Manirafasha, 2020).
Volume of NaOH (2cm <sup>3</sup> )	Using a 1cm <sup>3</sup> micropipette, a total 2cm <sup>3</sup> of NaOH will be added to methanol to catalyze the transesterification process.	Without NaOH, the transesterification process will proceed very slowly due to the high activation energy of 111.6 kJ/mol (Xiao, 2010).
Type of Oil (Canola oil)	Canola oil will be used to produce biodiesel.	Canola oil has more than 43% of fatty acid while other oil types have only 18% (Anderson, 2008). Hence, more biodiesels can be produced using canola oil (increased production).
Combustion Time (7 min)	Each biodiesel will be combusted for a total of 7 minutes. The timer will be set for 7 minutes.	This is because, for the preliminary trials, the biodiesel was combusted 5 minutes, and the temperature of the water did not decrease which is required to extrapolate the maximum temperature as shown in appendix 8.
Warming Time (8 min)	The canola oil will be warmed for 8 minutes inside the water bath. Timer will be used to measure the time.	By warming the oil for 8 minutes, it ensures that the temperature of the canola oil reaches the optimum temperature for transesterification.
Stirring Time (10 min)	After adding methanol and NaOH to the warm oil, it will be placed on a magnetic stirrer for 10 minutes to stir the solution.	To increase the rate of transesterification, the flask containing crude biodiesel solution should be shaken (Jamal, 2019). Instead of shaking, a magnetic stirrer will be used for 10 minutes to ensure faster reaction.

Uncontrollable	Potential Impacts
Incomplete Combustion	During the combustion of biodiesel, the flame color is expected to be orange or red but not blue. This is because of the incomplete combustion of biodiesel. This happens because there is not enough oxygen to react with the fuel. Instead of producing carbon dioxide and water, carbon monoxide and carbon soot will be produced which forms black smoke. As a result the calorimeter will be covered with black carbon soot. Hence, not all biodiesels will be fully combusted and heat energy released by combustion of biodiesel will be lower than expected value.
Heat Loss	Since it is impossible to use a bomb calorimeter at school, a simple calorimeter will be made using a coffee can. However, this will lead to heat loss because there is no lid to prevent heat from escaping the calorimeter. Although the coffee can will be wrapped with cotton and aluminum foil as an insulator, not all heat energy will be transferred to water, and temperature change would be lower which will lead to lower heat energy (kJ/g).
Temperature Fluctuation of Water Bath	To maintain the temperature of water bath, water pump circulates the warm water inside the water bath. However, sometimes water bath temperatures fluctuate. This causes the temperature of the water to change. Although temperature change is not extreme, it may affect the transesterification process of biodiesel. For instance, due to lower temperature, less methyl ester will be produced which cause biodiesel to produce less heat energy when combusted..

### Apparatus

Chemicals	Glassware	Other equipment
-Canola Oil (100cm <sup>3</sup> each) -NaOH (aq) (2 cm <sup>3</sup> each) -Methanol (aq) ( 20, 40, 60, 80, 100cm <sup>3</sup> ) -Distilled water (3dm <sup>3</sup> )	-2 100 cm <sup>3</sup> graduated cylinder (±0.5cm <sup>3</sup> ) -1 25cm <sup>3</sup> graduated cylinder (±0.1cm <sup>3</sup> ) -1 300 cm <sup>3</sup> conical flask (±0.06cm <sup>3</sup> ) -2 500cm <sup>3</sup> glass beaker (±5%) -2 empty spirit burner	-1 thermometer (±0.5°C) -1 separating funnel -1 glass pipette (25 cm <sup>3</sup> ±0.03 cm <sup>3</sup> ) - 1 100 cm <sup>3</sup> volumetric flask (±0.1cm <sup>3</sup> ) -1 pipette -1 water bath -2 funnel -2 clamps -1 stand -1 metal coffee can -1 magnetic stirrer -1 micropipette (1cm <sup>3</sup> ±0.01) -10x20 cm cotton -1 circle clamp -10x20 cm aluminum foil -1 balance pan (±0.01g) -1 timer -1 lighter

### Safety Measures

Hazards	Risks	Precautions	Disposal
Water Bath	-Electrocution of operator due to electrical malfunction or the operation of the equipment with wet hands. -Fire hazard is possible when it is overheated. -Injured when hand, hair, or clothes get caught in a water circulation impeller ( <i>Risk</i> , n.d.).	-Before handling the machine, dry both hands. -Unplug the machine before moving it. -Make sure that the machine is not continuously used for an extended period. -Keep hands, clothes, and hair away from the machine. -Make sure there is enough water.	-Clean the bath using detergent to prevent pathogenic growth which can cause electrical failure ( <i>Risk</i> , n.d.).

