The Effects of Carbon Chain Length on an Alcohol's Fuel Viability

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October 29, 2024

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Abstract

This study compares the effectiveness of different carbon chain length alcohols in a propulsion system. To determine the effectiveness of the different alcohols as fuels a mixture of methods including enthalpy change, horizontal travel distance and horizontal velocity are tested to compare the efficiency and propulsion properties of the fuels.

With increasing incentives from green initiatives and programs, alternative fuels should be considered, researched, modified, and implemented into practice. Ethanol and methanol are two alternative green fuels which appear to be quite promising, comparing these two to select a more efficient fuel could very well provide a new way to produce sustainable aviation fuels (SAFs).

Our study found that the same propulsion system was able to travel farther with methanol as the propellant, when compared to ethanol. Ethanol, on average, tended to travel with a larger velocity by a small margin of less than 5%. This suggests that the velocity was not significantly affected by fuel type. These conclusions suggest that methanol makes for a more efficient fuel.

Our research proposes that alcohols would be able to work in propulsion systems and would work as effective alternatives to current aircraft fuels and suggests that methanol would be a better fit for the criteria provided.

Introduction

As the aerospace industry continues to expand, a more pressing concern regarding aircraft fuel emissions has emerged. In late 2021, the International Air Transport Association released a mission statement committing member airlines to achieve net zero carbon emissions by 2050. This commitment underscores the importance of the development and implementation of low-carbon emission alternative fuels into standard practice.

Alcohol-based fuels have been shown to possess advantageous properties for this criterion. Ethanol and methanol are two such fuels which can be derived from renewable resources such as agricultural residues and herbaceous crops. These attributes contribute to their potential for sustainability and reduced environmental impact. The combustion of these fuels typically results in lower emissions of particulate matter and other pollutants compared to conventional aircraft fuels. These propellants can be obtained through the aforementioned environmentally friendly sources to reduce total carbon dioxide production during combustion by 65-80%.[1]

Our investigation aims to compare the differences between different alcohols in a propulsion system. Our results enable us to determine the most efficient fuel when comparing ethanol and methanol. These results can then be utilized by the aerospace industry in the future when looking towards alternative sustainable aviation fuels.

Our hypothesis is that methanol will make for a better fuel due to its lower flash point. The ability to ignite at a lower temperature ensures that more methanol is ignited than ethanol at the same temperature, which should, theoretically, produce more thrust.

Methods and Materials

Propellants:

- Methanol (CH_3OH) Purity 99.8%
- Ethanol (C_2H_5OH) Purity 99.9%

Figure 1

Propulsion System Materials:

- 5-gallon jug (19L)
- 2 (250 ml) beakers
- Meter rule
- Splints
- Lighter
- Skateboard
- Tape (Varying widths)

Safety:

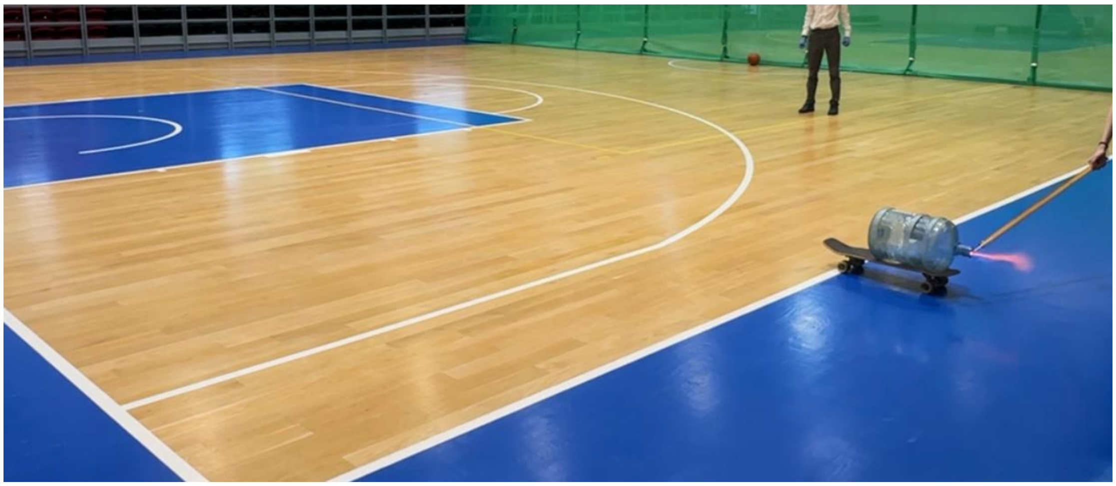
- Goggles
- Gloves

Four trials were done in a laboratory (Table 1, Table 5) with ample oxygen supply and limited people in the room. Humidity was not measured. The following procedure was applied:

1. A water jug's interior is coated with roughly 5 cm^3 of the respective fuel.
2. A single splint is taped onto the meter rule.
3. The water jug is taped to a skateboard.
4. The propulsion system is placed at a fixed point (marked with tape)
5. The splint is lit and placed near (not in) the finish.
6. A video records the entire combustion and how long it travels for.
7. Measuring tape is used to measure the displacement between the fixed point and the final point.

Four Trials were done in a large gymnasium (Table 2, Table 6) with ample oxygen supply and limited people in the room. Humidity was not measured. The following procedure, which was slightly modified to account for previous errors to increase accuracy, was applied:

Figure 2



1. The water jug was cooled with water for roughly 1 hour (until it reached roughly 22.5°C)
2. The water jug's interior was coated with roughly 5 cm^3 of the respective fuel.
3. A cap of the rough diameter of the neck of the jug was fixed onto its finish.
4. A splint was taped onto the meter rule.
5. The water jug was brought to the gymnasium.
6. The water jug was taped to the skateboard.
7. The propulsion system was placed at a fixed point (marked with tape)
8. The cap is removed
9. The splint is lit and placed near (not in) the finish.
10. A video records the entire combustion and how long it travels for.
11. Measuring tape is used to measure the displacement between the fixed point and the final point.

The calorimetry experiment was made using:

- A methanol spirit burner
- An ethanol spirit burner
- A 250 ml beaker filled with 100ml cold water
- A 250 ml beaker to support the spirit burner
- Thermometer (0-100˚C accurate to 0.1˚C)
- Stand
- Goggles for safety

For calorimetry, the following setup was used:

Results

Table 1

	Average Displacement (m)	Average Velocity (ms^{-1})
Methanol	8.96	0.718
Ethanol	6.01	0.737
Percentage difference	39.41%	2.61%

Table 2

	Average Displacement (m)	Average Velocity (ms^{-1})
Methanol	11.47	0.624
Ethanol	10.35	0.653
Percentage difference	10.22%	4.54%

Table 3

	Average Displacement (m)	Average Velocity (ms^{-1})
Methanol	10.22	0.671
Ethanol	8.18	0.695
Percentage difference	22.13%	3.51%

Table 4

	Water Mass (g)	ΔT (°C)	Substance (mol)	ΔH ($kJmol^{-1}$)
EtOH	100	49.5	0.008109	-255.17
MeOH	100	56.5	0.14563	-162.17

For the first set of experiments (Table 1), the displacement when methanol is the fuel is much larger than ethanol. The velocities of the two fuels are within a 5% difference, but the time for ethanol is much shorter.

For the second set of experiments (Table 2), the displacement has a percentage difference of 10.22%, which suggests methanol allows the propulsion system to travel farther. The velocity, on the other hand, has a percentage difference of 4.54%, which would suggest there is no major difference between the velocities.

When taking the averages of all values (Table 3), the observed trend persists. Displacement exhibits a percentage difference of 22.13%, indicating a preference for methanol, whereas velocity shows a negligible difference of less than 5%, suggesting no significant correlation.

When looking at extreme data values, methanol's largest produced velocity was 62.6% greater than ethanol's smallest produced velocity. When looking at it vice versa, the result is 58.3% greater. We also concluded that methanol's range is 85.15% larger than ethanol's range.

For our calorimetry results (Table 4), we obtained a much less negative enthalpy change than the real value for the enthalpy of combustion of the respective fuels. Methanol had a result of 22.68% of the real value (-715 $kJmol^{-1}$). Ethanol produced a result of 18.61% of the real value for its enthalpy of combustion (-1370.7 $kJmol^{-1}$).

