Exploring the fuel efficiency and environmental impact of biofuels

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Abstract

Biofuels are the next generation of renewable fuel sources that are less harmful than conventional non-renewable fuel sources. With the growing knowledge of harmful environmental impacts of the fossil fuel industry, biofuels serve as an attractive alternative. Therefore, it is important to look at the fuel efficiency and environmental impact of these fuels. First aim of this project compares fuel efficiency and CO_2 release between renewable sources (ethanol and soybean biodiesel) to a non-renewable source (kerosene). Second aim of this project is to determine oil (sunflower vs. canola) best for making biodiesel. Fuels were combusted inside a glass burner and temperature change of water in an aluminum can was measured. Energy released was calculated using $Q=mc\Delta t$. CO_2 was measured via NaOH titration. Biodiesels were made through transesterification with methoxide and canola or sunflower oil. Results from Aim 1 show that ethanol is 42% less efficient as kerosene($p=0.015$) but released 32% less CO_2 than kerosene ($p=0.00004$). Soybean biodiesel is 6.6% more efficient as kerosene (not significant) and released 11% less CO_2 than kerosene ($p=0.007$). Aim 2 shows that canola biodiesel was as efficient as soybean biodiesel but released less CO_2. These results show that biodiesels are a good alternative to diesel as it produces a similar amount of fuel, costs around the same. Further studies need to be done to take a closer look at canola oil biodiesel as it may be a better alternative to soybean diesel and the effects of various fatty acids in oils on biodiesel production.

Background

Non-renewable versus renewable energy

Non-renewable energy resources are finite and cannot be replenished. They are broken down into two categories- fossil fuels and nuclear fuels. Examples of fossil fuels are coal, oil, and natural gas. Some examples of nuclear fuels are Uranium-235 and Uranium-238. Renewable energy resources can be replenished quicker than consumed. These resources are also broken down into 2 categories- potentially renewable and nondepletable. Examples of potentially renewable are biofuels and wood. Examples of nondepletable are wind, solar, hydroelectric.

Gasoline and Diesel

Gasoline comes from petroleum and is used in car engines as fuel. Gas engines work through a spark-ignition engine. Diesel comes from petroleum and typically used in larger vehicles such as trucks and buses. Uses a compression ignition engine.

Ethanol and Biodiesel

Ethanol is a type of biofuel that is a substitute for gasoline. Ethanol is an alcohol and is made from starches and sugars. It can be blended to form E-85. Ethanol comes from corn, sugarcane, and barley. Biodiesel is a biofuel alternative for diesel. Biodiesel is made through transesterification where glycerin is separated from fats or vegetable oil leaving behind methyl esters (biodiesel) and glycerin. It can be blended with diesel to form B-20. Biodiesel comes from soybean oil, palm oil, and algae. To make biodiesel, oil should be mixed thoroughly with a methoxide solution (methanol % potassium hydroxide) that will produce biodiesel and glycerin. Then the biodiesel should be separated, washed, dried and then it is ready to use.

Fatty Acid content

Fatty acids have an impact on biodiesel production. Various fatty acids will produce different qualities of biodiesel. Oleic acid is one of the fatty acids that allows for quality biodiesel production.

Objective

Aim 1: compare fuel efficiency and CO_2 release between renewable sources (ethanol and soybean biodiesel) to a non-renewable source (kerosene).

- Kerosene was used as a non-renewable source over gasoline and diesel because kerosene is safer to burn in a school laboratory.

Aim 2: Determine which oil (sunflower vs. canola) is best for making biodiesel.

Hypothesis

Aim 1: If kerosene, ethanol, and soybean biodiesel are combusted then soybean biodiesel will be more efficient and will burn cleaner.

Aim 2: If soybean biodiesel, canola biodiesel, and sunflower biodiesel are combusted then canola biodiesel will be more efficient and burn cleaner due to a higher oleic fatty acid content.

Variables

Independent Variable

- Type of fuel (Ethanol, Soybean biodiesel)

Dependent Variable

- Fuel efficiency, color of the bottom of can, and CO_2 released

Control

- Kerosene

Materials

Glass burner with fuel, balance, ruler, temperature probe, aluminum can, safety goggles, matches, graduated cylinder, paperclip, stopwatch, water, ring stand, graduated cup, Bromothymol Blue (BTB).

