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Educating Engineers on the Use of Renewable Ethanol Fuel as a Drop-in Replacement for Gasoline in Small Engines

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Abstract. The use of high-blend ethanol fuels to reduce emissions produced by on-road vehicles has been extensively studied. However, much less research has been done to study the effect of operating small off-road engines on high-blend ethanol fuel as a drop-in replacement for gasoline. Most small engine manufacturers only certify proper operation on low ethanol blends such as E10 (10% ethanol, 90% gasoline by volume).

Most engineering students are unaware of the benefits that can be achieved when using high-blend ethanol fuel in small engines without substantial modifications. In this study, students conducted performance testing and analysis of a small engine using a dynamometer and a raw exhaust emissions analyser. The exhaust emissions and performance of the engine were evaluated using the U. S. Environmental Protection Agency (EPA) 6-mode duty cycle for small recreational engines (under 19 kW). Testing and analysis followed the recommendations of the SAE J1088 recommended practice.

Students were motivated by the contemporary nature of the project and the use of commercially available equipment for testing. Further, students learned about the use of standardized testing to demonstrate the performance and emissions results.

Keywords. Ethanol, engine, emissions, education, fuel.

1. Introduction

Small off-road engines are currently widespread. For example, it is estimated that nearly 121 million small gasoline engines are in use for lawn and garden equipment in the United States alone [1]. Examples of this usage range from small chainsaw engines to lawn tractors. These engines generally produce much higher levels of exhaust emissions per unit power than comparable on-road engines.

Additionally, these engines most often use a carburetor for fuel control. A carburetor, while relatively inexpensive to produce, provides only limited control over the fuel-air mixture. Further, since this type of fuel control has not been used in the on-road sector for some time, students have little to no familiarity with them.

Research into the use of high-blend ethanol fuel has shown promise in reducing exhaust emissions. For instance, Hsieh et al. [2], conducted an experimental study investigating performance and pollutant emission of a commercial Spark-Ignited engine, using various blend rates of ethanol. The results indicated that when using ethanol–gasoline blended fuels, the torque output and fuel consumption of the engine slightly increased, while carbon monoxide (CO) and unburned hydrocarbons (HC) emissions decreased, as a result of the leaning effect caused by the ethanol. Srinivasan and Saravanan [3] demonstrated improvements in engine performance and exhaust emissions with ethanol blends and oxygenated additives to gasoline. Guerrieri *et al* [4] investigated the effect of different concentrations of ethanol in later model vehicles. It was found that the emission responses to increasing ethanol concentrations were almost linear.

Clearly, students need to learn about the benefits and challenges encountered when using renewable fuels in engines to reduce pollution and the reliance on fossil fuels.

This introduction to sustainable development is difficult to achieve in an academic setting. For example, Felguieras [5] discusses how sustainability solutions require increased complexity, analyzing systems and sub-systems together, not in isolation. Mulder [6] argues that successful technological change requires engineers who have acquired strategic competencies. Mulder goes on to argue that the traditional paradigm of individual disciplines is a barrier to teaching these competencies.

To overcome these challenges in traditional education, students need to be motivated to work in teams to develop real solutions to contemporary issues which transcend the classroom. Further, students are intrinsically motivated through competition. The Society of Automotive Engineers (SAE) offers a series of engineering design competitions which are well received by students from around the world.

2. SAE Collegiate Design Challenge Goals

SAE offers an assortment of different vehicle design competitions. These vehicle design challenges include race cars, off-road vehicles for summer and winter use, and airplanes. Competition goals vary from competition to competition. Some competitions focus on the development of chassis and suspension systems, while others focus more on powertrain development. All of the competitions share a common vision:

Encourage students to work in teams to

- Design,
- Build,
- Describe, and
- Compete using their own vehicles.

These competitions are popular with students all around the world. In figure 1, Davis [7] illustrates the international nature of these competitions in 2010.