Hazards	Risks	Precautions	Disposal
Glass Apparatus	<ul style="list-style-type: none"> <li>-Forcing glass tubing into stoppers may cause cuts.</li> <li>-Touching broken glass pieces may cause cuts (<i>Safe</i>, n.d.).</li> </ul>	<ul style="list-style-type: none"> <li>-Never use laboratory glassware to serve foods or drinks.</li> <li>-Discard or repair any chipped or cracked items.</li> <li>-At least 10% of air space should be left (<i>Safe</i>, n.d.).</li> <li>-Never pick up broken glass pieces with bare hands.</li> </ul>	<ul style="list-style-type: none"> <li>-Wear gloves and use a brush and dustpan to clean up broken glasses.</li> <li>-Dispose of broken glasses in the sharp glass bin (<i>Safe</i>, n.d.).</li> </ul>
Fire	<ul style="list-style-type: none"> <li>-Fire can cause skin burns and serious injuries.</li> <li>-Smoke from the fire can cause eye irritation.</li> <li>-Inhaling smoke can cause acute respiratory distress (<i>Fire Safety</i>, n.d.).</li> </ul>	<ul style="list-style-type: none"> <li>-Always wear protection against a flame such as a lab coat.</li> <li>-Avoid inhaling flames.</li> <li>-Use a fire extinguisher if you are trained.</li> <li>-Roll on the floor if a person catches a flame.</li> <li>-Remove flammable materials such as alcohol.</li> </ul>	<ul style="list-style-type: none"> <li>-Always experiment under a fume cover.</li> <li>-Use a fire extinguisher when there is a fire (<i>Lab</i>, n.d.).</li> <li>-Place a bucket of water or any fire extinguishing equipment near your experiment site (<i>Fire Safety</i>, n.d.).</li> </ul>

***\*Personal Protection Equipment (PPE) is laboratory coats and safety glasses***

Chemical	Risks	Precautions	Disposal
Methanol (aq)	<ul style="list-style-type: none"> <li>-Highly flammable.</li> <li>-Toxic when swallowed.</li> <li>-Toxic in contact with skin.</li> <li>-Toxic when inhaled.</li> <li>-It may cause damage to the organ.</li> </ul>	<ul style="list-style-type: none"> <li>-Wear PPE including gloves.</li> <li>-Wash skin immediately after contact.</li> <li>-Keep away from heat or fire.</li> </ul>	<ul style="list-style-type: none"> <li>-Do not allow methanol to reach open water.</li> <li>-Absorb the chemical with an incombustible absorbent such as sand with enough ventilation (<i>Safety Data Sheet Methanol</i>, 2015).</li> </ul>
Sodium Hydroxide (aq)	<ul style="list-style-type: none"> <li>-It may be corrosive to metals.</li> <li>-It may cause severe skin burns and eye damage when contacted.</li> </ul>	<ul style="list-style-type: none"> <li>-Do not breathe vapors or mist.</li> <li>-Make sure to wear safety gear such as PPE including gloves.</li> <li>-Wash hands after handling.</li> </ul>	<ul style="list-style-type: none"> <li>-Prevent from reaching nearby water or drainage without proper disposal.</li> <li>-After the use transfer it to a disposal or recovery container (<i>Safety</i>, 2015).</li> </ul>
Biodiesel (l)	<ul style="list-style-type: none"> <li>-May cause eye irritation.</li> <li>-Highly flammable.</li> <li>-May cause skin irritation.</li> <li>-No adverse effect expected for ingestion.</li> </ul>	<ul style="list-style-type: none"> <li>-Wear PPE and gloves.</li> <li>-Wear self-contained breathing equipment.</li> <li>-Wash after contact with water.</li> <li>-Always have extinguishing media.</li> </ul>	<ul style="list-style-type: none"> <li>-Keep product away from heat and source ignition.</li> <li>-Dispose under local regulations.</li> <li>-Recycling is preferred to disposal or incineration. (<i>Greenergy</i>, 2020)</li> </ul>

### Environmental & Ethical Consideration

There is no significant ethical issue as it does not involve living organisms. Although this investigation involves the combustion of biodiesel which produces CO<sub>2</sub>, the volume of CO<sub>2</sub> is too small and will have less effect on global climate change as not a lot of CO<sub>2</sub> accumulates in the atmosphere. Hence, this investigation has no significant ethical issue.



This investigation involves the use of methanol and NaOH which are toxic chemicals. If methanol is released into the environment, it can cause serious damage. Since it is extremely flammable, it can be dangerous to be released into open water, and it is extremely toxic when inhaled or contacted which can be harmful to many aquatic organisms. Similarly, NaOH is toxic to many organisms. When it is consumed, it can cause serious organ damage. Hence, all chemicals will be properly disposed by diluting or neutralizing them using appropriate methods under the guidance of a lab technician.