Procedure

Combustion & Titration Procedure

1. Wear safety goggles.
2. Measure out 50 mL of water into a graduated cylinder and put it into an aluminum can.
3. Mass the burner to get initial mass of burner with the lid on.
4. Attach the can to the ring stand by using a paperclip to connect the tab of the can to the ring of the ring stand and use a temperature probe to measure initial temperature of water.
5. Put the burner on the ring stand underneath the can.
6. Adjust the height of the ring stand so the flat bottom of the can is 5 cm above the tip of the burner. Observe the color of the bottom of the can.
7. Take the lid off the burner and light the burner with a match. Leave the probe inside the can and let it burn for 5 minutes. Extinguish flame by putting the lid back on.
8. After 5 minutes measure the final temperature of the water. Observe the color of the bottom of the can.
9. Mass the burner again with the lid on to measure the final mass of the burner.
10. Switch cans and add new water to the can for 2 more trials and repeat steps above.
11. Add 10 mL of water into two graduated cups, add 6 drops of BTB to each cup, and swirl till the solution turns blue.

12. Light the burner and place the open mouth of the bottle over the wick of the burner. When the flame is extinguished, lift the cup and screw on the cap.
13. Turn the bottle right side up and add one the BTB solution in. Recap the bottle and shake 20 times. Finally pour the contents into the empty graduated cup and compare the color to the other graduated cup.
14. Add 0.05 M NaOH one drop at a time to the BTB solution until the blue color returns.

Biodiesel Procedure

1. Make a methoxide solution by mixing 5.33 g of potassium hydroxide with 200 mL of methanol. Mix it until the potassium hydroxide has dissolved and let it sit overnight.
2. Heat up 1 liter of oil to 55°C and pour into a blender. Next pour in the methoxide solution and blend for 30 minutes. Transfer the solution into a glass bottle and let sit overnight.
3. Once the glycerin has separated and a layer has formed, pour out the top layer of biodiesel.
4. Wash the biodiesel by adding water, shaking the bottle, letting it sit for 3 hours, and pouring out the water. Repeat the washing step 2 more times.
5. Let the biodiesel sit for 48 hours and it is ready to use.

Results

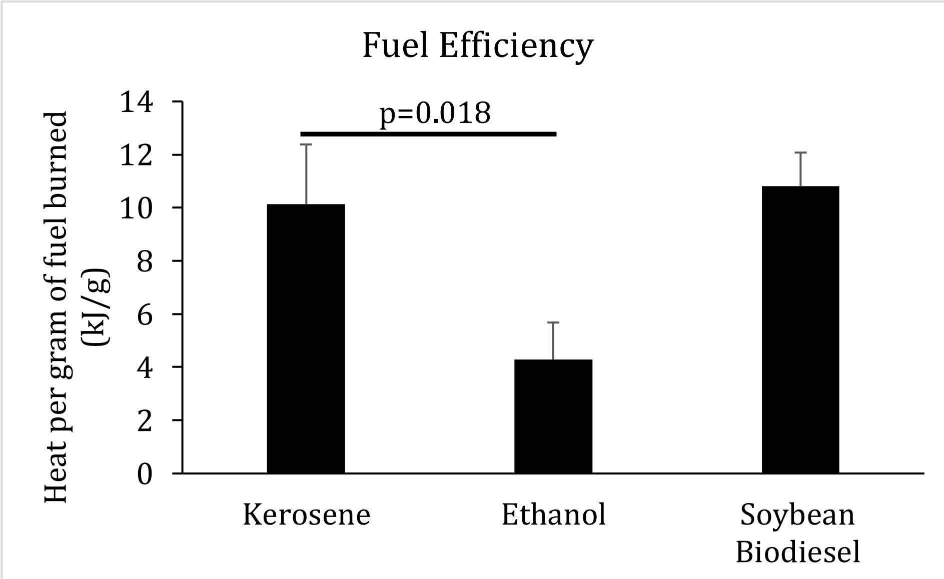

Figure 1: Fuel efficiency of Non-Renewable fuels (Kerosene) vs. Renewable fuels (Ethanol & Soybean Biodiesel) (n=3)