Discussion

In the first set of experiments involving methanol, cooling times were varied. We believe that this contributed to the range of velocities due to the discovery of a direct correlation between the temperature of the water jug and the velocity of the propulsion system. In the second set of experiments involving methanol, we were able to keep the surface temperature of the jug constant. This is proven through the relationship between the ranges of velocities in the first and second sets of experiments. The range of the velocities of the first set of experiments (0.424 ms^{-1}) was five times larger than the range of velocities (0.0847 ms^{-1}) in the second set of experiments.

Meanwhile, in the ethanol experiments, the percentage difference between the two kinematic ranges was 23.45%, favoring the former range. We theorize that this can be attributed to the discrepancy between the volume of fuel used to coat the interior of the fuel vessel. If we were to use constant propellant volume to ensure unbiased coating in respective experiments, we would likely not observe significant differences in kinetic ranges.

The calorimetry results differ from real values due to heat lost to the environment, possible errors and delays in the temperature measurement, and the equipment setup. Although ethanol has a more negative enthalpy change, its longer carbon chain may lead to less efficient combustion dynamics in this specific application.

The design of the propulsion system favors the combustion characteristics of methanol. The five-gallon jug optimizes fuel dissipation, ensuring a thorough mix with air for efficient combustion. The system also benefits from methanol's cooling effect, which lowers the intake air temperature, increasing the pressure so it boosts the air density. So, the design maximizes power output and efficiency, making methanol a favorable choice for the propulsion system.

In future analyses, velocities at discrete time intervals may be measured to show acceleration values and provide an accurate thrust value. By recording velocity data continuously, researchers can derive precise thrust values, enabling a thorough assessment of each fuel's performance in terms of propulsion efficiency. This approach may provide insights into how variations in fuel properties, environmental conditions, and combustion dynamics impact overall thrust generation. Information, such as this, would be crucial for optimizing engine performance and fuel efficiency in aerospace applications, and would contribute to the development of more sustainable and effective propulsion systems.

Further improvements could also include a larger set of propellants for comparison, such as incorporating propanol and butanol in addition to methanol and ethanol. By broadening the range of alcohol-based fuels examined, our study could provide a more comprehensive analysis of how carbon chain length affects fuel efficiency and combustion dynamics. Longer carbon chain alcohols may exhibit distinct combustion characteristics that could influence their suitability as alternative fuels for aviation. An expanded comparison would allow us to assess a wider spectrum of alcohol fuels, offering deeper insights into their respective advantages and limitations. An inclusive approach, such as this one, could lead to more informed decisions regarding the best potential candidates for SAFs.

