Electrorheology Improves Engine Efficiency

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Abstract. Improving engine efficiency and reducing pollutant emissions are extremely important. Here, we present our fuel injection technology based on physics principle that application of electrorheology can reduce the viscosity of petroleum fuels. A small device is introduced just before the fuel injection, producing a strong electric field to reduce the fuel viscosity, resulting in much smaller fuel droplets in atomization. As combustion starts at the droplet surface, smaller fuel droplets lead to cleaner and more efficient combustion. Both lab and road tests confirm that this technology improves fuel mileage significantly.

1. Introduction
Fuel atomization plays an important role in combustion efficiency and pollutant reduction. Since combustion starts at the interface between fuel and air and most harmful emissions are coming from incomplete burning, reducing the size of fuel droplets would increase the surface area to start burning, leading to a cleaner and more efficient engine.

This concept has been widely accepted as the discussions about future engine for efficient and clean combustion are focused on ultra-dilute mixtures at extremely high pressure to produce much finer mist of fuel for combustion [1-3].

Here we present our technology for efficient combustion, based on new physics principle that application of electrorheology can reduce the viscosity of petroleum fuels. A small device is thus introduced, producing a strong electric field to reduce the viscosity of petroleum fuels just before the fuel atomization. This viscosity reduction leads to cleaner and more efficient combustion. Both lab tests and road tests confirm our theory and indicate that such a device improves fuel mileage significantly. The technology is expected to have broad applications.

2. Viscosity Reduction, Atomization, and Test Results.
The principle of our device is sketched in Fig.1a. The fuel flows through two metallic meshes before it reaches the fuel injector. A voltage is applied on the two meshes to produce an electric field of around 1.0 kV/mm between the two meshes. The device consumes very low electric power, lower than 0.1 watt. In our setup, the field direction is opposite to the flow direction, which may help to provide negative charges to the fuel droplets. However, the main function of our device is to reduce the viscosity of the fuel as it passes the electric field [4,5].

Reducing the fuel viscosity improves the fuel injection. As shown in Fig.1b, the injected fuel has a pressure higher than that in the combustion chamber. The droplets are thus split, becoming smaller and smaller after they are emitted from the nozzle. If the droplets are allowed to reach the equilibrium, their radius is given by \( a = 2\gamma /\Delta P \), where \( \gamma \) is the fuel’s surface tension and \( \Delta P = P_i - P_o \) is the pressure difference between the fuel’s inside pressure \( P_i \) and the pressure outside.
the fuel $P_o$. However, in reality, the fuel droplets can never reach equilibrium because the viscosity acts against any deformation of the droplets. Therefore, reducing viscosity of the fuel greatly improves the fuel atomization.

Proper application of electrorheology can reduce the viscosity of liquid suspensions. According to the Krieger-Dougherty formula,\(^6,7\) the effective viscosity of a liquid suspension $\eta$ is related to the viscosity of base liquid $\eta_0$ by 
$$\eta = \eta_0 (1 - \phi/\phi_m)^{-\eta/[\eta]}$$
where $\phi$ is the volume fraction of suspended particles, $\phi_m$ is the maximum volume fraction to pack particles randomly, and $[\eta]$ is the intrinsic viscosity, related to the particle shape. For example, $[\eta] = 2.5$ for spherical particles.

![Figure 1](image)

**Figure 1.** (a) In the device, the fuel flows through two metallic meshes before it reaches the fuel injector. A voltage is applied to produce an electric field of about 1kV/mm between the two meshes. (b) The emitted droplets split to become smaller and smaller.

Utilizing the mismatch in dielectric constant or magnetic permeability between the suspended particles and the base liquid, we can apply an electric field to aggregate the small particles into large ones. Normally, we aggregate nanoscale or sub-micrometer particles into micrometer particles. While this change in rheology does not alter $\phi$, it makes $\phi_m$ increased as a result of increase of polydispersity and average particle size.\(^4,5\) Hence the effective viscosity $\eta$ is reduced.

Here we extend the above physics principle to refinery fuels. In fact, refinery fuels, such as diesel fuel and gasoline, are made of many different molecules. They can be regarded as liquid suspensions if we take the large molecules as suspended particles and the base liquid is made of small molecules. Under a strong electric field, the induced dipolar interaction makes the large molecules aggregate into small clusters. Similarly, this change reduces the effective viscosity of refinery fuels. The above theory was verified by our experiment. As shown in Fig. 2, after application of an electric field of 1kV/mm for about 2 seconds, the diesel oil’s viscosity is reduced by about 9%. While this reduction is not permanent, it provides the opportunity to improve fuel atomization.