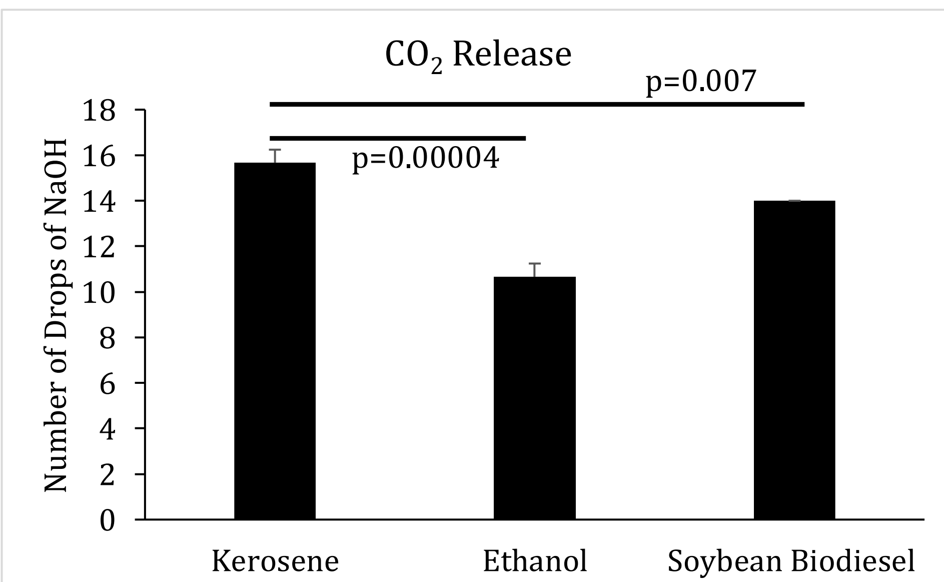

Figure 2: Carbon dioxide release from Non-Renewable fuels (Kerosene) vs. Renewable fuels (Ethanol & Soybean Biodiesel) (n=3)

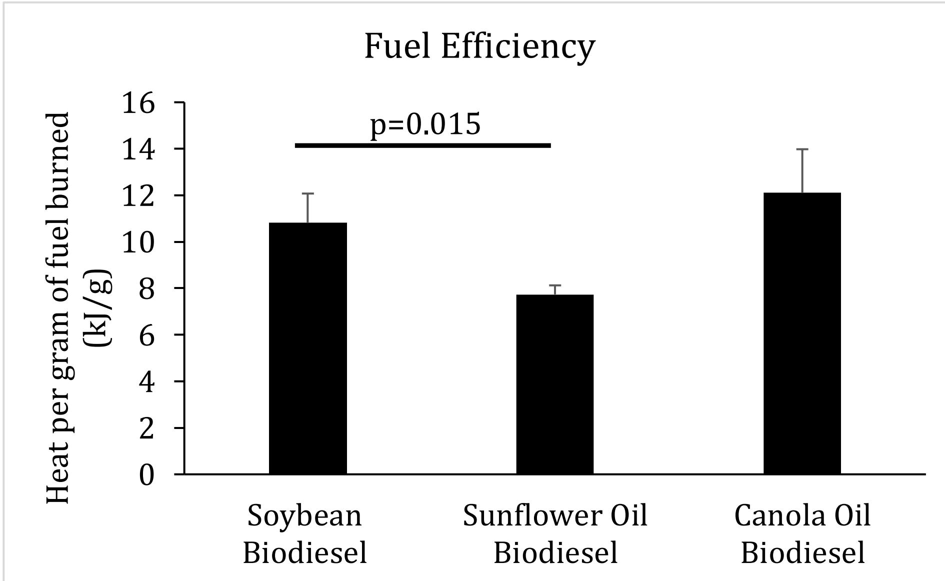

Figure 3: Fuel efficiency of different biodiesels, (n=3)

