Fuel injection temperature determination and effect on the injection process for different alternative fuels

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Abstract. The influence of the fuel temperature on injection using a pump-line-nozzle system of a medium speed diesel engine was studied for different fuels. The impact of the temperature was significant, suggesting that accurate knowledge of the injected fuel temperature is necessary in order to provide quantitative spray data. The experiments are performed in a constant volume combustion chamber with temperature control of the chamber and the injector cooling. The injector is both in contact with the chamber walls and injector cooling, resulting in a temperature gradient inside the injector. A method to correlate the fuel temperature with chamber and injector cooling temperature is proposed resulting in increased accuracy for the injected fuel temperature.

1. Introduction

The spray process in internal combustion engines is a very popular topic and has been studied for several decades, especially for direct injected engines. The research has to resolve two main issues: the understanding and the prediction of the process's behavior. Experimental contributions have been made by several different types of experiments such as engine tests, optical engines, constant volume combustion chambers and rapid compression machines.

Many modelers make use of experimental results to evaluate their results or to define the initial boundary conditions. Unfortunately, different experimental setups and methods might result in different solutions for the "same" conditions (Meijer 2011). Some initial parameters are not measured or difficult to control in experiments.

One of these parameters is the injected fuel temperature. In a single shot setup, as the one considered in this work, the fuel temperature will be defined by the chamber temperature and cooling temperature of the injector, since all fuel of the single injection is already available inside the injector. From the behavior of the injection system with different fuels and temperatures it is found that accurate knowledge of the fuel temperature is required for spray measurements. A second goal of this work is to minimize the uncertainty of the injected fuel temperature.

2. Experimental setup & Measurement conditions

Experiments have been conducted in a constant volume combustion chamber (cfr. Fig.1 on the left), baptized as the Ghent University Combustion Chamber I (GUCCI) (Galle 2012). Here, N_2 up to 80bar is used as the inert ambient gas. The chamber has a cubical shape with an internal volume of 4.1l and optical access is assured by quartz windows with a diameter of 150mm. The fuel injector is located at the top of the chamber in such way that the investigated spray propagates along the space diagonal of the chamber. The combustion chamber can be electrically heated up to 200°C. The injector holder is equipped with a cooling circuit to control the injected fuel temperature. The implementation is shown in Fig.1 on the right.

The temperature gradients are measured with a 1.5mm K-type thermocouple along the injector axis. The original injector needle was replaced a dummy needle with a central hole for the thermocouple.

The different measured conditions are summarized in Fig.2. Note that the conditions in which the injector coolant temperature T_c exceeds the ambient chamber temperature T_a are not considered, since this is not relevant for engine research. The artificial points were added to increase the accuracy of the correlation.

The injection system is characterized by cam angle based injection pressure and needle lift measurements.

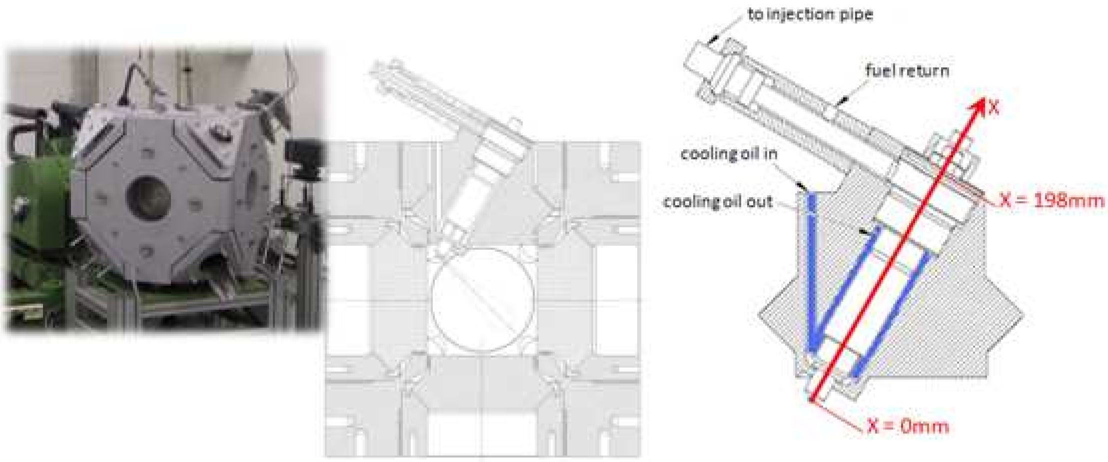

Fig. 1. (left) Constant volume combustion chamber, (right) injector cooling

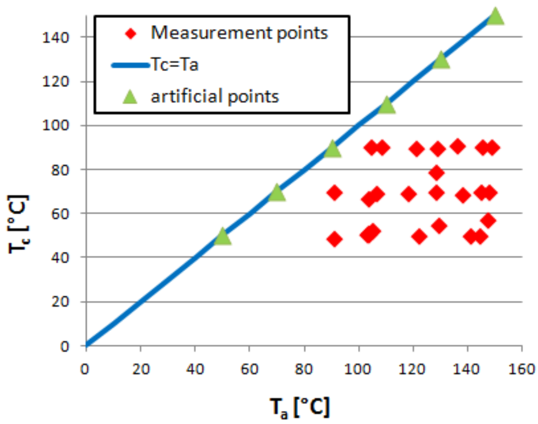

Fig. 2. Measurement points (red diamonds) for the chamber T_a and coolant temperature T_c. The blue line represents $T_a = T_c$. The green triangles represent 'artificial' measurement points used for $T_f(T_a,T_c)$ correlation