## Experiment Setup

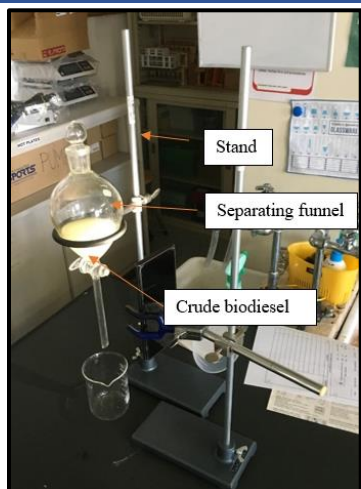


Figure 5 – Biodiesel purifying setups

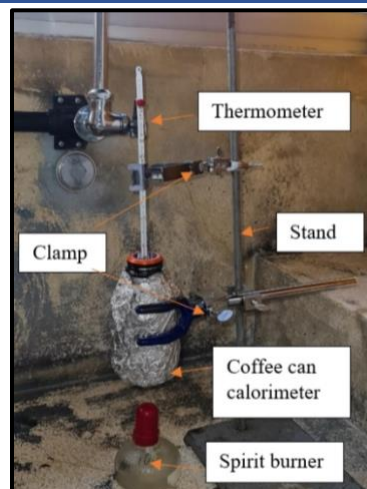


Figure 6 – Calorimeter setups

## Methodology

### Biodiesel making process:

1. Prepare 100cm<sup>3</sup> of canola oil using a graduated cylinder (100cm<sup>3</sup>) and transfer the oil inside a conical flask (300cm<sup>3</sup>). Then, place the conical flask with canola oil inside the water bath set at temperature 65°C and warm the oil for 8 minutes.
2. Measure the volume of pure methanol (aq) using a graduated cylinder (100cm<sup>3</sup>). Depending on the concentration (% v/v), pour different volumes of pure methanol into a 100cm<sup>3</sup> volumetric flask for mixing reactants together (e.g. 20cm<sup>3</sup> for 20%).
3. Transfer methanol (aq) solution with different water concentrations inside conical flask (300cm<sup>3</sup>).
4. Prepare 2cm<sup>3</sup> of NaOH (aq) using a 1cm<sup>3</sup> micropipette and transfer it into the conical flasks with 100cm<sup>3</sup> of methanol solutions.
5. Put a stopper on the conical flask and shake the flask to mix NaOH and methanol solution, and transfer 25cm<sup>3</sup> of methanol and NaOH solution inside the conical flask containing warm canola oil using a glass pipette (25cm<sup>3</sup>).
6. Put a magnetic bar inside the conical flask containing biodiesel solution and stir the solution for 10 minutes. RPM of the stirrer should be set at 700 and the temperature should be set at 65°C.
7. After 10 minutes, settle the biodiesel solution for a day to make sure fatty acid methyl ester and glycerol separate.
8. The clear layer at the bottom is waste glycerol and the cloudy layer at the top is crude biodiesel. Using a separating funnel, remove all the glycerol (figure 5).
9. To purify crude biodiesel, use hot water to dissolve excess alcohol remaining inside the solution. Slowly pour 100cm<sup>3</sup> of hot water inside the separating funnel to dissolve excess alcohol (figure 5).
10. Due to density differences, hot water will always be placed below biodiesel. Remove hot water from the biodiesel by pouring it out of the separating funnel. Repeat this process a total of 3 times.
11. After purifying biodiesel, transfer biodiesel to an empty spirit burner.

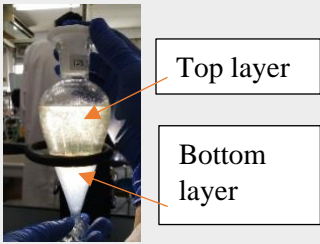

### Coffee can calorimeter making process:

1. To create a calorimeter, make a small hole into a coffee can for the thermometer.
2. Wrap the coffee can with cotton first, then wrap the cotton with aluminum foil to prevent it from catching on fire.

### Calorimetry experiment:

1. Using a graduated cylinder, measure a total of 100cm<sup>3</sup> of distilled water and transfer it inside a metal can and fix the metal can in place using a stand and clamp (figure 6).
2. Using a balance pan, measure the initial mass of the spirit burner with biodiesel.
3. Place spirit burner containing biodiesel under the metal can and set the distance between spirit burner and calorimeter to be 1.5cm apart (figure 6).
4. Put a thermometer inside the metal can and fix it in place using another clamp. Make sure the thermometer does not touch the bottom of the metal can (figure 6).
5. Measure the initial temperature and record it.
6. Using match or lighter, but the spirit burner on fire for 7 minutes. Measure the temperature every 30 seconds.
7. Put a lid on the spirit burner, and measure the final temperature using a thermometer. Then, use a balance pan to measure the final mass of biodiesel.
8. Repeat steps 1 to 7 for every alcohol concentrations (20, 40, 60, 80, 100% v/v), and for each alcohol concentration, a total of 3 trials should be done (5×3 trials).

### Qualitative Data

	Observation	Explanation
Biodiesel is separated into two layers. The top layer, which is crude biodiesel, has a lighter color than the bottom layer which is waste glycerol (figure 7).	 <p>Figure 7 – Two different layers of crude biodiesel</p>	This is due to the density difference between crude biodiesel and glycerol. Although methyl ester contains polar molecules, the long non-polar hydrocarbon chain reduces polarity leading to there only being weak London forces between biodiesel molecules which causes it to be loosely packed ( <i>Biodiesel Chemistry Tutorial</i> , 2021). On the other hand, glycerol contains three hydroxyl groups (OH), which form strong hydrogen bonds between molecules and make them denser ( <i>Biodiesel Chemistry Tutorial</i> , 2021).
As shown in figure 8, biodiesel made from 100% methanol had a bigger flame size compared to biodiesel made from 20% methanol.	 <p>Figure 8 – Biodiesel made from 20% (right) and 100% methanol (left)</p>	This is due to the difference in water molecules inside methanol. More water molecules inside methanol cause soap formation when it reacts with fatty acids (Kusdiana, 2004). Hence, biodiesel that is made from methanol with more water molecules has a smaller flame size as less energy is produced.
Biodiesel has a pungent odor when it is combusted which is similar to that of petroleum diesel. When it is not combusted, biodiesel has a similar smell to nail polish.		This distinct smell indicates that biodiesel is a type of hydrocarbon. This pungent odor is unique to many hydrocarbon fuels such as diesel and gasoline (Cernansky, 2012).