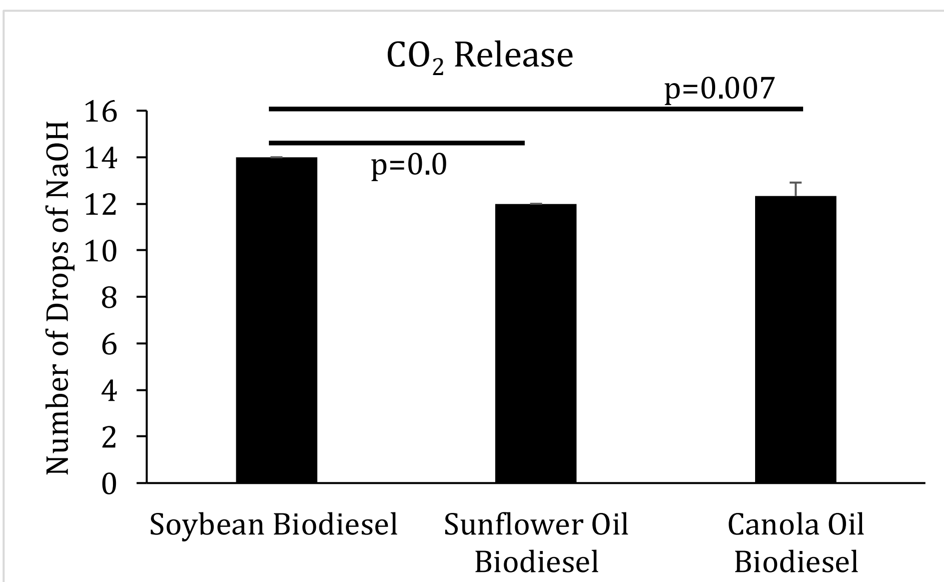

Figure 4: Carbon dioxide release from different biodiesels. (n=3)

Type of Fuel	**Kerosene**	**Ethanol**	**Soybean biodiesel**	**Sunflower oil biodiesel**	**Canola Oil Biodiesel**
5 min flame exposure					
Description	Complete Black	Slight Charring	Multiple Black Spots	Slight charring around the rim of can	Slight charring around the rim of can

Figure 5: Measurement of cleanliness of combustion after five-minute flame exposure of various fuels

As shown in Figures 1 through 5, comparing non-renewable (kerosene which was the control) and renewable (ethanol and soybean biodiesel) fuels, ethanol had a significantly lower fuel efficiency of 4.29 kJ/g with a p value of 0.018 when compared to kerosene, 10.14 kJ/g. Soybean biodiesel had the highest fuel efficiency of 10.81 kJ/g. Soybean biodiesel (14 drops) and ethanol (11 drops) significantly released less CO_2 than kerosene (16 drops) with p values of 0.007 and 0.0000 respectively. When comparing the 3 biodiesels, soybean (control), sunflower, and canola, sunflower biodiesel had a significantly less fuel efficiency (7.74 kJ/g) when compared to soybean (10.81 kJ/g) with a p value of 0.015. Canola biodiesel did have the highest fuel efficiency of the 3 biodiesels (12.11 kJ/g). Sunflower biodiesel (12 drops) and canola biodiesel (12 drops) significantly released less CO_2 than soybean biodiesel (14 drops) with p values of 0;0 and 0.007 respectively. After 5 minutes of flames exposure, kerosene was completely black, soybean biodiesel had multiple black spots, sunflower and canola biodiesel had slight charring around the sides, and ethanol had slight charring. Supplemental data used for calculating the results is shown in Appendix A.

Discussion

The higher the fuel efficiency the better the fuel is. Canola biodiesel was the best fuel, in this regard, because it had the highest fuel efficiency (12.11 kJ/g). A higher fuel efficiency means that the fuel will last longer because it will release the most amount of energy with the same amount of fuel burned. The lower the drops of NaOH the better. BTB is a solution that is blue when the pH is neutral and is yellow when the solution is acidic. CO_2, when in water, will turn into carbonic acid and will cause the BTB solution to be acidic and yellow. NaOH is used to titrate the solution and will increase the pH and bring the solution back to a blue color. A lower NaOH drop count means that less carbonic acid was in the solution, so the fuel released less CO_2. Ethanol was the best fuel, in this regard, because it released the least CO_2 (11 drops). Canola biodiesel did release the second least amount of CO_2 (12 drops) tying with sunflower biodiesel. However, sunflower biodiesel and ethanol did not have a fuel efficiency as high as canola; therefore, canola was the best fuel.

