Combustion of Tertiary Biofuel Blends

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Purpose

This project analyzed the combustion behavior of tertiary blends of biofuels. In particular, the analysis focused on the occurrence of microexplosions (see Project Overview) and the effect these had on the biofuel combustion.

Hypothesis

It was hypothesized that as the relative concentration of soybean oil increased, microexplosions would exhibit increased magnitude while occurring earlier in the droplet burn. This is because the viscosity and low volatility of soybean oil would leave the more volatile fuels trapped within the droplet, which would then superheat and cause microexplosions.

Project Overview

As stated above, this project focused on the presence of microexplosions during the biofuel combustion. Microexplosion often occur in multi-component fuel blends in which the components have large differences in volatility. Initially, the more volatile components quickly burn off the surface of the fuel droplet. Thus, the surface composition is then dominated by the components of lower volatility, and the volatile fuels are trapped within the droplet. As the heating continues, the volatile components begin to superheat and boil, resulting in jets of fuel bursting through the droplet surface. These microexplosions releas many smaller fuel droplets, which exhibit increased atomization and burn rates due to their larger surface area-to-volume ratio compared to the original droplet. Therefore, microexplosions are typically beneficial to combustion behavior.

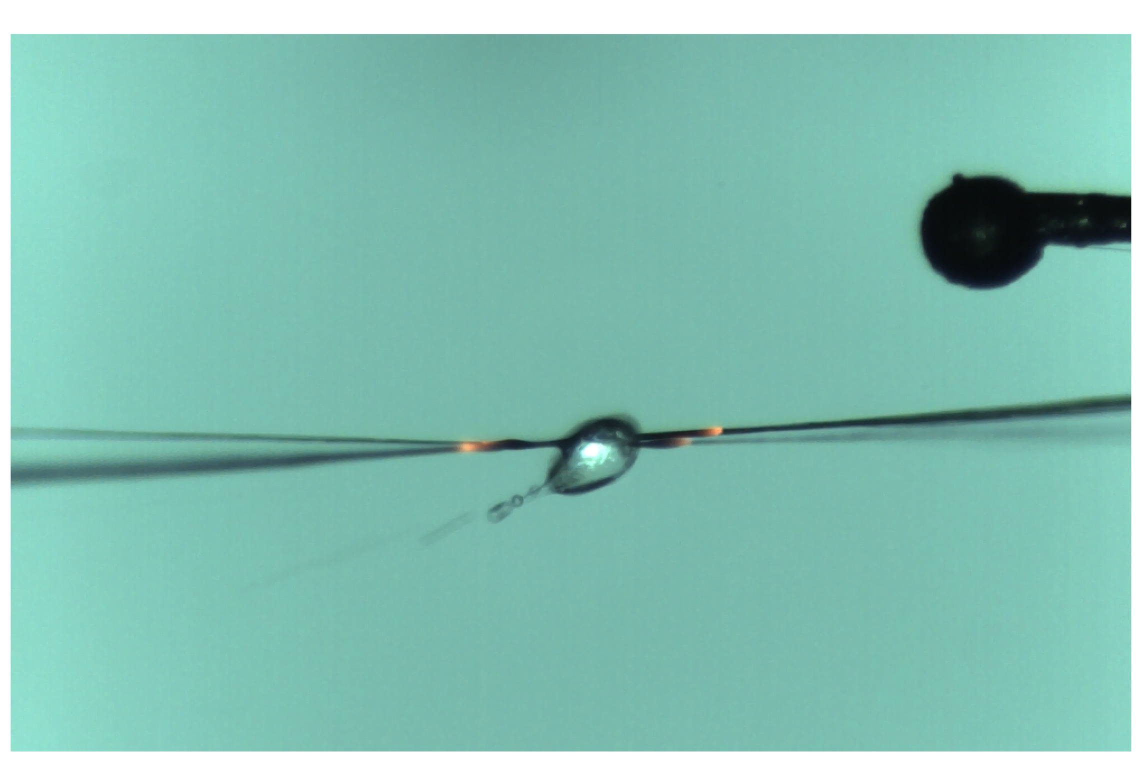

Figure 1: Biofuel droplet during a microexplosion

Biofuel Blends

The tertiary biofuel blends investigated during this project were composed of B99 biodiesel, refined, bleached, and deodorized (RBD) soybean oil, and butanol, mixed together in the following relative concentrations:

1.) 33.3% biodiesel, 33.3% soybean oil, 33.3% butanol

2.) 50% biodiesel, 25% soybean oil, 25% butanol

3.) 25% biodiesel, 50% soybean oil, 25% butanol

4.) 25% biodiesel, 25% soybean oil, 50% butanol

Procedure

A small droplet of the biofuel tertiary blend was placed at the intersection of two ceramic microfibers within a temperature-controlled furnace. Trials were conducted at an ambient temperature of 100°C. At the start of each trial, a heating element rose from the base of the furnace to ignite the droplet. A high-speed camera recorded each trial through a viewing port on the side of the furnace. Two thermocouples, located above and to the side of the droplet, measured the temperature near the droplet. These thermocouples were connected to LabView software, which recorded the temperature data 10 times per second.

After the combustion, a Python-coded program was used to perform frame-by-frame analysis of the recorded video. The program was able to accurately distinguish the droplet from the surroundings, and calculated the cross-sectional area of the droplet for each frame. This data was entered into Microsoft Excel spreadsheets, and then a droplet area vs. time graph was constructed for each trial.

Statistical Analysis

Several statistics were used to analyze the combustion behavior for each trial:

- Time to microexplosion: the time elapsed from the start of the tiral to the onset of microexplosions divided by the time of the entire burn
- Microexplosion duration: the time elapsed during the microexplosion period divided by the time of the entire burn
- Trendline variance (v): the variance of the droplet area vs. time graph from a linear trendline fitted to the graph; a large trendline variance indicates violent microexplosion activity
- Burn rate: the burn rate over the entire trial, in units of mm^2/s
- Burn rate during microexplosion period: also in units of mm^2/s
- Largest microexplosion (A_{ex} / A_0): the area of the droplet during the largest microexplosion divided by the initial droplet area

Results

Blend (relative concentration of each fuel)	Time to ME (t/t_{tot})	ME duration (t/t_{tot})	v	Rate	Rate (ME)	A_{ex}/A_0
Biod33SB33Bu33	0.263	0.54	0.0022	0.532	0.623	0.988
Biod50SB25Bu25	0.316	0.466	0.00097	0.583	0.618	0.865
Biod25SB50Bu25	0.189	0.753	0.00323	0.537	0.646	1.196
Biod25SB25Bu50	0.553	0.277	0.00796	0.571	1.048	1.014

Table 1: Results for each blend. The statistics listed are the averages of the four trials conducted for each specific blend

As shown in Table 1, Biod25SB50Bu25 demonstrated the largest microexplosions (A_{ex} / A_0 values), had the longest and fastest-burning microexplosion period, and the least time elapsed prior to the microexplosion period. However, Biod25SB25Bu25 showed the largest trendline variance.

Additionally, Biod50SB25Bu25 showed the highest overall burn rate. All four blends had a largest burn rate during the microexplosion period than they did for the trial as a whole.

Conclusion

The blend with the highest relative concentration of soybean oil, Biod25SB50Bu25, showed the largest microexplosions and had the longest and earliest-occurring microexplosion period. This is in agreement with the hypothesis. However, according to the trendline variance statistic, Biod25SB25Bu50 exhibited the most violent microexplosion period. Yet Biod25SB25Bu50 also had the shortest microexplosion period of all four blends and was shorter than the microexplosion period of Biod25SB50Bu25 by a factor of nearly three. Therefore, this brief microexplosion period had a small impact on the combustion as a whole despite being relatively violent. Overall, the hypothesis was supported by the experimental results, due to the relatively high duration and magnitude of microexplosions demonstrated by Biod25SB50Bu25.

Also, all four blends showed a significant increase in burn rate within the microexplosion period compared to the burn rate over the entire trial. This supports the theory that microexplosions improve the combustion behavior of multi-component biofuel blends.