## Raw Data

Concentration	Trials/Time	Temperature ( $^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ )						
		0	30	60	90	120	150	180
20% $\pm 0.7\%$	1	25.0	26.0	27.0	28.0	30.0	32.0	33.0
	2	27.0	29.0	30.0	32.0	33.0	34.0	35.0
	3	26.0	27.0	28.0	29.0	30.0	31.0	31.0
40% $\pm 0.9\%$	1	21.0	22.0	24.0	26.0	27.0	29.0	30.0
	2	21.0	22.0	24.0	26.0	27.0	28.0	29.0
	3	26.0	28.0	29.0	30.0	32.0	33.0	33.0
60% $\pm 1.1\%$	1	23.0	24.0	26.0	27.0	29.0	31.0	32.0
	2	24.0	25.0	26.0	28.0	30.0	32.0	34.0
	3	38.0	39.0	41.0	43.0	46.0	48.0	49.0
80% $\pm 1.3\%$	1	30.0	31.0	31.0	32.0	34.0	36.0	38.0
	2	26.0	27.0	28.0	30.0	32.0	35.0	37.0
	3	32.0	33.0	34.0	37.0	39.0	41.0	42.0
100% $\pm 1.5\%$	1	23.0	24.0	26.0	29.0	30.0	32.0	33.0
	2	23.0	24.0	25.0	27.0	29.0	31.0	33.0
	3	30.0	31.0	32.0	33.0	36.0	37.0	39.0

Table 1 – Raw data for temperature of  $100\text{cm}^3$  of water from 0 minutes to 3 minutes (full data on appendix 1)

Methanol Concentration (% v/v)	Mass of Biodiesel ( $\text{g} \pm 0.01\text{g}$ )					
	Trial 1		Trial 2		Trial 3	
	Initial Mass	Final Mass	Initial Mass	Final Mass	Initial Mass	Final Mass
20% $\pm 0.7\%$	181.57	180.60	180.55	179.88	179.93	179.09
40% $\pm 0.9\%$	190.55	189.60	189.58	188.76	188.74	187.88
60% $\pm 1.1\%$	184.10	183.22	205.42	204.67	204.27	202.97
80% $\pm 1.3\%$	197.13	196.25	214.38	213.48	214.96	214.00
100% $\pm 1.5\%$	177.46	176.58	176.08	175.20	174.95	174.01

Table 2 – Raw data for mass change for each trial

## Calculations

For all uncertainty calculations, the rules below are used.

- When quantities with uncertainties are added or subtracted, the absolute uncertainties are added (Owen, 2014).
- Percentage uncertainties are added when multiplying or dividing quantities with uncertainties (Owen, 2014).
- When multiplying or dividing a quantity with uncertainty by a pure number, the absolute uncertainty is multiplied/divided by that number so that the percentage uncertainty stays the same (Owen, 2014).
- When averaging values with uncertainties, the A.U. should be converted into P.U. and averaged since just adding the P.U. will exaggerate the error and be contrary to the purpose of repeating and averaging measurements (Coates, 2015).

$$\text{percentage uncertainty (P. U.)} = \frac{\text{absolute uncertainty}}{\text{value}} \times 100$$

$$\text{absolute uncertainty (A. U.)} = \frac{\text{percentage uncertainty}}{100} \times \text{value}$$

$$\text{Average uncertainty} = \frac{(\text{P. U.}_1 + \text{P. U.}_2 + \dots)}{\text{number of trials}}$$



