Additives for rapeseed oil fuel – Improvement of the low temperature flow behaviour

Johannes Kastl, Edgar Remmele and Klaus Thuneke, Technologie- und Förderzentrum (TFZ), Schulgasse 18, D-94315 Straubing

Abstract

In previous works, aiming at the optimisation of rapeseed oil fuel quality, the possibility of using additives has not been researched sufficiently. During the first part of the research project ‘Additives for Rapeseed Oil Fuel’, a test method was developed that allows the investigation of the low temperature flow behaviour by measuring the dynamic viscosity in a rotational viscometer. This laboratory test method provides a fast and simple way for rating the flow behaviour at low temperatures. With this test method, two additives could be found for the improvement of the low temperature flow behaviour of rapeseed oil fuel.

Within the second part of the research project ‘Additives for Rapeseed Oil Fuel’ these promising additives were investigated further in engine tests and long term storage studies in regard to their practical suitability.

The efficacy of the additives IRGAFLO 649P (BASF SE) and Mathy Plus DA/W (MVG Mathé-Schmierstofftechnik GmbH) in regard to the cold flow behaviour shown in the laboratory could be verified by measurements on an actual tractor fuel system. For rapeseed oil fuel containing one of these two additives, a significantly increased fuel delivery rate compared to pure rapeseed oil fuel, was obtained at temperatures below -5 °C. Using K03, the fuel delivery rate even at -15 °C was clearly above the minimum fuel delivery rate required for running the tractor’s engine in idle. The results are in good agreement with the results that were obtained previously in the laboratory, using the newly developed test method.

The use of both additives is in compliance with the requirements of the German fuel standard DIN 51605. A negative influence of the additives could not be seen during the measurements on a tractor test stand, neither on lawfully limited emissions nor on non-regulated components like aldehydes or polycyclic aromatic hydrocarbons. Additionally, the storage of the fuel at +5 °C in the dark for up to 12 months does not result in a loss of fuel quality or a lower efficacy of the additives.

The full research report (Kastl, Remmele, & Thuneke, 2014) can be downloaded at www.tfz.bayern.de (German only).

Keywords: rapeseed oil, additives, viscosity, low temperature flow behaviour, biofuel

1 Introduction

Rapeseed oil fuel (ROF) is used as an alternative to diesel fuel, mainly in the agricultural sector and in stationary CHP plants. It is non-hazardous to waters, nontoxic, easy to handle and has a much smaller carbon footprint compared to fossil diesel fuel (European Parliament and Council of the European Union, 2009). Due to the differences between rapeseed oil fuel and fossil diesel a technical adaption of the engine system is required. The specifications of rapeseed oil for the use as fuel in engines capable of running on vegetable oils are defined in the German standard DIN 51605. The use of additives to improve properties of rapeseed oil
fuel is explicitly allowed if there are no negative effects on the operating performance or the effectiveness of the exhaust gas treatment. Also the water hazardousness of the mixture must still be classified as “non-hazardous to water” according to the German “Administrative Regulation on the Classification of Substances hazardous to waters into Water Hazard Classes” (VwVwS 2005). In contrast to fossil diesel fuels, the use of additives is not common with rapeseed oil fuel, yet.

2 Problems and objective

Rapeseed oil fuel differs from fossil diesel fuel amongst others in regard to the low temperature flow behaviour (Figure 1). The flow behaviour can be improved by heating the fuel in the engine system, but even so the use of rapeseed oil at low temperatures is limited, especially at cold start or at low load conditions. It has not been thoroughly researched whether the low temperature flow behaviour can be improved by the use of additives. Compared to fossil diesel fuel, vegetable oils show a different chemical structure and composition. Because of that it was in dispute if additives suitable for fossil diesel fuel can improve the properties of rapeseed oil fuel at all.

![Figure 1: Kinematic viscosity of rapeseed oil fuel and diesel fuel at different temperatures](image)

3 State of knowledge

One goal of the first project part (Kastl et al., 2014) was to investigate the effectiveness of additives, which are commercially available for the use in fossil diesel fuel, fatty acid methyl esters (FAME, “biodiesel”) or vegetable oils, in regard to improving the low temperature flow behaviour of rapeseed oil fuel. To achieve this goal a test method suitable for rapeseed oil fuel was to be developed, because existing test methods for diesel fuel were not appropriate. The test method allows the investigation of the low temperature flow behaviour by measuring the dynamic viscosity in a rotational viscometer. This test method provides a fast and simple way for rating the flow behaviour at low temperatures. With this test method, two additives could be found for the improvement of the low temperature flow behaviour (Kastl & Remmele, 2011a, Kastl & Remmele, 2011b, Kastl & Remmele, 2011c; Kastl et al., 2014).
Besides the cold flow behaviour, a second goal of the first project part was the improvement of the ignitability by using additives. By measuring the ignition delay in a device using a constant volume combustion chamber (Attenberger & Remmele, 2003a, Attenberger & Remmele, 2003b), two additives could be identified that bring about a significant increase of the ignitability of rapeseed oil fuel. Within the second part of the research project ‘Additives for Rapeseed Oil Fuel’ these promising additives were investigated further in engine tests and long term storage studies in regard to their practical suitability. First results in regard to the engine tests have been published elsewhere (Kastl, Remmele, & Thuneke, 2013).

