The Influence of Fuel Properties on Spray Propagation, Atomization and Evaporation

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Abstract
Understanding the relationship between physical properties and spray behavior is essential for the development of future synthetic diesel fuels. Therefore, in the present work the fuel influence on the spatial and temporal spray structure is studied experimentally using multiple methods. The macroscopic spray propagation is investigated by means of visualization measurements. Additionally, a two component PDA is used for a simultaneous study of the velocity field and the particle size distribution at different axial and radial positions inside the spray. A parametric study is conducted on the effects of fuel properties. Specific fuels of various substance classes were chosen to represent a wide range of potential synthetic fuels. In detail, Butanol, Ethanol, Dodecane, Iso-Octane and Tetrahy-drofurfuryl Alcohol are analyzed. In order to quantify the influence of evaporation on the droplet size reduction the investigations are performed under different ambient conditions. A significant influence of the hydrodynamic and thermodynamic properties on the macroscopic and microscopic spray structure is detectable. As previously known, close to the nozzle the droplet size is mainly controlled by surface tension, density ratio and viscosity through primary and secondary breakup. It was found that further downstream the fuel properties relevant for evaporation are the main factors for further droplet size reduction.

Introduction

World-wide increasing carbon dioxide emissions, a rising energy demand and limited availability of fossil energy resources constitute major challenges today's societies are facing. In this context the project 'Tailor Made Fuels from Biomass' takes an interdisciplinary and inverse research approach towards new synthetic fuels based on biomass feedstock. In clustering expertise from natural and engineering sciences a model-based design procedure is pursued. A mixture of well-defined candidate fuel components with tailored properties will be derived from the requirements of the combustion process. The long-term objective is to describe the optimum combination of fuel components and related combustion behavior. As a prerequisite to the engine combustion process, the injection system and the related strategy need to be adapted to the potential fuel properties. Besides alkanes and alcohols, furans as potential chemicals from biomass provide a basis for the iterative and inverse development process. In order to determine desirable and tolerable properties of tailor-made fuels a systematic investigation of the fuel property influence on spray propagation is inevitable.

Materials and Methods

In this work the influence of fuel parameters on spray propagation, atomization and evaporation is investigated using Butanol, Ethanol, Dodecane, Iso-Octane and Tetrahydrofurfuryl Alcohol (THFA) as fuels for covering a wide range of chemical properties. The corresponding sprays are investigated with complementary measurement systems. In detail, visualization measurements and phase doppler measurements provide macroscopical and microscopical information. The diesel set-up is composed of a pressurized chamber and a diesel common rail injection system. For basic investigations on fuel spray behavior, optically accessible pressurized vessels are used as test facilities. This decoupling from the engine combustion processes ensures a detailed and repeatable investigation of the influence of specific parameters on fuel-mixture generation. The chamber can be configured according to the needs of the desired investigation. The ambient conditions in the pressurized chamber have been set to temperatures of 600 and 800 K and a pressure of 3 and 5 MPa. A diesel common-rail system is used with an injection pressure of 72 MPa and an energizing time of the injector of 400 μs. The nozzle orifice diameter is 109 μm.

Results and Discussion

The measured penetration lengths, droplet size and velocity distributions are used to understand the fuel dependence of spray phenomena in detail. Considering conditions relevant for a diesel engine, the droplet size