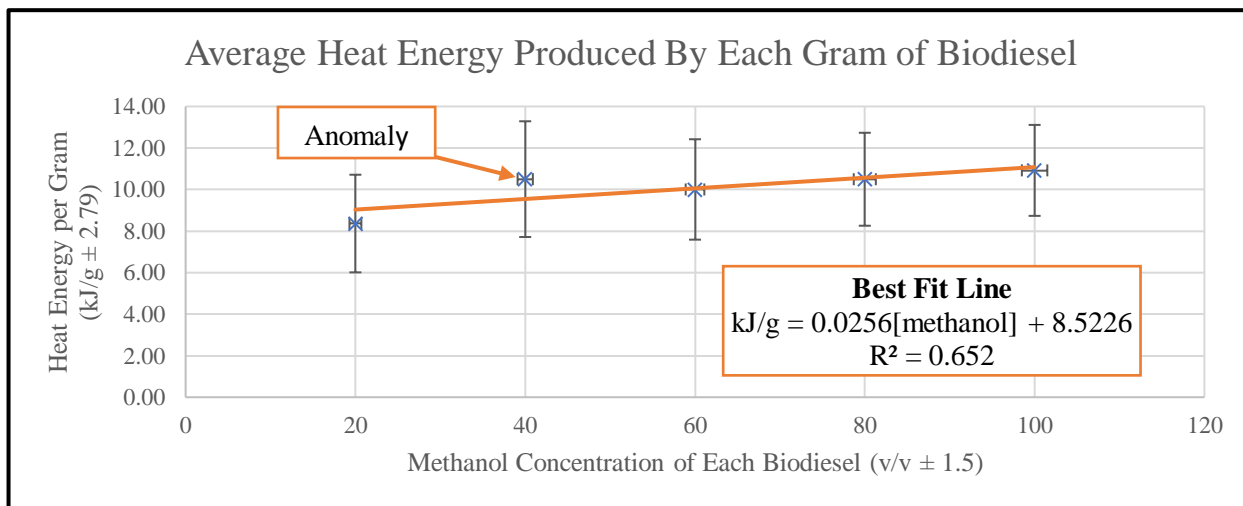
Calculation		Examples (methanol concentration of 20.0% trial 1)
<b>Calculation 1: Methanol Concentration</b> $\frac{v}{v} = \frac{\text{methanol volume}}{\text{methanol} + \text{water volume}}$	<i>*Used 100cm<sup>3</sup> graduated cylinder (<math>\pm 0.5\text{cm}^3</math>).</i> Methanol volume: 20.0cm <sup>3</sup> Water volume: 80.0cm <sup>3</sup> $= \frac{20.0}{20.0 + 80.0} \times 100$ $= 0.2 \times 100$ $= 20.0\%$	<b>Uncertainty</b> Methanol Uncertainty = $\pm 0.5\text{cm}^3$ Water Uncertainty = $\pm 0.5\text{cm}^3$ $0.5 + 0.5 = 1.0$ $\text{P. U.} = \frac{0.5}{20.0} \times 100 = \pm 2.5\%$ $\frac{1.0}{100.0} \times 100 = \pm 1.0\%$ $= 2.5 + 1.0 \approx \pm 3.5\%$ $\text{A. U.} = \frac{3.5}{100} \times 20 \approx \pm 0.7$
<b>Calculation 2: Mean Temperature Change</b> <i>*For extrapolated temperature, the same uncertainty value for initial temperature (<math>\pm 0.5^\circ\text{C}</math>) will be used.</i> <b>Linear line = <math>ax + c</math></b> $T_{\text{maximum}} = a(0) + c \approx c^\circ\text{C}$ $\Delta T = T_{\text{maximum}} - T_{\text{initial}}$	<b>Example:</b> <i>*Used equation from appendix 8</i> Linear line = $-0.5x + 41.333$ $T_{\text{max}} = -0.5(0) + 41.333$ $\approx 41.3$ $T_{\text{initial}} = 25.0$ $\Delta T = (41.3 - 25.0) \approx 16.3$	$T_{\text{max}}$ Uncertainty: $\pm 0.5^\circ\text{C}$ $T_{\text{initial}}$ Uncertainty: $\pm 0.5^\circ\text{C}$ $\text{A. U.} = 0.5 + 0.5 = \pm 1.0^\circ\text{C}$ $\text{P. U.} = \frac{1.0}{16.3} \times 100 \approx \pm 6.13\%$
<b>Calculation 3: Mass Change</b> $\Delta g = \text{Mass}_{\text{initial}} - \text{Mass}_{\text{final}}$ $\Delta g = \text{Mass Change } (\pm 0.02\text{g})$ $\text{Mass}_{\text{final}} = \text{Final Mass } (\pm 0.01\text{g})$ $\text{Mass}_{\text{initial}} = \text{Initial Mass } (\pm 0.01\text{g})$	<b>Example:</b> <i>*used digital balance (<math>\pm 0.01\text{g}</math>)</i> $\text{Mass}_{\text{initial}} = 181.57\text{g}$ $\text{Mass}_{\text{final}} = 180.60\text{g}$ $\Delta g = 181.57 - 180.60$ $\approx 0.97\text{g}$	$\text{Mass}_{\text{final}}$ Uncertainty: $\pm 0.01\text{g}$ $\text{Mass}_{\text{initial}}$ Uncertainty: $\pm 0.01\text{g}$ $\text{A. U.}_{\Delta g} = 0.01 + 0.01 = \pm 0.02\text{g}$ $\text{P. U.} = \frac{0.02}{0.97} \times 100 \approx \pm 2.06\%$
<b>Calculation 4: Heat energy calculation</b> $q = \frac{mc\Delta T}{1000}$ $q$ = heat energy (kJ) $m$ = mass of water (g) $c$ = specific heat capacity of water ( $4.18 \text{ Jg}^{-1}\text{C}^{-1}$ ) $\Delta T$ = Temperature change	<b>Example:</b> <i>*used graduated cylinder (<math>\pm 0.5\text{g}</math>)</i> $m = 100.0\text{g}$ $c = 4.18 \text{ Jg}^{-1}\text{C}^{-1}$ $\Delta T = 16.3$ $q = \frac{(100 \times 4.18 \times 16.3)}{1000}$ $\approx \frac{6827.2}{1000}$ $q \approx 6.83\text{kJ}$	Uncertainty of $m$ : $\pm 0.5\text{g}$ Uncertainty of $\Delta T$ : $\pm 1.0^\circ\text{C}$ $\text{P. U.} = \frac{0.5}{100} \times 100 = \pm 0.5\%$ $\frac{1.0}{16.3} \times 100 \approx \pm 6.13\%$ $= 0.5 + 6.13 \approx \pm 6.63\%$
<b>Calculation 5: Energy per mass of biodiesel</b> $\text{kJ/g} = \frac{q}{\bar{x}}$ kJ/g = Heat energy produced per gram of biodiesel $q$ = Heat energy (kJ) $\bar{x}$ = Mean mass change ( $\Delta g$ )	<b>Example:</b> $q = 6.83\text{kJ}$ $\bar{x} = 0.97$ $\text{kJ/g} = \frac{6.83}{0.97}$ $\approx 7.04$	Uncertainty of $q = \pm 0.452\text{kJ}$ Uncertainty of $\bar{x} = \pm 0.02\text{g}$ $\text{P. U.}_{\bar{x}} = \frac{0.02}{0.97} \times 100 = \pm 2.06\%$ $\text{P. U.}_{\frac{\text{kJ}}{\text{g}}} = 2.06 + 6.63 \approx \pm 8.69\%$

