

Effect of Different Nozzle Geometries using Pure Rapeseed Oil in a Modern Diesel Engine on Combustion and Exhaust Emissions

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ABSTRACT

Rapeseed oil can be a possible substitute for fossil fuel in Diesel engines. Due to different physical properties of rapeseed oil like higher viscosity and higher compressibility compared to diesel fuel, rapeseed oil cannot be easily used in conventional Diesel engines without modifications. Especially incomplete combustion leads to deposits in the combustion chamber and higher exhaust gas emissions. These unfavorable characteristics are caused primarily by insufficient mixture preparation.

The adjustment of the injection system will improve the mixture preparation and the combustion of a Diesel engine, operated with rapeseed oil. The nozzle geometry is the main parameter of the whole injection system chain to realize a better combustion process and so higher efficiency and lower exhaust gas emissions.

To elaborate the effect of different nozzle geometries on the combustion behavior and exhaust gas emissions, experimental investigations using a modern single-cylinder heavy-duty engine were performed. The influence of rapeseed oil on the exhaust gas emissions was investigated and compared to analyze the interaction of a high viscous fuel like rapeseed oil with the nozzle geometry of a modern diesel injector. Since ultra-fine particles are of significant importance concerning Diesel engine emissions, analyzing the particle size distribution got special attention during these investigations.

INTRODUCTION

Internal combustion engines are not only the guarantor for today's and the future's individual mobility but also one of the most important pillars of our industry due to its extensive application area. Further reducing the exhaust gas emissions and saving fossil source of energy, hence reducing carbon

dioxide emissions that are responsible for the greenhouse effect, are the main topics in combustion engine research.

The use of biofuels will reduce the carbon dioxide accumulation in the atmosphere, because these fuels have an almost closed CO₂ circuit if they are produced sustainably. Concerning the atmosphere, this circuit can be considered as nearly closed [1][2] and there are almost no consequences on the greenhouse effect. Pure rapeseed oil is one potential substitute for regular fuel that can be used in Diesel engines. Pure rapeseed oil has also no negative impact on the groundwater and can therefore be easily used in water protection areas and it needs considerably less energy and additives for production than other biofuels.

MOTIVATION

There are different physical properties of rapeseed oil compared to diesel fuel that are the reason why conventional Diesel engines cannot be easily operated with rapeseed oil without any modifications. For example, the viscosity of rapeseed oil at ambient temperature is ten times higher than that of diesel fuel. As a result the vaporization behavior of rapeseed oil is completely different, leading to larger fuel droplets and therefore to an overall lower surface area. This is in contrast to a good atomization, which is based on the formation of a large surface area and a good interaction and mixing of fuel and air [3][4]. This negative property of rapeseed oil is the main reason for higher exhaust gas emissions. Due to this poor spray atomization behavior of all vegetable oils, an increased fuel entrainment leads to higher oil dilution. The carbonization in the combustion chamber and deposits at the injectors and valves are further drawbacks, which are occurring by using rapeseed oil with injection systems designed for conventional diesel fuel. Only preheating rapeseed oil cannot solve these problems sufficiently [5]. To realize a good

combustion process with high efficiency and low exhaust gas emissions, the whole fuel path from the fuel tank to the injectors have to be considered. An adjustment of the injection system and therefore improving the mixture preparation is the main factor to achieve a good combustion with high efficiency and low exhaust emissions.

A variation of the nozzle geometry offers significant potential to optimize the spray propagation and therefore the atomization and combustion for the use of rapeseed oil. Therefore, the impact of the nozzle geometry on the mixture propagation and the combustion of rapeseed oil is the key topic of a research project, which is performed at the Institut für Kolbenmaschinen at the KIT. The aim within this research project is to analyze the combustion of rapeseed oil in modern heavy-duty Diesel engines. Apart from preventing deposits in the combustion chamber, the major goal is to achieve a good combustion with lowest possible emissions.

The research project is divided in a fundamental research part and an operational test part. Main points of the first part are the reduction of deposits in the combustion chamber, optimization of the spray propagation and the combustion process. The second part will deal with testing the first parts results under practical conditions in a railcar.