4 Materials and methods

In the preceding research project (Kastl et al., 2014) the efficacy of 21 additives, including ignition improvers, cold flow improvers as well as combinations of both, has been investigated in laboratory experiments. Two additives showed a positive influence on the low temperature flow behaviour, namely IRGAFLO 649P from BASF SE (labelled K03) and Mathy Plus DA/W from MVG Mathé-Schmierstofftechnik GmbH (labelled K07). These additives were used for the tests in the second project part. The concentrations were the same as in project part 1, namely 0.27 vol% for K03 and 0.19 vol% for K07. Rapeseed oil fuel (ROF) in compliance with DIN 51605 has been used as base fuel for the additive-ROF-mixtures and also as reference.

In project part 1 two ignition improvers were showing promising results, these were Chimec 9133 (labelled Z09) and Lubrizol OS62648 (labelled Z13). Both of the ignition improvers were used in combination with one of the cold flow improvers (K03), to check whether using both types of additives simultaneously has an influence on the efficacy in regard to the cold flow. These fuels were labelled as K03+Z09 and K03+Z13, respectively. The concentration of the cold flow improver in these combinations was the same as above. The ignition improvers were used in concentrations of 0.19 vol% (Z09) and 0.10 vol% (Z13).

To research the influence of the additives on the cold flow behaviour of rapeseed oil fuel the actual fuel system of the tractor used for the emission testing was installed in a cold chamber. Figure 2 shows the schematic setup. Basically the setup contains the low pressure part of the fuel system, beginning at the fuel tank (capacity 50 litres) up to the place where the high pressure fuel pump normally is installed. Instead of delivering to the high pressure fuel pump, the fuel is being pumped in the collection tank. By placing both the fuel tank and the collection tank on scales, the fuel delivery rate can be calculated with good accuracy.

![Figure 2: Schematic representation of the experimental setup used inside the cold test cell](image)
The cold test chamber, in which the fuel system is mounted, can control the temperature in a range between +10 °C and -25 °C. In the tests six discrete temperatures (+10 °C / 0 °C / -5 °C / -10 °C / -13 °C / -15 °C) have been selected. Each fuel mixture was cooled down to the next temperature level overnight. When the target temperature had been reached, three measurements were carried out, with a pause of two hours after each measurement to let the temperatures reach a stationary state again. Each test runs for a period of 5 minutes. By comparing the courses of the different pressure values and scale weighing between the three measurements, outliers can be identified. Nevertheless, in our tests there were no measurements to discard, as each triplicate was in good agreement.

After measuring at -15 °C, the setup was allowed to warm up slowly to -5 °C and then to 0 °C, where three more measurements each were conducted. So the influence of cooling down and warming up could be examined further.

The complete volume of test fuel needed for all the measurements is filled into the fuel tank at the beginning of the test run, so all of the measurements are using the exact same batch of test fuel.

The emission tests were conducted with a John Deere 6930 Premium tractor, which has been modified by the machine supplier to run on vegetable oils. The experimental setup has been described before in detail (Emberger, Schreiber, Thuneke, Remmele, & Pickel, 2011; Kastl et al., 2013; Thuneke, Gassner, Emberger, & Remmele, 2009).

5 Results and Discussion

Figure 3 shows the resulting mass flows into the collection tank for each of the tested ROF-additive-mixtures as well as the blank sample. As can be seen, all mass flows are comparable to the blank sample. Also, the repeated measurements are in good agreement with each other, as can be seen from the small range. An influence of the additives was not to be expected at this temperature, as their target temperatures are below 0 °C.

![Figure 3: Mass flow into the collection tank for each of the tested ROF-additive-mixtures and the blank sample, measured at a temperature of +10 °C](image-url)
In contrast to +10 °C, the influence of the additives K03 and K07 on the mass flow can be seen at a temperature of -13 °C, shown in Figure 4. The blank sample and the mixtures containing one of the ignition improvers only are showing a significantly lower fuel delivery rate than mixtures containing K03 or K07. This behaviour starts to show at -5 °C (not shown) and increases further at -15 °C, where only mixtures containing K03 could be pumped at all. The fuel containing K07 was still liquid, but could not be pumped through the system. One reason could be that the filters were clogged by the forming of bigger particles caused by e. g. crystal growth inside the liquid, thus preventing a considerable mass flow. For the other mixtures, all of the measurements had to be cancelled after one minute as no mass flow could be seen.