Calculation	Examples (methanol concentration of 20.0% trial 1)	
<b>Calculation 6: Average kJ/g of biodiesel</b> $\bar{y} = \frac{(\text{trial}_1 + \text{trial}_2 + \text{trial}_3)}{n}$ $\text{trial}_n = \text{kJ/g for each trials}$ $n = \text{number of trials}$	<b>Example:</b> $\text{trial}_1 = 7.04 \text{ kJ/g}$ $\text{trial}_2 = 10.5 \text{ kJ/g}$ $\text{trial}_3 = 7.55 \text{ kJ/g}$ $\bar{y} = \frac{(7.04 + 10.5 + 7.55)}{3} \approx 8.36 \text{ kJ/g}$	$\text{P.U.}_{\text{trial 1}} = 3.5 + 6.13 + 2.06 + 6.63 + 8.69 \approx \pm 27.01\%$ <p>*P.U. for trials 2 and 3 used the same calculation as above.</p> $\text{P.U.} = \frac{27.01 + 28.3 + 29.03}{3} \approx \pm 28.1 \text{ kJ/g}$ $\text{A.U.} = \frac{28.1}{100} \times 8.36 \approx \pm 2.35 \text{ kJ/g}$

## Results

Methanol Conc. (% v/v)	20.0 ± 0.7	40.0 ± 0.9	60.0 ± 1.1	80.0 ± 1.3	100.0 ± 1.5
Energy per mass (kJ/g)	8.4	10.5	10.0	10.5	10.9
A.U.	±2.4	±2.8	±2.4	±2.2	±2.2
P.U.	±28%	±27%	±24%	±21%	±20%

Table 3 – The average heat energy produced by each gram of biodiesel



Graph 1 - The average heat energy produced by each gram of biodiesel in scatter plot (based on table 3)

## Analysis

The best fit line on graph 1, plotted and calculated using Excel, shows that the heat energy produced by each gram of biodiesel shows a positive correlation as the concentration of methanol increases from 20% to 100%. According to the best fit line, the gradient of the line is 0.0256 which suggests that a 1% increase in methanol concentration will result in a 0.0256kJ increase in energy produced per gram of biodiesel. Hence, increasing the methanol concentration for the transesterification process would result in increased fuel efficiency for biodiesel.

However, the  $R^2$  value of the best fit line suggests that this trend is weak. The  $R^2$  value is called “coefficient of determination” which shows how well the data points fit the regression model (line of best fit) (*R-Squared*, 2020). According to the best fit line, the  $R^2$  value for graph 1 equals 0.652.

The reason why the  $R^2$  is low might be because of the anomaly shown in graph 1. According to graph 1, the value for heat energy per gram for the concentration of 40% was higher than that of 60%. This is shown in more detail in

table 3. According to table 3, the value for heat energy per gram at 40% methanol is 10.5kJ/g, while the value at 60% methanol is 10.0kJ/g. Although the best fit line suggests that there should be a positive correlation, the fuel efficiency of biodiesel decreased from 10.5kJ/g to 10.0kJ/g as the methanol concentration increased from 40% to 60%.

According to graph 1, the vertical error bars are significantly larger than the horizontal error bars. The percentage uncertainties for the energy per gram of biodiesel were larger than  $\pm 20\%$ . For instance, the percentage uncertainty for methanol concentration of 20% was  $\pm 28\%$ . The high percentage uncertainty suggests that the data collected has low precision. This may be due to both random and systematic errors. For example, a large proportion of heat released from the combustion of biodiesel was lost to the surrounding air, since the bottom of the calorimeter was covered with soot. Due to incomplete combustion, combustion of biodiesel produced less heat energy. This leads to systematic error. Also, mass measurement using electronic balance may have been affected by the airflow as windows were forced to be left open for COVID-19 precautions and there was no draft shield available to block the air current. Hence, the trend shown in graph 1 may not be reliable due to high percentage uncertainty.

## Conclusion

Overall, as the concentration of methanol increases from 20% to 100%, the heat energy produced by each gram of biodiesel increases which shows a positive correlation. According to table 3, the energy per mass of biodiesel increased from 8.36kJ/g to 10.9kJ/g, showing an increase in overall production of heat energy per gram.

These findings moderately support the hypothesis for this investigation. Although the hypothesis states that heat energy per mass would increase as the methanol concentration increases, which is similar to the trend shown in graph 1, the low  $R^2$  value (0.652) and anomaly at a concentration of 40% suggests that the trend may not be valid. Also, the high percentage uncertainty suggests that the precision of the results is low which reduces the reliability of the results. This investigation results could not be compared to theoretical value because there was no published research available online. Hence, there are not enough sources to check the accuracy and support my conclusion.

The reason for the trend shown in a graph might be because of the presence of water molecules. When triglyceride reacts with water molecules instead of methanol, it forms free fatty acids (FFA) and a diglyceride (Clifford, n.d.). Then the dissociated  $\text{Na}^+$  ions from NaOH, which was used to make methoxide, will react with the FFA forming soap (Atadashi, 2012). This reaction is called saponification and it is a side reaction during transesterification (Atadashi, 2012). The more water molecules are present, saponification will occur more frequently which increases the loss of methyl ester (Atadashi, 2012). As a result, biodiesel will contain more impurities, and the total yield decreases (Atadashi, 2012). Hence, as the concentration of methanol increases, heat energy produced by the biodiesel would also increase since there are fewer water molecules causing saponification.

## Evaluation

### a) Strengths

Strengths	Explanation
Putting a lid on top of a calorimeter	When the water inside the calorimeter is heated, the water may evaporate and be lost, causing its mass to decrease. If the water evaporates, the temperature change will be higher since the same amount of heat is transferred to a smaller volume of water, leading to systematic error. Hence, the calorimeter was sealed using a cap and made a tiny hole for a thermometer to prevent a lot of evaporation.
Using cotton as an insulator	Since cotton is a great thermal insulator, the calorimeter was wrapped with a cotton sheet to prevent heat loss to the surrounding air. Without the cotton, the temperature would be lower which decrease the heat energy produced by biodiesel. Hence, systematic error due to heat loss was prevented.