In our spray experiment, we used an Accel high impedance fuel injector to simulate fuel injection at engine chambers. When the device was on, the fuel took about 5 seconds to pass the electric field. The spray lasted for 4 milliseconds. The droplets were collected and analyzed for both cases, with the field and without the field. The statistical results for diesel fuel are in Fig. 3. All of them are averaged over 50 tests. The repeatability was quite good with an error less than 5%. In both experiments with diesel fuel and gasoline, the current was less than 10 $\mu$A, i.e. the electric power consumption is below 0.1W. For diesel fuel, the fuel pressure was 13.79 bar (200 lb/in\(^2\)) and the electric field was about 1.0kV/mm in the experiment. The electric field increased the number of droplets with diameter less than 40 $\mu$m dramatically. The number of droplets of diameter below 5 $\mu$m was increased from 5.3% to 15.3% when the device was on. The effect on diesel fuel is very significant. In the experiment with gasoline (with 20% ethanol), the fuel pressure was 7.59 bar (100 lb/in\(^2\)) and the electric field was 1.2kV/mm. The effect on gasoline is also significant. The number of
droplets with diameter around 10 µm was increased from 17.6% to 20.7%, an increase of 18% when the device was on.

Figure 2. The diesel viscosity is reduced by 9% after application of an electric field of 1kV/mm for 2 seconds: from 4.6cp down to 4.18cp. Afterwards, the viscosity is rising to return to the original value.

Figure 3. The size distribution of petreleum fuel in atomization with or without an applied electric field: (a) for diesel fuel and (b) for gasoline (with 20% ethanol).

Because the spray experiment suggests that diesel engines would significantly benefit from our device, we conducted extensive tests with our device on diesel engines. Our recent tests have been done on a 1993 Mercedes-Benz 300D, diesel sedan. The device on the vehicle has two mesh electrodes separated by 1cm for the diesel fuel to pass in 5 seconds. The field is about 1 kV/mm.

A continuous road tests of the Mecedes-Benz 300D for six months showed that our device increased the fuel mileage significantly. On the highway, the device increased the fuel mileage from 32 miles per gallon (mpg) to 38 mpg. In city driving, the improvement of fuel mileage was not as good as that on the highway, but was averaged at 12-15%.

Since our road tests reported significant fuel mileage improvement, we brought the vehicle to a Dynamometer for lab tests, which confirmed the road tests. The typical result is shown in Fig. 4. At a fixed fuel consumption rate close to 500g/h, the Dynamometer measured the engine output. When the device was off, the average power output was 0.3677hp. It increased to 0.4428hp after the device was turned on. This indicates that the power output was improved by about 20.4% at the same fuel consumption rate. The test was repeated for three hours and had an error within 5%.
We also did tests at high fuel consumption (power output about 40-50 hp) and at acceleration, where the improvement was even better than that at low fuel consumption. In our opinion, the low fuel consumption is more representative since the fuel mixes with air better and the different results should be the representative indication between combustion with large fuel droplets and the combustion with small droplets.

![Graph](image_url)

**Figure 4.** The lab test of Mercede-Benz 300D with a dynamometer. The average power output was originally about 0.368hp and increased to 0.443hp after the device was turned on.

### 3. Discussions

Our tests with the Mercedes-Benz indicate that there are optimal values for two parameters, the applied electric field strength and the time duration for the diesel fuel to pass through the electric field. The device with the Mercedes-Benz has 1kV/mm field strength and 5 seconds time duration. It is possible to have some improvement by adjusting these two parameters.

There are a couple of other alternatives to increase fuel efficiency, such as adding additives to the fuel to reduce the viscosity. Unfortunately these fuel additives are quite expensive. The extremely high fuel pressure method, as mentioned before, is still under development and not applicable to current engines. Since our technology, developed on new physics principle, consumes very small power and improves fuel efficiency significantly, we expect it will have wide applications on all types of internal combustion engines, present ones and future ones. By adjusting the values for the electric field and time duration, we could make this technology work effectively for other fuels, such as biodiesel, kerosene, and gasoline.

**Acknowledgements:** This work was supported in part by RAND and STWA.

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