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Boric acid as a lubricating fuel additive – Simplified lab experiments to understand fuel consumption reduction in field test

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ABSTRACT

In field tests, a boric acid based fuel additive has led to reduced fuel consumption. The reduction was substantial, an average of 6 and 10% in passenger cars and diesel generators respectively. Aiming towards improved understanding of mechanisms behind the fuel saving, three methods to mimic the effect of the additive in the piston-ring/cylinder contact have been evaluated. A reciprocating cylinder/flat configuration with ball bearing steel against grey cast iron was used, and it was lubricated with base oil. The different methods were as following: A) repeated spraying of a small amount of the boric acid solution onto the surfaces, B) predeposition of a boric acid layer on the flat surface and C) a combination of method A) and B). The three methods all showed effects of the additive, spanning from about 20% to 50% reductions (in the latter case, from roughly 0.1 to 0.05 in coefficient of friction averaged over the stroke). The greatest potential of the additive was seen with local coefficient of frictions lower than 0.020 in tests at room temperature with *Method C*. This means a reduction of around 75% compared to the lowest levels measured for the reference tests run without the additive. The most stable friction test was *Method A*, where a small amount of boric acid solution was repeatedly sprayed onto the lubricated sliding surfaces. In this type of test, friction reductions of roughly 20% and 40% were found at 100 °C and room temperature respectively. The tribological and chemical mechanisms of boric acid in this test configuration are yet not fully understood and more studies are needed. However, the observed poor stability of the tribofilms containing boron and oxygen complicates such activities.

1. Introduction

Recent estimates give that one third of the fuel energy in an average passenger car is lost due to friction in the engine, transmission, tires and brakes, and only 21.5% of the energy is used to move the car [1]. For heavier vehicles, as trucks and buses, the same number is 33% and 34% respectively [2]. The transport sector accounts for approximately 20% of the total energy use in the world and 18% of the greenhouse gas emissions [1]. 73% of the total energy consumption in transports is consumed by road transport (light duty vehicles, trucks and buses), 10% by aviation, 10% by marine and 3% by rail [3].

To have a chance to fulfill the 2030 climate and energy framework of the European Commission and the Paris Climate Agreement, consumption of fossil fuels from transports must be reduced. The 2030 climate and energy framework targets greenhouse gas emission reductions of at least 40% (from 1990 levels), at least 27% share for renewable energy and at least 27% improvement in energy efficiency [4]. At the Paris Climate Conference 2015, 195 countries agreed to reduce their greenhouse gas emissions to limit the global warming well below 2 °C (above pre-industrial-levels) [5]. The climate and energy goal may feel difficult to accomplish when considering the expected increase in transportation demand. Even in an optimistic scenario, fossil fuels might remain the primary energy source for transports for the next two decades [3]. However, CO_2 emissions can be reduced in several ways, e.g. by using new technologies to reduce friction. Since the friction losses in the piston assembly in an engine accounts for 45% of the total engine friction losses [1], a large amount of work has already been focused on their reduction. Suggested technologies include advanced surface texturing, coatings, lubricants and additives. In their scenario Holmberg et al. [1] estimate that such technologies could enable reductions of CO_2 emissions with 290 million tonnes in the next 5–10 years and 960 million tonnes in the next 15–25 years.

One candidate for this friction reduction is boric acid ($B(OH)_3$), a solid lubricant that is abundant in nature and thereby cheap. Erdemir et al. [6] showed in 1990 that its layered structure provides lubricity. Low tangential forces are needed for sliding to

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occur within the material due to the weak interaction between the layers. Boric acid is also considered as relatively safe and has been used for numerous consumer products as well as in industrial applications. Detergents, insulation, metal working fluids and fertilizers constitute some examples. Some health concerns have been raised due to observed developmental and reproductive toxicity effects when laboratory animals are exposed to high levels of boric acid [7]. However, no such toxic effects have been observed in studies on highly exposed human populations, e.g. workers in mines.

Boron compounds in tribology have been reviewed by Shah et al. as well as by Spikes [8,9]. Among many approaches, addition of various concentrations and sizes of boric acid particles to lubricating oils have been tested [10,11] and commercial products with emulsified boric acid particles are available. However, boric acid is not soluble in oil and dispersions of particles are often associated with agglomeration, which so far have rendered such products unsuccessful for use in engines. To prevent agglomeration, surfactants can be added to the lubricant to create a dispersion that is stable over a longer period of time. Such a lubricant was studied by Kim et al. [12] with resulting friction reduction. However, the long-time stability of the dispersion was not investigated.

Sawyer et al. [13], instead studied the effect of boric acid powder delivery into stainless steel sliding contacts without oil lubrication. A coefficient of friction below 0.1 was achieved and the wear was reduced by 100 times or more.