Strengths	Explanation
Extrapolating the maximum temperature	Although the calorimeter was surrounded by a thermal insulator, the spirit burner was exposed to the surrounding air which could lead to heat loss. However, by extrapolating the maximum temperature using the cooling curve, the temperature could be more accurately estimated. This reduced the impact of the heat loss on the experiment to obtain a more accurate value for heat energy produced.

## b) Limitations

Limitations	Potential effect on the result	Suggested improvements
Incomplete Combustion	The color of the flame was orange which means that there was not enough oxygen for complete combustion. Due to incomplete combustion, less heat energy was produced. Hence, the temperature measured would be lower than its actual value as incomplete combustion of biodiesel resulted in a systematic error.	To prevent incomplete combustion, the biodiesel could be combusted in oxygen-rich space. However, this can be dangerous due to huge flame and complete combustion may not occur.
Limited Trials	For this investigation, only 3 trials were done for each biodiesel. Due to fewer trials, more data could not be gained to make the data more precise. This was especially true for energy per mass of biodiesel as there were some data much higher than other data. Hence, the data would be less precise due to fewer trials.	To reduce outliers, more trials should be done for each biodiesel. For example, a total of 5 trials can be done to reduce the impact of random errors.
Analog Thermometer	For this investigation, an analog thermometer was used to measure the temperature change of water inside the calorimeter. Since the analog thermometer's lowest unit is 1°C with uncertainty of $\pm 0.5^\circ\text{C}$ , it was difficult to know the exact temperature without assumption. Hence, because the measurement is not accurate, data for temperature may not be reliable.	Instead of using an analog thermometer, a digital thermometer can be used for future experiments. These thermometers can read up to 1 decimal place with smaller uncertainty of $\pm 0.1^\circ\text{C}$ , which is more specific than analog ones.
Combustion Time	When extrapolating temperature, a cooling curve is required to estimate the maximum temperature without heat loss. However, the flame did not last more than 7 minutes since the wick (string) of the spirit burner burned faster than expected. Since there are only 3 data points to create the cooling curve, the maximum temperature could be lower than the actual value which would make heat energy value lower (appendix 8).	To increase the number of data points for the cooling curve, the combusting time of biodiesel should be longer. For instance, to get a sufficient number of data, the biodiesel should be combusted for 10 minutes. To do this, the length of the wick should be longer.

## Further Investigation

As an extension of this investigation, the temperature of the water bath could be changed to test the optimum temperature for the transesterification. Some sources say temperature between 40 to 60°C is the optimum (Manirafasha, 2020), while other sources state temperature between 60 to 70°C is optimum (Clifford, n.d.). Thus, to investigate at which temperature does biodiesel yield reaches its maximum, the temperature of the water bath will be changed for the transesterification process.

Also, the effect of different types of oil on transesterification could be investigated. Although canola oil is thought to be most efficient since they have a very low percentage of saturated fat (7%) which improve the performance of the biodiesel during cold weather, other oils such as coconut oil, vegetable oil, and olive oil also have very low saturated fat contents (Cporuscio, 2019). Hence, since other oils can be used to make efficient biodiesel, an experiment investigating the energy efficiency of biodiesel produced from different oils is a suitable investigation. These results could be beneficial to people in North America who manufacture their biodiesel at home because they are one of the continents with one of the highest ownership of personal vehicles in the world.

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## Appendixes

### Appendix 1: Temperature change of biodiesel

Time (sec)	Temperature ( $\pm 0.5^{\circ}\text{C}$ )														
	Methanol 20% $\pm 0.7\%$			Methanol 40% $\pm 0.9\%$			Methanol 60% $\pm 1.1\%$			Methanol 80% $\pm 1.3\%$			Methanol 100% $\pm 1.5\%$		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
0	25.0	27.0	26.0	21.0	21.0	26.0	23.0	24.0	38.0	30.0	26.0	32.0	23.0	23.0	30.0
30	26.0	29.0	27.0	22.0	22.0	28.0	24.0	25.0	39.0	31.0	27.0	33.0	24.0	24.0	31.0
60	27.0	30.0	28.0	24.0	24.0	29.0	26.0	26.0	41.0	31.0	28.0	34.0	26.0	25.0	32.0
90	28.0	32.0	29.0	26.0	26.0	30.0	27.0	28.0	43.0	32.0	30.0	37.0	29.0	27.0	33.0
120	30.0	33.0	30.0	27.0	27.0	32.0	29.0	30.0	46.0	34.0	32.0	39.0	30.0	29.0	36.0
150	32.0	34.0	31.0	29.0	28.0	33.0	31.0	32.0	48.0	36.0	35.0	41.0	32.0	31.0	37.0
180	33.0	35.0	31.0	30.0	29.0	33.0	32.0	34.0	49.0	38.0	37.0	42.0	33.0	33.0	39.0
210	34.0	36.0	32.0	30.0	30.0	34.0	34.0	36.0	50.0	41.0	37.0	43.0	34.0	34.0	40.0
240	34.0	36.0	33.0	31.0	30.0	35.0	36.0	37.0	51.0	43.0	38.0	45.0	36.0	36.0	42.0
270	34.0	37.0	33.0	31.0	31.0	36.0	37.0	38.0	52.0	46.0	41.0	47.0	37.0	39.0	44.0
300	34.0	37.0	34.0	31.0	31.0	36.0	37.0	38.0	53.0	46.0	42.0	48.0	38.0	39.0	45.0
330	35.0	37.0	35.0	31.0	32.0	37.0	38.0	38.0	53.0	45.0	42.0	48.0	40.0	39.0	46.0
360	35.0	38.0	35.0	33.0	32.0	39.0	39.0	40.0	54.0	45.0	41.0	47.0	39.0	38.0	45.0
390	34.0	37.0	35.0	32.0	32.0	38.0	39.0	40.0	54.0	45.0	40.0	46.0	39.0	37.0	45.0
420	33.0	36.0	34.0	32.0	31.0	37.0	38.0	39.0	53.0	44.0	40.0	45.0	38.0	36.0	44.0

