How biodiesel/diesel fuel blends affect spray breakup and emissions

I. Gostic*, C. Senghaas*, M. Willmann† and M. Wensing††
* L'Orange GmbH, Stuttgart, Germany
† MTU GmbH, Friedrichshafen, Germany
†† Lehrstuhl für Technische Thermodynamik LTT
University of Erlangen, Erlangen, Germany

Abstract

This paper presents the correlations between the increasing proportion of biodiesel in biodiesel-diesel-blends and the spray breakup of the fuels in a cold chamber (L'Orange GmbH) as well as the emissions in a heavy duty application (MTU Friedrichshafen).

Introduction

Fossil fuels are increasingly supplemented by biofuels for climatic protection reasons as well as for limited ressources. The rapid development in the usage of biodiesel-diesel-blends is the main motivation of this study, aiming to better understand physical effects in spray breakup and chemical effects leading to altered emission genesis when biofuels are used. Current studies provide very differentiated results. Zhang et al. [1] have observed that the spray cone angle of the biodiesel decreases to only a half of the diesel spray cone angle. Suh et al. [2] show that the penetrations of diesel and biodiesel do not differ significantly. The higher viscosity and the surface tension lead however, to a reduced atomization quality of the spray. The reduced atomization quality of the biodiesel spray induces smaller flame temperature and results in reduced NOx-emissions [1]. Opposed to that thesis are the results of the studies [3-5] where the usage of biodiesel leads to the increased NOx-emission. The rise of NOx-emissions is explained by the increasing oxygen content of the biodiesel-diesel-blends [6]. Using biofuels, soot and hydrocarbon emissions decrease strongly in comparison to the diesel operation. This reduction in HC emissions can be found in many current studies [1,2,5,6,8] giving a uniform picture and indicating the enhanced oxygen content of the biodiesel to be the main reason for this reduction.

Materials and Methods

First, a spray diagnostic investigation was conducted in a cold injection-test-chamber. The cold chamber is a high pressure cell with constant volume of 34l. It is filled with the inert gas nitrogen. The injection nozzle D_{Basis} has a typical sachole nozzle design for common rail injection system in heavy duty engines. The nozzle has 6 spray holes and a flow value Q100 of 5100ml/min. The optical unit of the test stand consists of a CCD-camera and stroboscope lighting (xenon lightnings) providing shadow images of the injected spray. The in-house-software MIA automatically evaluates the images and delivers various geometrical spray data. A nozzle mask was used to shield 5 of 6 spray holes, so that only one isolated spray cone penetrates in the chamber. This isolated spray cone is examined optically. Second, a combustion investigation was made on single-cylinder-engine with 4l displacement. Emission values were measured in three for full engine relevant operating points of EU heavy duty diesel engine cycle: one full load point C1_1 and two part-load points C1_7 and C1_4. The base Diesel B0 and biodiesel FAME B100 as well as the blends B5, B10, B20 and B50 were examined. The designation BX stands for X% biodiesel percentage by volume in the base diesel fuel.

Results and Discussion

The blending of the diesel B0 with biofuel FAME B100 leads to the decrease of the soot and the unburned hydrocarbons emissions. An increase of the NOx emissions was observed only with very high percentage of biodiesel blend (50%) and with pure biodiesel FAME B100 (**Figure 1**). The lowest HC and soot values were measured with pure biodiesel FAME B100. In all three operating points investigated, the decrease of the soot is approximately proportional to the volume percentage of the biodiesel blend. The enhanced oxygen content in the biodiesel blends promotes exothermal oxidation reactions, which probably lead to reduced soot emissions. Increased exothermal oxidation reactions also contribute to reduce unburned hydrocarbons HC. Due to intensified exothermal oxidation reactions the temperature in the combustion chamber increases and as expected the NOx-emissions rises. However, this is only valid for the high biodiesel blend B50 and the pure biodiesel B100 in the