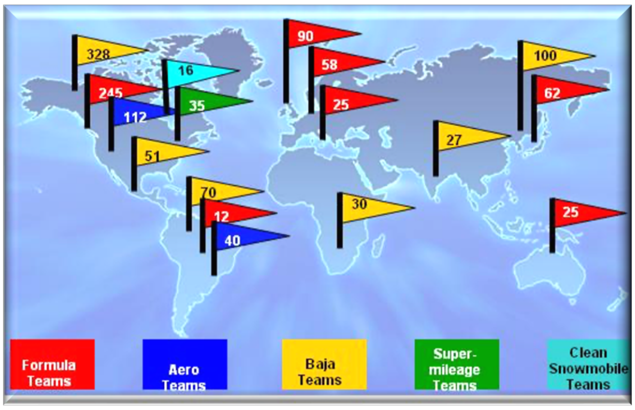

Fig. 1. Number of University Teams (located in flags) and Locations of Various Competitions, 2010.

Survey results of alumni from undergraduate programs in mechanical or electrical engineering demonstrated that participation in the design competitions improved the motivation of the students involved. More than 75% indicated that this improved or greatly improved both their motivation and preparation. [7]

Because of the success of these competitions, many Universities have integrated these into the capstone design curriculum. But these competitions also offer the ability to work directly with faculty on relevant research projects related to the competition.

The SAE Baja uses small gasoline engines in off-road competitions. Engineering students are tasked with designing and building a single-seat, off-road vehicle that is to be a prototype for a simple and economic production vehicle, which could serve the recreational user market [8].

3. Experimental Approach

For this study, the Baja SAE competition engine was used. Students were tasked, in the laboratory, to study the use of high-blend ethanol fuel as a drop-in replacement for gasoline. Since ethanol is an oxygenated fuel, it can provide lower emissions of unburned hydrocarbons and carbon monoxide. In addition, it is a renewable fuel derived from biomass, which lowers overall life-cycle carbon emissions.

Students explored the possibility of reducing emissions by replacing the base gasoline fuel (10% ethanol, balance gasoline by volume, or E10) with one based on biomass derived ethanol. A high ethanol blend (77% ethanol, balance gasoline by volume, or E77) was chosen for testing. This blend represented a compromise between a "summer-blend E85" (85% ethanol) and a "winter-blend E85" (70% ethanol).

A commercially available small engine, used by teams in the SAE Baja competition, was chosen as representative of typical engines in this class. This engine, rated at 7.5 kW (gross power) utilizes a carburetor for fuel control (Fig. 2).

Fig. 2. Commercially Available, 7.5 kW Briggs-Stratton Engine used in the SAE Baja Challenge.

This engine was tested using a dynamometer and a raw exhaust emissions analyser. The exhaust emissions and performance of the engine were evaluated using the U. S. Environmental Protection Agency (EPA) 6-mode steady duty cycle for small recreational engines, while testing and analysis followed the recommendations of the SAE J1088 recommended practice (Table I).

Table 1. U.S. EPA Six-mode Duty Cycle for Small Non-road Gasoline Engines: 7.5 kW Briggs-Stratton Engine

Mode No.	Engine speed (percent)	Speed Target (rpm)	Torque (percent)	Torque Target (N-m)	Weighting factors
1	85	3060	100	18.7	0.09
2	85	3060	75	14.0	0.20
3	85	3060	50	9.4	0.29
4	85	3060	25	4.5	0.30
5	85	3060	10	1.8	0.07
6	Idle	1080	0	0	0.05