### Appendix 2: Initial, maximum temperature, and temperature change calculation

Methanol Conc. (v/v)	Trials	Temperature ( $^{\circ}\text{C}$ )		
		Initial ( $\pm 0.5^{\circ}\text{C}$ )	Maximum ( $\pm 0.5^{\circ}\text{C}$ )	Temperature Change ( $\pm 1.0^{\circ}\text{C}$ )
20% $\pm 0.7\%$	1	25.0	41.3	16.3
	2	27.0	43.8	16.8
	3	26.0	41.2	15.2
40% $\pm 0.9\%$	1	21.0	38.3	17.3
	2	21.0	44.0	23.0
	3	26.0	51.0	25.0
60% $\pm 1.1\%$	1	23.0	45.2	22.2
	2	24.0	46.2	22.2
	3	38.0	60.2	22.2
80% $\pm 1.3\%$	1	30.0	51.2	21.2
	2	26.0	46.8	20.8
	3	32.0	59.0	27.0
100% $\pm 1.5\%$	1	23.0	45.2	22.2
	2	23.0	50.0	27.0
	3	30.0	51.2	21.2

### Appendix 3: Initial and final mass of biodiesel

Methanol Concentration (% v/v)	Mass of Biodiesel ( $\pm 0.01\text{g}$ )					
	Trial 1		Trial 2		Trial 3	
	Initial Mass	Final Mass	Initial Mass	Final Mass	Initial Mass	Final Mass
20% $\pm 0.7\%$	181.57	180.60	180.55	179.88	179.93	179.09
40% $\pm 0.9\%$	190.55	189.60	189.58	188.76	188.74	187.88
60% $\pm 1.1\%$	184.10	183.22	205.42	204.67	204.27	202.97
80% $\pm 1.3\%$	197.13	196.25	214.38	213.48	214.96	214.00
100% $\pm 1.5\%$	177.46	176.58	176.08	175.20	174.95	174.01

### Appendix 4: Mass Change for each biodiesel

Methanol Concentration (% v/v)	Mass Change ( $\Delta g \pm 0.02g$ )		
	Trial 1	Trial 2	Trial 3
20% $\pm 0.7\%$	0.97	0.67	0.84
40% $\pm 0.9\%$	0.95	0.82	0.86
60% $\pm 1.1\%$	1.21	1.14	1.06
80% $\pm 1.3\%$	0.88	0.90	0.96
100% $\pm 1.5\%$	0.88	0.88	0.94

### Appendix 5: Heat energy produced by each biodiesel

Methanol Concentration (% v/v)	Heat Energy (kJ)		
	Trial 1	Trial 2	Trial 3
20% $\pm 0.7\%$	$6.83 \pm 0.45$	$7.04 \pm 0.45$	$6.34 \pm 0.45$
40% $\pm 0.9\%$	$7.25 \pm 0.45$	$9.61 \pm 0.47$	$10.45 \pm 0.47$
60% $\pm 1.1\%$	$9.27 \pm 0.46$	$9.27 \pm 0.46$	$9.27 \pm 0.46$
80% $\pm 1.3\%$	$8.85 \pm 0.46$	$8.71 \pm 0.46$	$11.29 \pm 0.47$
100% $\pm 1.5\%$	$9.27 \pm 0.46$	$11.29 \pm 0.47$	$8.85 \pm 0.46$

### Appendix 6: Heat energy per gram produced by each biodiesel

Methanol Concentration (% v/v)	Fuel Efficiency (kJ/g)		
	Trial 1	Trial 2	Trial 3
20% $\pm 0.7\%$	$7.04 \pm 0.61$	$10.5 \pm 0.99$	$7.55 \pm 0.72$
40% $\pm 0.9\%$	$7.63 \pm 0.64$	$11.72 \pm 0.85$	$12.15 \pm 0.83$
60% $\pm 1.1\%$	$10.53 \pm 0.77$	$12.35 \pm 0.95$	$7.13 \pm 0.47$
80% $\pm 1.3\%$	$10.05 \pm 0.75$	$9.68 \pm 0.73$	$11.76 \pm 0.74$
100% $\pm 1.5\%$	$10.53 \pm 0.77$	$12.82 \pm 0.83$	$9.41 \pm 0.69$

### Appendix 7: Average heat energy produced per gram of each biodiesel

Methanol Concentration (% v/v)	Heat Energy per Gram (J/g)	Absolute Uncertainty	Percentage Uncertainty
20% $\pm 0.7\%$	8.36	$\pm 2.4$	$\pm 28\%$
40% $\pm 0.9\%$	10.50	$\pm 2.8$	$\pm 27\%$
60% $\pm 1.1\%$	10.00	$\pm 2.4$	$\pm 24\%$
80% $\pm 1.3\%$	10.50	$\pm 2.2$	$\pm 21\%$
100% $\pm 1.5\%$	10.92	$\pm 2.2$	$\pm 20\%$

Appendix 8: Graph for extrapolating the maximum temperature (20.0%)