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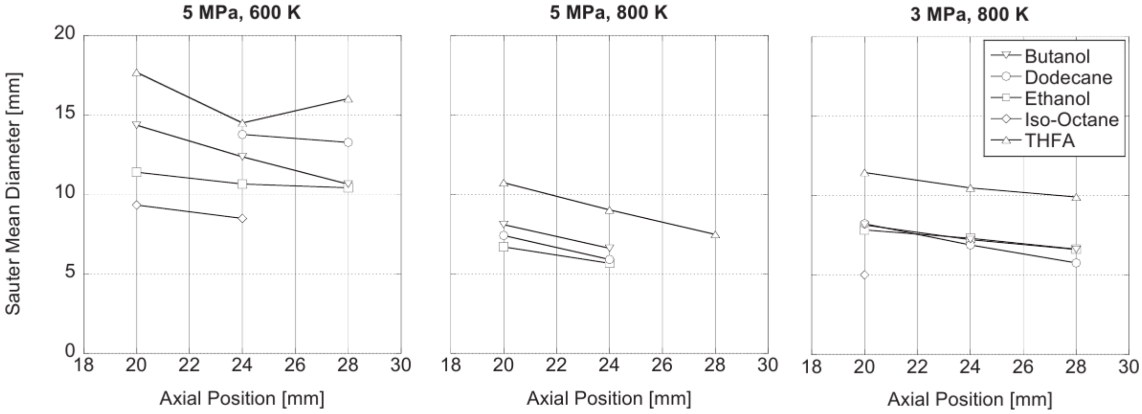

Figure 1. Sauter mean diameter on the spray axis for different ambient conditions.

distribution depends on both evaporation and liquid breakup. Besides the thermodynamic properties the evaporation time is mainly influenced by the initial droplet diameter. Smaller droplets lead to an increased heat and mass transfer due to a larger effective surface. Figure 1 shows the mean Sauter diameter on the spray axis. For THFA the combination of less-pronounced atomization due to a high surface tension and slow evaporation (due to a high density) leads to the biggest droplets compared to the other fuels. On the other hand Ethanol has small droplets by reason of its small surface tension. One can conclude that the surface tension is the most relevant parameter for the initial droplet diameter whereas further diameter reduction mainly depends on the thermodynamic properties. Especially for Ethanol the reduction of the droplet diameter is lower than for the other fuels due to its high enthalpy of vaporization. The low evaporation rate leads to a comparatively long penetration length of the spray tip. Figure 2 shows the influence of ambient conditions and fuel properties on the radial velocity distribution in the quasistationary region of the spray 20 mm downstream the nozzle. Both Iso-Octane and THFA are characterized by a high axial velocity even though they have oppositional fuel properties. Iso-Octane has the lowest and THFA the highest density of all investigated fuels. On the one hand a low density leads to a high outlet velocity (following the Bernoulli law) and on the other hand to a strong deceleration of the droplets due to aerodynamic forces. Following the assumption that aerodynamic forces affect the spray core by means of droplet interaction both effects neutralize each other depending on the axial position.

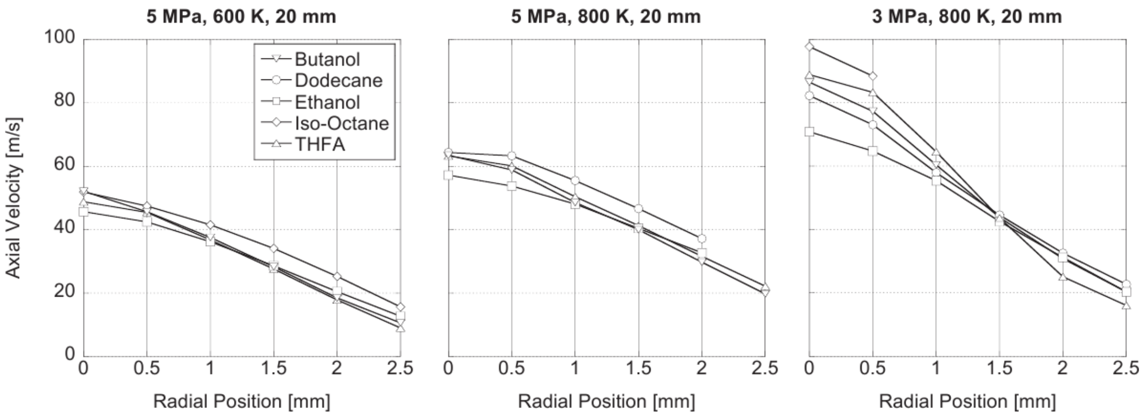

Figure 2. Axial Velocity for different ambient conditions.

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