Appendix

Figure 4

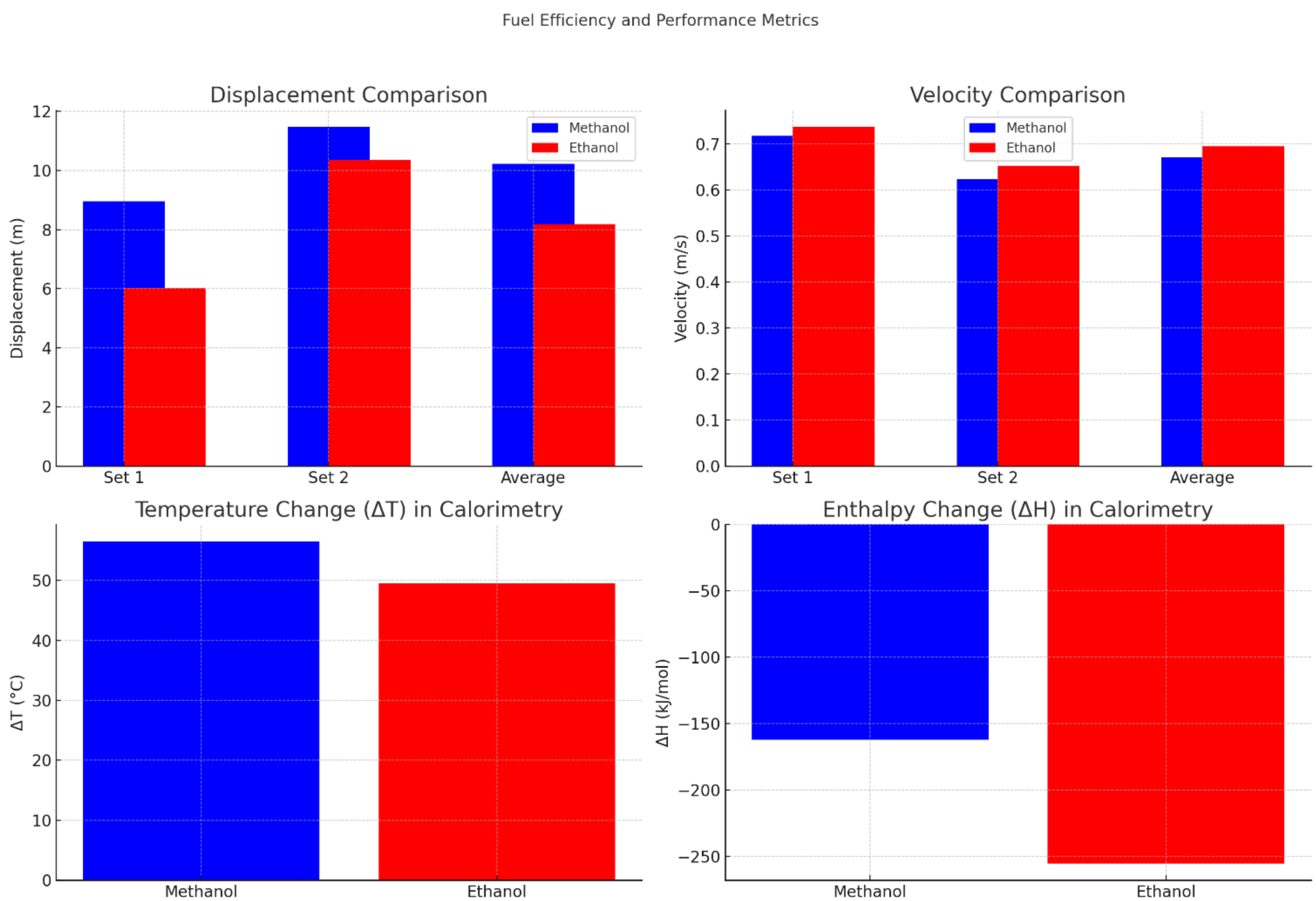


Figure 4 provides a visual representation of data displayed in tables previously. It includes a comparison of displacement, as well as a contrast of velocity. Enthalpy and temperature changes are also compared in the two bottom graphs.

Table 5

	1st Displacement (m)	1st Velocity (ms^{-1})	2nd Displacement (m)	2nd Velocity (ms^{-1})
Methanol	7.22	0.506	10.70	0.930
Ethanol	6.57	0.801	5.45	0.673

Table 5 includes data collected from the four experiments located in the laboratory. Note that the column labeled velocity is not the maximum velocity, but the average velocity for the distance the propulsion system travels.

Table 6

	1st Displacement (m)	1st Velocity (ms^{-1})	2nd Displacement (m)	2nd Velocity (ms^{-1})
Methanol	10.57	0.582	12.36	0.667
Ethanol	10.35	0.734	10.35	0.572

Table 6 includes data collected from the four experiments located in the gymnasium. Note that the column labeled velocity is not the maximum velocity, but the average velocity for the distance the propulsion system travels.

Regarding the results section, Table 1 contains average values from Table 5 for both displacement and velocity for their respective fuels. Table 2 contains average values from Table 6 for both displacement and velocity for their respective fuels. Table 3 contains average values for velocity and displacement from both Table 1 and Table 2.

Conclusion

Methanol is a better fuel than ethanol due to its greater displacement and overall higher efficiency. The higher displacement value for methanol indicates that it produces more thrust, which may be due to the greater volatility and lower flash point of methanol. While ethanol remains a competitive alternative due to its higher energy content, methanol's performance advantages and lower production costs suggest it may be preferable in certain propulsion systems.[2]

In the future, studies may more deeply explore the relationship between fuel vessel temperature, thrust, and fuel efficiency. Specifically, examining how differing the temperature of the fuel vessel would affect the combustion characteristics of methanol and ethanol. Maintaining an optimal fuel vessel temperature would enhance fuel vaporization and air-fuel mixing, leading to more efficient combustion and increased thrust. This would surely provide valuable insights into propulsion system characteristics.

Acknowledgements

We would like to thank our head of lab, Sahar Nahib, for her invaluable guidance and dedication to ensuring a safe working environment throughout this research project. We would also like to express our gratitude to St. George International School and Preschool for providing the facilities, resources, and funding necessary for conducting our experiments.

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