In this paper, the results of the fundamental research are presented, where the influences of rapeseed oil and different nozzle geometries on the combustion behavior, the exhaust gas emissions and the particle size distribution are investigated. The particle size distribution has become an important evaluation criterion for Diesel engine emissions, as it is assumed that particles of the nuclei mode are respirable and can be dangerous for human health. The experiments were carried out in a modern single-cylinder heavy-duty engine with common-rail-injection.

TEST CONFIGURATION

FUEL

The experiments were performed with pure rapeseed oil conforming to the German fuel standard for rapeseed oil (DIN 51605 [6]) which is effective since October 2010. For the purposes of comparison, diesel fuel according to DIN EN 590 was used. In table 1 the main properties of the used fuels are shown.

Rapeseed oil shows a minor lower heating value than diesel fuel but higher density. Therefore, the energy content by mass of rapeseed oil is nearly the same compared to diesel fuel. Due to the neutrality to groundwater and the very high flash point, rapeseed oil is easy to use concerning transport and storage.

However the viscosity of rapeseed oil at ambient temperature is ten times higher than that of diesel fuel (figure 1). This causes a worsening of flow rate and problems at cold start but it can be improved by

preheating the rapeseed oil up to 75 °C. Higher temperatures would lead to a decomposition of the rapeseed oil.

	Rapeseed oil	Diesel fuel
standard	DIN 51605	DIN EN 509
cetane number [-]	47	52
viscosity [mm ² /s] (40°C)	34.3	2.7
density [kg/mm ³] (15°C)	919.5	819.3
low. cal.value [MJ/kg]	37.1	42.9
flash point [°C]	238	66

Tab.1: Relevant fuel properties

Another effect of the higher viscosity and the higher surface tension of rapeseed oil is the impact on the vaporization behavior of the fuel. The vaporization behavior is completely different, leading to larger droplet sizes and therefore to an overall lower surface area. This is in contrast to a good atomization and will lead invariably to an incomplete combustion and higher emissions.

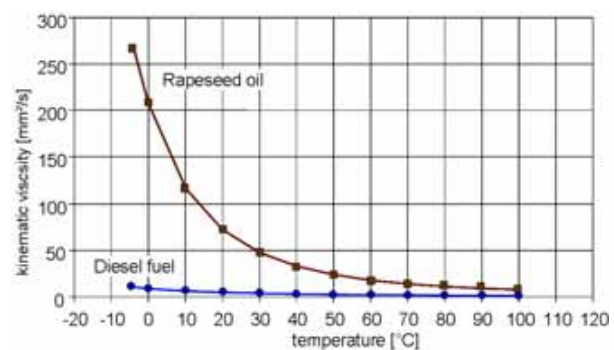


Fig.1: Kinematic viscosity of rapeseed oil and Diesel fuel

TESTBED AND ENGINE

For the experiments a single-cylinder research engine was selected. This engine is derived from a modern heavy-duty Diesel engine for ships and trains. The technical specifications are listed in Table 2.

displacement	2.2 liter
compression ratio	17.5 : 1
fuel pressure	up to 1800 bar
supercharging	6 bar abs.
maximum speed	2400 rpm

Tab.2: Specification of the single-cylinder research engine

The engine was equipped with an intake air conditioning system and a cooled exhaust gas recirculation system. The complete testbed configuration can be seen in figure 2. A in-cylinder pressure indication and several measuring points for pressure and temperature are adapted. The exhaust gas was analyzed with a standard exhaust gas analysis system, which is able to measure the HC; CO, O₂ and NO_x emissions as well as an AVL 415s smoke meter.