Conclusion

In conclusion the hypothesis was partially correct. Biodiesel was the most efficient and released 6.6 % more energy than kerosene. However, ethanol was burned the cleanest as it showed the least amount of charring on the can. Biofuels are an alternative to fuels because for the CO_2 they release during combustion, they also take in CO_2 in their plant form. Biodiesel has closed the gap on price compared to diesel and energy produced; however, the production of nitric oxide from incomplete combustion is troubling. Ethanol does burn cleaner than gasoline, however it does not produce as much energy as gasoline does per kg of fuel. While comparing biodiesels to see which one is the best it is concluded that canola biodiesel is the best type of biodiesel as it was the most fuel-efficient fuel and tied for releasing the least amount of CO_2.

Future Directions

Based on the research findings, recommendations for future study includes calculating the percentage of various compounds after incomplete combustion, testing other biofuels such as biogas and estimating the effect of fatty acids and temperature on biodiesel production.

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Appendix A

Supplemental Data

	Kerosene Trial 1	Kerosene Trial 2	Kerosene Trial 3	Ethanol Trial 1	Ethanol Trial 2	Ethanol Trial 3	Soybean biodiesel Trial 1	Soybean biodiesel Trial 2	Soybean biodiesel Trial 3
Mass of water (g)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Initial water temp (°C)	18.9	19.3	19.3	10.7	15.7	13.6	16.7	16.2	14.4
Final water temp (°C)	59.4	62.4	43.3	50.7	55.7	35.6	62.2	72.5	73.6
Heat absorbed (kJ)	8.47	9.02	6.06	8.37	6.28	4.60	9.52	11.78	12.38
Initial mass of burner (g)	103.21	102.45	101.68	89.53	88.06	86.59	111.17	110.16	109.10
Final mass of burner (g)	102.45	101.68	100.88	88.06	86.59	85.01	110.16	109.10	108.06
Mass burned (g)	0.76	0.77	0.8	1.47	1.47	1.58	1.01	1.06	1.04
Heat per gram of fuel burned (kJ/g)	11.14	11.71	7.58	5.69	4.27	2.91	9.43	11.11	11.90

Table 1: 3 trials of combustion from Renewable (Kerosene) and Non-renewable (Ethanol & Soybean biodiesel)

	Sunflower biodiesel Trial 1	Sunflower biodiesel Trial 2	Sunflower biodiesel Trial 3	Canola biodiesel Trial 1	Canola biodiesel Trial 2	Canola biodiesel Trial 3	Soybean biodiesel Trial 1	Soybean biodiesel Trial 2	Soybean biodiesel Trial 3
Mass of water (g)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Initial water temp (°C)	16.9	16.8	16.9	17.6	17.8	17.8	16.7	16.2	14.4
Final water temp (°C)	51.2	54.3	49.8	59.2	53.3	53.4	62.2	72.5	73.6
Heat absorbed (kJ)	7.18	7.85	6.88	8.70	7.43	7.45	9.52	11.78	12.38
Initial mass of burner (g)	105.78	104.86	103.89	113.26	112.39	111.81	111.17	110.16	109.10
Final mass of burner (g)	104.86	103.89	102.95	112.39	111.81	111.26	110.16	109.10	108.06
Mass burned (g)	0.92	0.97	0.94	0.87	0.58	0.55	1.01	1.06	1.04
Heat per gram of fuel burned (kJ/g)	7.80	8.09	7.32	10.00	12.80	13.54	9.43	11.11	11.90

Table 2: Three trials of combustion from various biodiesels.

CO_2 Release (Average number of drops of NaOH)					
Type of Fuel	Kerosene	Ethanol	Sunflower Biodiesel	Canola Biodiesel	Soybean Biodiesel
Number of drops of NaOH	16	11	12	12	14

Table 3: Carbon Dioxide release measured by NaOH titration.