Using K03, the fuel delivery rate even at -15 °C was clearly above the minimum fuel delivery rate required for running the tractor’s engine in idle. The results are in good agreement with the results that were obtained in the laboratory during project part 1, using the newly developed test method (Kastl & Remmele, 2011d).

A second result of the laboratory measurements was the ratification of the hysteresis of rapeseed oil fuel, which means that there is a difference between the dynamic viscosity measured at a given temperature depending on whether the sample was being cooled down or warmed up to that temperature. Therefore, another goal of the cold flow measurements in the second project part was to examine if this hysteresis can also be verified in practical use. Figure 5 shows the mass flows of the ROF-additive-mixtures at a temperature of -5 °C. In the picture the results measured during cooling down are compared with results gained when the fuel system was being warmed up after it had been cooled down to -15 °C. The results state clearly that there is difference between cooling down and warming up. Also, the additives K03 and K07 are not only effective at keeping rapeseed oil fuel in a liquid state at low temperatures. They also significantly increase the fuel delivery rate when the fuel system is being warmed up.

The use of additives for rapeseed oil fuel is regulated in the German standard (DIN 51605). One requirement is that there is no negative influence on the operating behaviour and the emissions. Thus, the additives K03 and K07 were investigated in this regard on the tractor test stand. As can be seen in Figure 6, the use of these additives has no influence on the emissions of the regulated emission components nitrogen oxides NOₓ, carbon monoxide CO,
hydrocarbons HC and particulate matter PM in the test cycle according to ISO 8178-4 (DIN EN ISO 8178-4). The results for the non-regulated emissions like laughing gas N\textsubscript{2}O, formaldehyde or acetaldehyde also show no significant influence of the additives on the overall emission behaviour, apart from small differences in single test phases. Same holds true for the analysis of the emissions of polycyclic aromatic hydrocarbons PAH.

Figure 5: Mass flow into the collection tank for each of the tested ROF-additive-mixtures and the blank sample, measured at a temperature of -5 °C during cooling down and during warming up

* not measured

Figure 6: Specific emissions of nitrogen oxides, carbon monoxide, hydrocarbons and particulate matter for the tested mixtures, shown as mean and range of three measurements each
6 Conclusions

In the previous research project ‘Additives for Rapeseed Oil Fuel’ two additives could be found, which show promising laboratory results in regard to the improvement of the cold flow behaviour. The efficacy of the additives K03 (concentration 0.27 vol%) and K07 (concentration 0.19 vol%) shown in the laboratory could be verified in measurements on an actual tractor fuel system in the course of this project. For rapeseed oil fuel containing one of these two additives, a drastically increased fuel delivery compared to pure rapeseed oil fuel was measured at temperatures below -5 °C. Using K03, the fuel delivery even at -15 °C was clearly above the minimum fuel delivery rate required for running the tractor’s engine in idle.

The influence of the additives on operating behaviour and emissions of a tractor were thoroughly examined on a tractor test stand. Also, the possibility of storing the additivated fuel for a time frame of 12 month was evaluated. The use of both additives K03 and K07 is in compliance to the requirements given in the German fuel standard DIN 51605 as well as in respect to the emissions. A negative influence of the additives could not be seen, neither on lawfully limited emissions nor on non-regulated components like aldehydes or polycyclic aromatic hydrocarbons. Also, the ROF-additive-mixtures are still classified as “non-hazardous to water” according to VwVwS 2005. Additionally, the storage of the fuel at +5 °C in the dark for up to 12 month does not result in a loss of fuel quality. The efficacy of the additives is preserved almost completely.

Based on these results, the additives K03 or K07 can allow and increase the usage of rapeseed oil fuel during colder periods and can extend the possible range of application for rapessed oil fuel in regard to colder climatic zones or altitudes.

In the first project part, a test method was developed that allows the investigation of the low temperature flow behaviour by measuring the dynamic viscosity in a rotational viscometer. This test method provides a fast and simple way for rating the flow behaviour at low temperatures. The results of this method are in good agreement with results obtained on an actual tractor fuel system in a cold test chamber. Thus, the results from the laboratory method can be applied to everyday practice.

The full research report (Kastl et al., 2014) can be downloaded at www.tfz.bayern.de (German only).

7 Acknowledgements

The authors would like to thank the Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e.V.) for financing the works (support code 22012211) as well as the John Deere GmbH & Co. KG for providing the tractor.

8 References