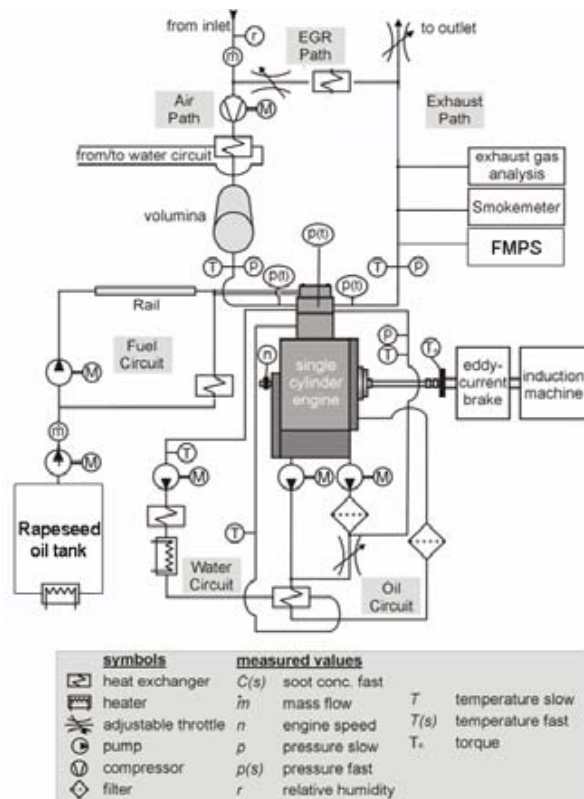


Fig.2: Testbed configuration

FMPS

Since ultra-fine particles are of significant importance concerning Diesel engine emissions, they deserve special attention. A TIS Fast Mobility Particle Sizer (FMPS) model 3091 (figure 3) which is able to measure particles with diameters in the range from 5.6 to 560 nanometres was used.

The exhaust-gas was sampled out of the exhaust system, diluted and cooled. Thereafter it was drawn into the inlet of the measurement system continuously. The particles in the exhaust-gas were charged at a charger and led to the high voltage electrode via filtered sheath air. The electrical field at electrodes deflected the particles outward according to their electrical mobility. The lower the electrical mobility of a particle is, the lower is the electrometer the particle will strike. There the charge was transferred which allows a concentration measurement of the particles [7]. With this, a spectrum of the particle size distribution can be created.

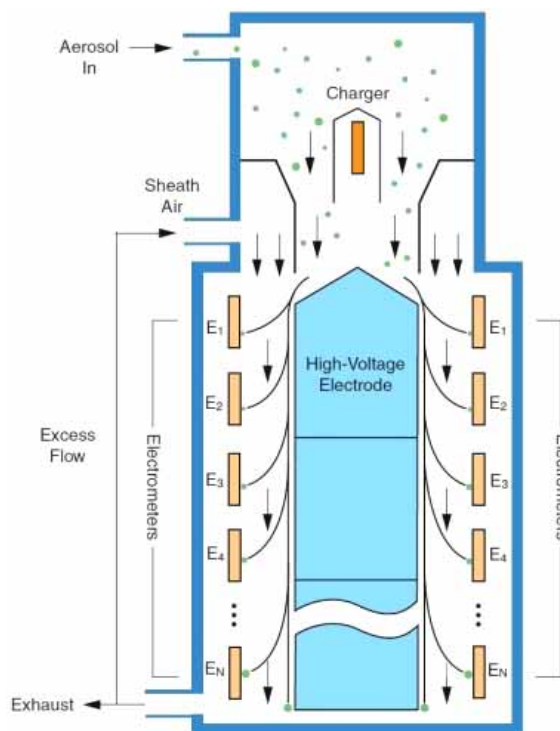


Fig.3: Operating principle of particle size distribution scanner [7]

FUEL SYSTEM

To realize the necessary fuel pressure and to constitute high flexibility, a common-rail system was used. The system was equipped with a Bosch CP3.3 high-pressure pump and a Bosch single storage injector. This injector was chosen due to the practical orientation of these investigations (cp. part two of the research project) and limits the maximum fuel pressure to 1800 bar.

To lower the viscosity of the rapeseed oil, a heater was implemented in the fuel tank to keep the rapeseed oil at 75 °C.

NOZZLES

The aim of these investigations was to show the influence of rapeseed oil and different nozzle

nozzle n°	A	B	C	D	E
bore diameter [µm]	275	265	240	245	255
K factor	0	1	2	1	2

Tab.3: Specification of tested nozzles