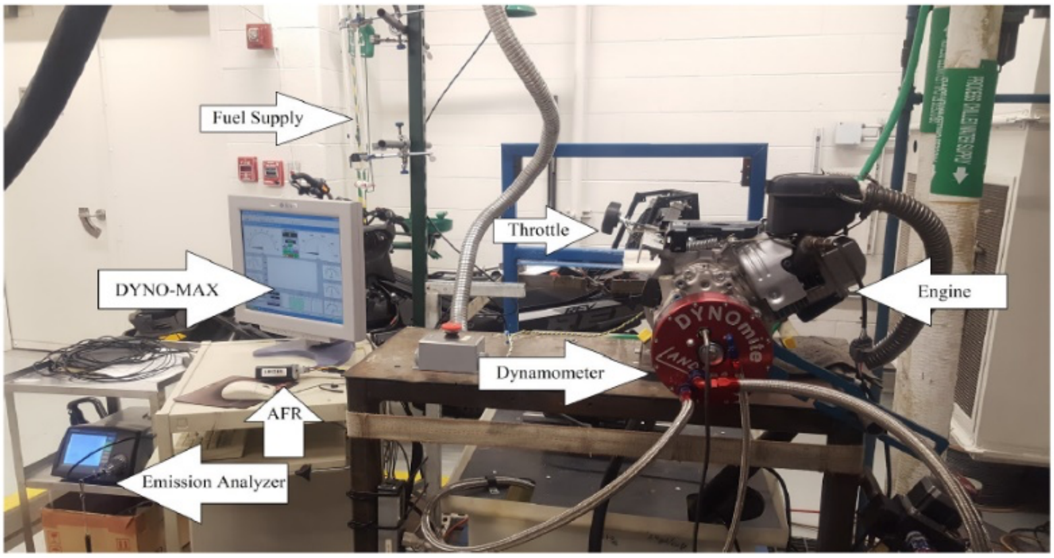

Fig. 3. Experimental Apparatus.

Performance and emissions results were measured and compared with the baseline operation found when using E10. Specifically, the fuel efficiency and normalized emissions levels of Carbon Monoxide, Carbon Dioxide, Oxides of Nitrogen (NOx) and unburned Hydrocarbons were determined.

The experimental apparatus used by the students in conducting the study is presented in Figure 3.

Since ethanol is an oxygenated fuel, stoichiometric combustion requires more fuel for the same engine airflow than operation on gasoline. If the air-fuel mixture becomes lean, the exhaust emissions of oxides of nitrogen (NOx) will tend to increase. In carburetors, the air-fuel mixture is controlled by the fuel jet orifice size. In order to try to minimize the increase in NOx emissions due to lean operation when using the E77 fuel mixture, larger diameter commercially available jets were used in the engine carburetor.

The original jet diameter size, designed for operation on gasoline, was 0.838 mm. In order to provide more fuel, a larger diameter jet was chosen, 0.889 mm. This larger diameter jet should improve the air-fuel mixture when using the E77 fuel.

4. Results

Results of the testing and performance of the engine are presented first, followed by some of the student perceptions of the project and class.

During testing, the students first found a large increase in NOx emissions when using the high-blend ethanol fuel in place of gasoline (Figure 4). This is an important limitation often encountered when using an oxygenated blend as a substitute fuel. The use of the larger diameter jet improved the situation, but high emissions of NOx were still noted. This indicates the need for an even larger diameter jet. As shown, the unburned hydrocarbons decrease, which is good for the environment.

