Comment/Rebuttal

Comments on "Electrorheology Leads to Efficient Combustion" by Tao et al.

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In a recent paper published in this journal by Tao et al.,[1] an automotive injection technology that involves application of a strong electric field to the fuel line, which reduces the liquid fuel viscosity causing a finer fuel atomization with smaller droplets, was reported. Further, applying this technology to a diesel-engine-powered car, as well as to a laboratory test engine, the authors claimed that the fuel mileage improved by up to 20%. Unfortunately, this paper has some serious deficiencies, and certain aspects of the experimental methodologies and analysis require clarification: some of the statements are not entirely justified; description of the experiments and experimental protocols are not complete; and the results and conclusions are at odds with established knowledge. The paper gives the impression that the authors may not be familiar with physics and chemistry of combustion in general and internal combustion (IC) engine combustion technology in particular. Given the importance of the subject matter of the paper, the objective of this Comment is to point out the major deficiencies and set the record straight regarding the results and conclusions of the authors.

The authors posit that "because 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 total surface area to start burning, leading to a cleaner and more efficient engine". It is not clear whether this statement is for gasoline engines or diesel engines. In a conventional gasoline engine, the charge in the cylinder before ignition is almost homogeneous; that is, fuel vapor and air are mixed at the molecular level. Gasoline injected into the inlet manifold evaporates when it is carried by the air through the inlet valve into the combustion chamber, and at the start of ignition, the fuel vapor and air are homogeneously premixed.[2] Then, how does improved atomization increase combustion efficiency in gasoline engines?

In a diesel engine, in which the fuel is injected into the cylinder, the combustion mode is non-premixed because of the operational principles of diesels.[3] The diesel spray burns as the fuel droplets evaporate and diffuse into the air. In both modern gasoline and diesel engines, built within the last 10−20 years, combustion efficiency is about 98−99%, if not better. That is, less than 1−2% of the fuel may survive combustion and show up in the exhaust stream as unburned hydrocarbons (HCs) and carbon monoxide (CO). In diesel engines, also present in the exhaust is the particulate matter (PM).

There seems to be a confusion about the thermodynamic efficiency and the combustion efficiency in the paper. The former is defined by the first and second laws (of thermodynamics), whereas the latter is a measure of the percentage of fuels enthalpy of combustion (heating value) that is released as heat. The basic claim of the authors is that the finer atomization provides more efficient combustion. If the combustion efficiency in IC engines is about 98−99% and only a few percent of the fuel may make it to the exhaust, which can be found documented in numerous sources on engines,[4−9] where does the improvement come from to enhance mileage by 20%?

Combustion efficiency η_c can be formally defined as[5]

$$\eta_c = \frac{m\left[\sum_{i,\text{reactants}} n_i \Delta\bar{h}_{f,i} - \sum_{i,\text{products}} n_i \Delta\bar{h}_{f,i}\right]}{m_f Q_{HV}} \qquad (1)$$

where m and m_f are the mass flow rates of reactants (fuel air mixture) and fuel, respectively. n_i is the number of moles of species i in the reactants or products per mass of working fluid, and $\Delta\bar{h}_{f,i}$ is the standard enthalpy of formation of species i at the standard temperature at which Q_{HV}, lower heating value of the fuel (same absolute value as the enthalpy of combustion), has been determined. For practical calculations based on exhaust gas analysis, eq 1 can be expressed as follows:[9]

$$\eta_c = \frac{Q_{HV} - [m_{CO}\Delta h_{f,CO} + m_{HC}\Delta h_{f,HC} + m_{PM}\Delta h_{f,PM} + m_{NO}\Delta h_{f,NO}]}{Q_{HV}} \qquad (2)$$

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where m_{CO}, m_{HC}, m_{PM}, and m_{NO} are the mass flow rates of CO, HC (unburned hydrocarbons), PM (particulate matter), and NO in the exhaust per unit mass of fuel flow rate (g/kg of fuel), respectively, $\Delta h_{f,i}$ values are the standard enthalpies of formation of respective species (kJ/g), and Q_{HV} is the lower heating value of the fuel (kJ/kg). A set of diesel engine combustion efficiency calculations based on eq 2 along with thermodynamic efficiencies are reported in detail in a recently published paper in this journal.[9]

Statements related to the injection pressures in current automotive engines are not entirely correct. In port-injected gasoline engines, as the authors correctly state, the injection pressures are low, because of the relatively high volatility of gasoline and availability of time for spray evaporation and proper mixing with air. In diesel engines, however, current injection pressures are in excess of 1600 bar.[10] The trend within the last 40 years, which saw a continuous increase from about 200 bar in the 1970s to about 2000 bar, has been driven by the efforts to curb PM emissions and NO_x control. The statement of the authors that "... new combustion technology with extreme pressure is still under development and not applicable to current engines because they cannot sustain such high pressures" does not reflect the state of the existing technology.

In spray measurement experiments, a lot of crucial information is missing.[11] For example, what was the distance of the plate covered with magnesium oxide from the injector tip; what was the exposure time? For both diesel fuel and gasoline experiments, the same injector was used. Although the injection pressure was about twice as high for diesel (13.79 bar) as for gasoline (7.59 bar), why are the droplet sizes about 10 times larger for gasoline? Why is the size distribution of gasoline bimodal? The use of impact plates coated with magnesium oxide could be suitable for very dilute droplet clouds like fog, but for fuel injectors, it is prone to significant errors, mostly because of the high number density of droplets. Figure 4 of the paper,[1] which depicts a picture of an impact plate with collected droplets, does not look like something resulting from a fuel spray lasting 4 ms.

Two tests were reported with a Mercedes-Benz 300D. The first test was in the laboratory on a chassis dynamometer. The power output was 0.368 hp without the device and 0.443 hp with the device turned on. Why was the load on the engine selected so low? These power levels correspond to conditions where the car is traveling at a very low speed, such as a few km/h, or idling at standstill. There is no information given about the year of the car, engine size, number of cylinders, and the injection system. The second test with the Mercedes-Benz sedan was a road test lasting 6 months. Road tests are not reliable and do not constitute scientific evidence because the environmental variables (such as driving style, wind, traffic flow, ambient temperature, and atmospheric pressure) have significant impact on vehicle fuel consumption and exhaust emissions. If the fuel consumption and exhaust emission levels of the engine of a vehicle are to be determined precisely and accurately, then the vehicle must be tested in an environmentally controlled test cell under the standardized conditions, which provide an accurate reflection of actual driving conditions. Testing is based on a standardized driving cycle, in which various accelerations, decelerations, idle phases, and standstill periods have been selected, such as the federal test procedure (FTP).[12,13] This is the only means of ensuring that individual fuel consumption and exhaust emission tests remain comparable.

In an archival journal paper in the field of energy and fuels, the author(s) should give sufficient details, so that a competent worker could repeat the experiments. If the method is new and unpublished, all of the needed details must be provided, but if the method has been previously published in a standard journal, then the literature reference should be given. Questions such as "why", "how", and "how much" should be precisely answered by the author(s) and not left for the reader to puzzle over.

The application of a strong electric field might reduce the fuel viscosity and lead to finer atomization, but there is no room that finer atomization would improve combustion efficiency by 20%. The authors do not present any credible evidence in the paper to support their claims, and these claims and conclusions violate the first law of thermodynamics.

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