Another possibility is to use boric acid as a fuel additive, which is the focus of this study. To the best of our knowledge, no similar studies have been performed. The studied fuel additive is a commercial product consisting of boric acid dissolved in a solvent, mainly consisting of ethanol. It is mixed with the fuel to reduce the friction in the engine and thereby decrease the fuel consumption. In field tests, performed by an independent consultancy company, the fuel consumption in cars and stationary diesel generators was reduced with an average of 6 and 10%, respectively, when using the fuel additive [14,15]. The test details are summarized in Section 1.1.

Aiming towards an improved understanding of tribological and chemical mechanisms behind the fuel saving, we examined the effect of the fuel additive in a simplified lab test mimicking the line contact of the reciprocating piston-ring/cylinder contact. Three methods to add the fuel additive into the sliding contact were tested. In all cases, a thin film of base oil was used as a simple representation of the engine oil. These simplified tests did not include mimicking of the combustion, gas pressure, fuel presence and oil replenishment.

1.1. Field test details

Field tests of passenger cars and diesel generators with and without using the boric acid based fuel additive have been performed by an independent consultancy company [14,15].

1.1.1. Passenger cars

Five different cars were used, chosen to represent an average of the current vehicle population. Both diesel and gasoline fueled engines, as well as both manual and automatic gearboxes were included. The 469 km test route was designed to represent general European driving conditions, with highways, country roads, mountain roads and urban driving. An experienced test leader controlled and managed the test rounds, vehicles, refueling and adding of the fuel additive. Fuel consumption, speed and weather conditions were measured during the test. Average speed (78.2 km/h) and driving time was the same throughout the test rounds, as well as the road and weather conditions with temperatures between +1 °C to +6 °C. The cars were driven in a caravan, and changed places during the test. Every test round started in a heated garage to avoid cold starts and the coolers and brakes were cleaned before each test. Other factors that were controlled before and during the test include tire pressure, oil condition, etc. All cars drove four rounds without the additive, followed by a running in period and finally four rounds with the additive, which was mixed 1:1000 in the fuel, according to specification.

All of the cars exhibited lower fuel consumption when the additive was used, with an average reduction of 6%.

1.1.2. Diesel generators

Two Atlas Copco QAX 12–60 (50 Hz) diesel generator sets, placed indoor, were used to test the effect of the fuel additive. Both generators were run at 80% (9 kW), 50% (6 kW) and 30% (3 kW) of their maximum capacity. The power outputs were monitored during the tests. Each of the three operating capacities was first run without the fuel additive in five hours and then with the additive mixed in the diesel (1:1000). Using the fuel additive, the fuel consumption was reduced with an average of 10%.

2. Materials and methods

2.1. Test procedure

A reciprocating cylinder on flat configuration was used to represent the piston-ring/cylinder contact. The tests were performed at room temperature and 100 °C. The high temperature was selected to represent a typical temperature at the cylinder wall, close to the top dead center and room temperature was chosen as reference. Three approaches to mimic the effect of fuel additive on the friction in the piston/cylinder contact were investigated, see Fig. 1. They differ with respect to how the boric acid additive is introduced into the tribosystem:

A) Repeated spraying of a small amount of the boric acid solution onto the surfaces.
B) Predeposition of a boric acid layer on the flat surface.
C) Predeposition of a boric acid layer plus spraying, i.e. a combination of A) and B).

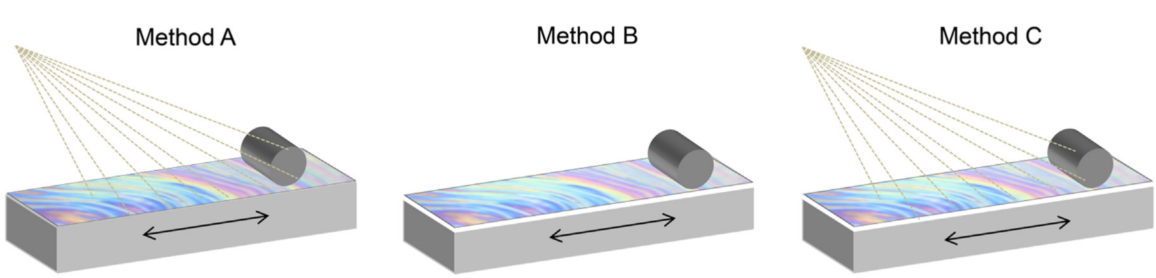

Fig. 1. Illustration of the three evaluated approaches. *Method A*) repeated fuel additive spraying, *Method B*) boric acid as a predeposited solid film on the flat surface and *Method C*) a boric acid film plus repeated fuel additive spraying. A thin oil film (PAO8) was predeposited onto the flat surface.