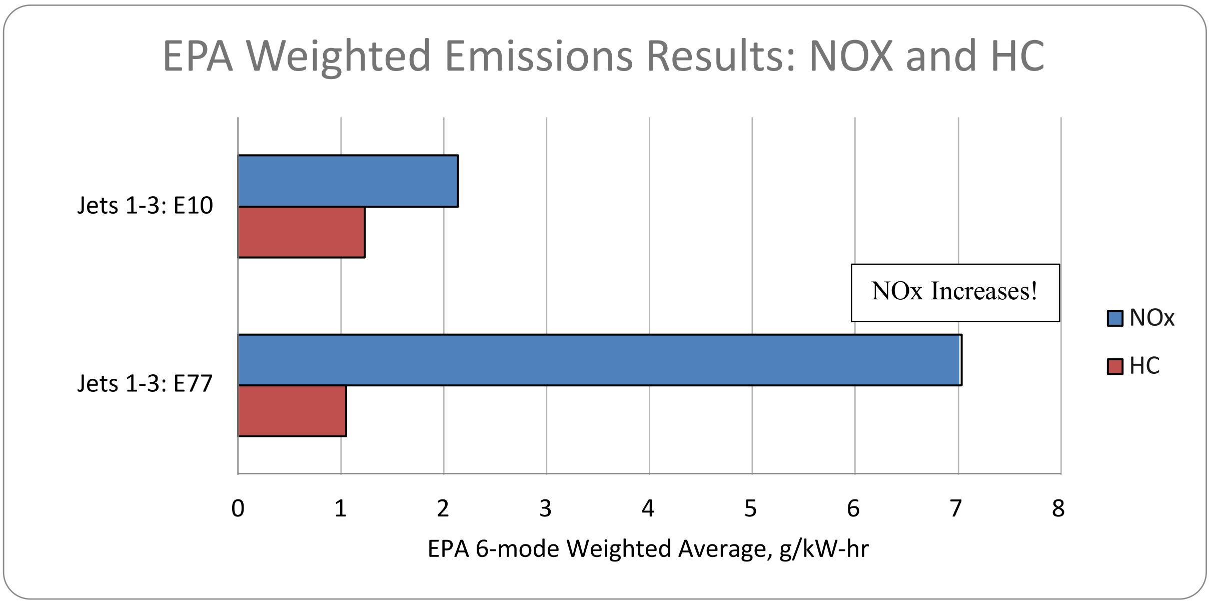

Fig. 4. Effect of High-Blend Ethanol Use on Exhaust Emissions

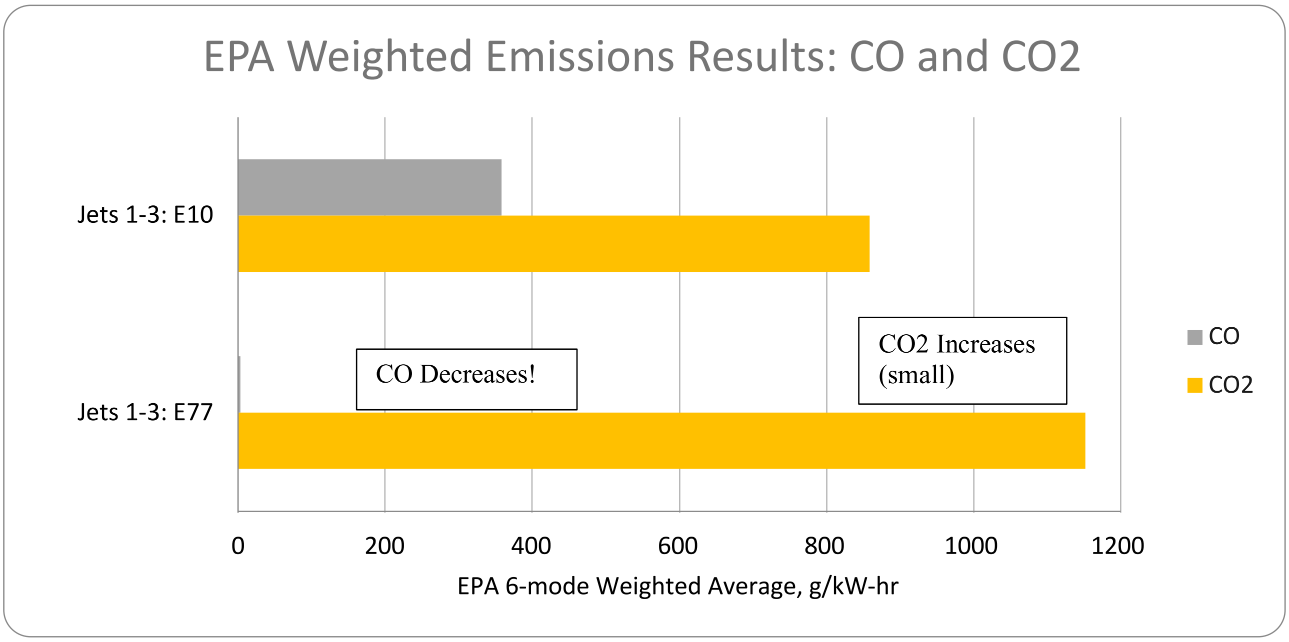

Fig. 5. Effect of High-Blend Ethanol Use on Exhaust Emissions

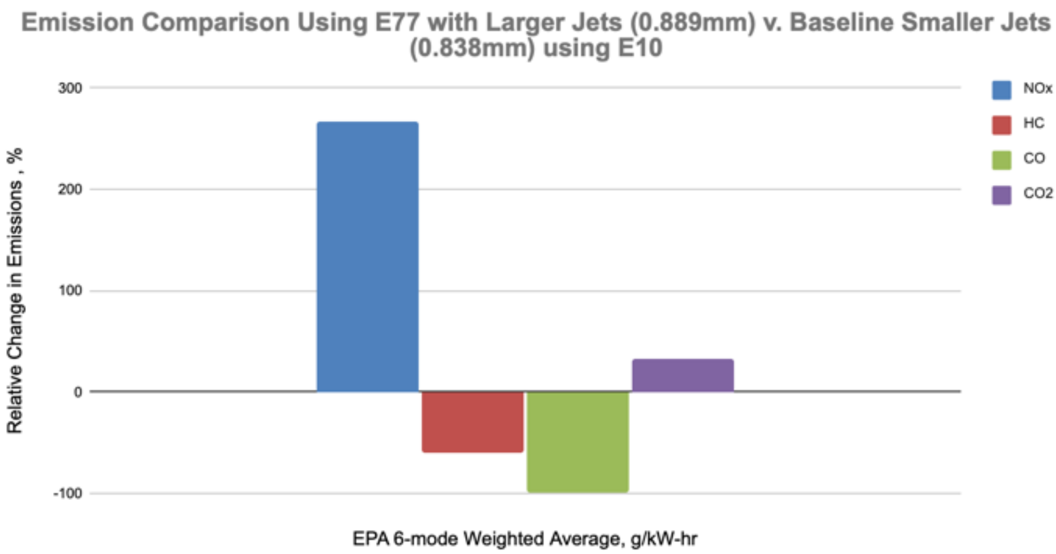

Fig. 6. Summary of Exhaust Emissions Changes when using Renewable Fuel and Larger Jet Diameter Compared with those Found using Gasoline and the Original Jet Diameter.

Figure 5 demonstrates the large decrease in in carbon monoxide (good for the environment). However, the exhaust carbon dioxide increases slightly. This is due to the additional renewable fuel that must be burned to produce the same output power as during operation on gasoline (E10). As discussed later, the life-cycle CO2 emissions are still reduced.

The final cycles of weighted exhaust emission species found, when using high-blend ethanol *and* the larger jet diameter, are compared to those found when using gasoline and the original size jet. These results are shown in Figure 6.

As shown, the students found a substantial improvement in the emissions of carbon monoxide and unburned hydrocarbons. These are some of the benefits of using the high-blend ethanol fuel. Students also noted a slight increase in the exhaust emissions of carbon dioxide. This increase is smaller with the larger jet size due to air-fuel mixtures which were less lean. Further, since the ethanol is renewably derived, the *life-cycle* emissions of carbon monoxide will be reduced compared to operation on gasoline (E10). As noted earlier, the NOx emissions are still dramatically increased indicating a need to substitute even larger diameter fuel jets to decrease the leanness of the air-fuel mixture.

Finally, student testing found that there was a large variation in results due to manufacturing tolerances and defects inherently present in the low-cost carburetors.