* Corresponding author: ilona.gostic@lorange.com

comparison to the diesel B0 in the load points C1_1 and C1_7. Despite the increased oxygen content the NOx output of the biodiesel blends B5, B10 and B20 is in all points lower than the NOx value of the diesel B0. The spray cone angle of the low biodiesel blends (B5, B10 and B20) is in the not ballistic phase (t > 300µs) approx. 10% smaller than the spray cone angle of the diesel B0. Although the density rises with the further increase of the biodiesel percentage (B50 and B100), it was found, that the spray cone angle is not reduced but grows on the level of the diesel B0, again. This is the effect of the strongly increasing viscosity of the biodiesel blends, whose influence more than compensates the density influence. The high viscosity of B50 and B100 leads to increased shearing stress between the fuel and the spray hole surface. The speed gradient at the spray-hole outlet increases with the increase of the friction. The momentum exchange between inside and outside speed at the spray-hole outlet leads to an enlargement of the spray cone angle. This dynamic process is called progressive profile relaxation.The intensity of the momentum exchange depends on the magnitude of the speed gradient and can even lead to circular replacements at the spray edge (**Figure 2**). The occurrence of the profile relaxation enhances the primary spray breakup and the atomization quality. This leads to an enlargement of the premixed flame zone and to less soot and the higher thermal NOx-genesis.

Summarizing it was found that the composition of the biodiesel-diesel-blend has an important influence on the spray breakup, the air/fuel-mixture formation and the resulting emission output, while the effect in the resulting emissions not in all cases is proportional or monotonically increasing with the biofuel content in a blend. The output of NOx-emission depends significantly on the physical fuel properties and the spray breakup.

References

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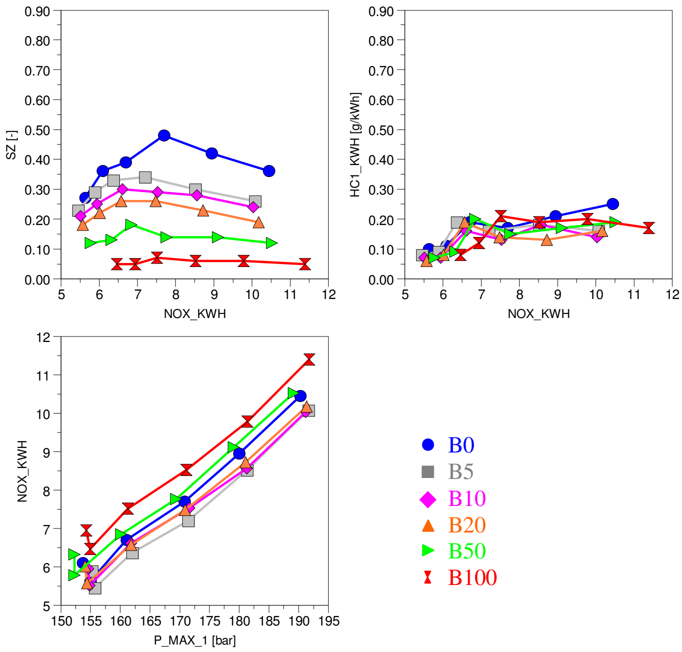

Figure 1. Emissions at the full load point C1_1 (variation: start of injection)

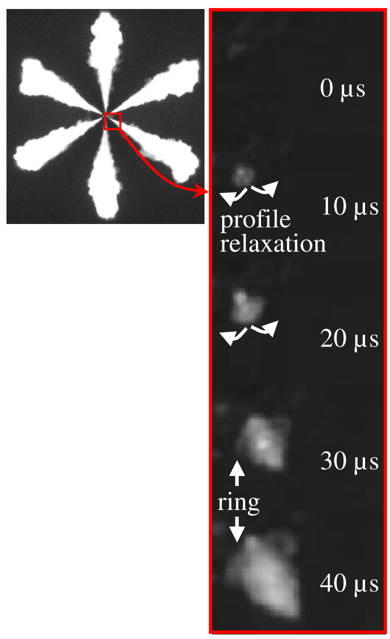

Figure 2. Profile relaxation at 1800bar injection pressure