Preliminary evaluations of the course and project were conducted. Overall, all of the students surveyed found the demonstration of the significance of the subject matter to be effective (average score 5 out of 5). This compares to an average score of 4.5 in the department. Even though this project imposed substantial time commitments from students outside of scheduled lecture time, they were overall satisfied with the effort in the course (4.7 out of 5). This compares with a score of 4.3 for the department.

Anecdotal comments included:

- "Hands on actual experience with a very knowledgeable and helpful professor."
- "Definitely take this course. Put some extra time working on the project and you will do great."

5. Conclusion

These projects served to introduce students to the benefits and trade-offs found when operating a small engine on a renewable fuel blend. Students were able to investigate small engine operation when using a high-blend ethanol fuel compared to that observed when using gasoline.

Students were able to measure reductions in the exhaust emissions of some harmful species due to the use of the renewable fuel. Further, since some species of emissions actually increased, it forced students to consider the challenges or negative impacts that need to be overcome when using the renewable fuel.

Different jets were then used, and their influence on the engine emissions was studied. Students were able to observe changes in the levels of exhaust emissions of harmful pollutants under different operating conditions due to the changes in air-fuel mixtures resulting from the different jet sizes.

Students were also exposed to the use of governmental regulations and professional standards practice in conducting the project. Thus, exposing them to the professional and ethical responsibilities expected from practicing engineers.
Finally, based on the results of the preliminary survey, students were motivated to work on this contemporary topic.

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