3. Results & Discussion

3.1 Fuel temperature influence on the injection system

The injection pressure profile was measured for different fuels (diesel, biodiesel, animal fat and vegetable oils) and fuel temperatures. The fuel temperature was found to affect the maximum pressure significantly, especially for the fuels with highest bulk modulus and viscosity. The result for rapeseed oil is shown in Fig. 3, indicating a difference in maximum pressure of 200bar for a fuel temperature range of 65°C.

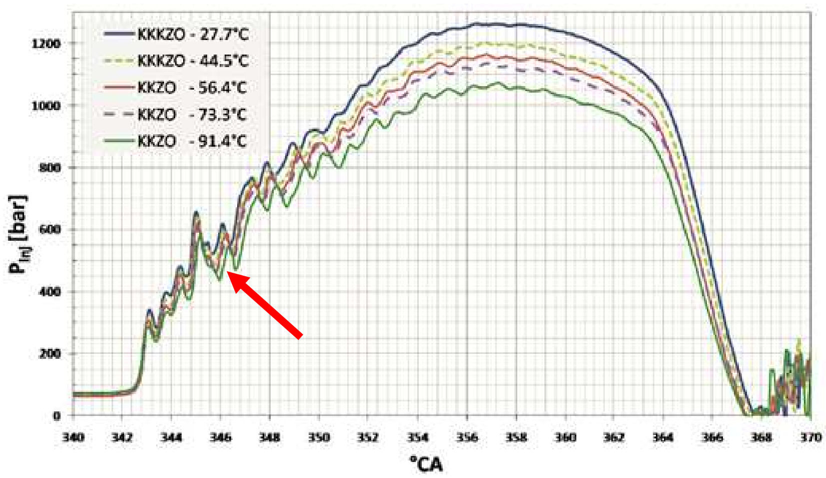

Fig. 3. Injection pressure for rapeseed oil for different fuel temperatures (P_a=80bar, 1000rpm)

The decreasing bulk modulus with increasing temperature allows the fuel to compress more, resulting in lower pressure rise and maximum injection pressure. Needle lift (arrow in Fig. 3) is slightly delayed while the injection duration is shortened with increasing temperature; the decreasing bulk modulus (and speed of sound) with temperature, delays the pressure build-up at the needle. Since the time of ignition is important for both emission and power output, knowledge of the injected fuel temperature is thus necessary to obtain quantitative data.

3.2 Temperature gradients inside the injector

Figure 4 shows some results of the fuel temperature gradient along the x direction of the injector (see Fig.1, right). Every temperature point was weighed with the estimated volume in the injector to arrive to the fuel temperature T_f (the gray area in Fig. 4 represents the relative volume in the injector; the solid line is the cumulative volume). The correlation $T_f(T_a,T_c)$ was found with the Levenberg-Marquadt algorithm (More 1978). The artificial points were added to increase the accuracy of the correlation; an accuracy of better than 1°C was found between the predicted and measured average fuel temperature. The difference between temperature on a certain position in the injector and the average temperature T_f depends on T_a and T_c and was between 0.5°C en 1.4°C, resulting in a sufficient prediction of the fuel temperature. The local temperature difference inside the injector was expected not to exceed 3°C.

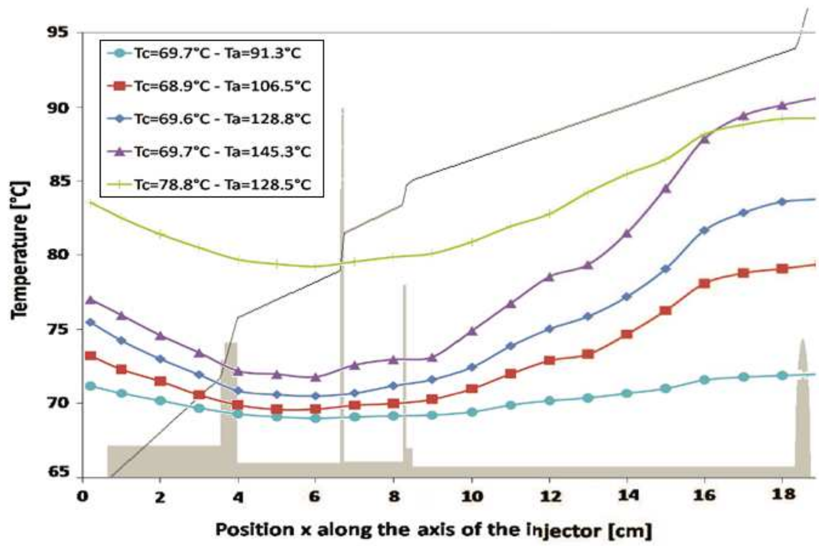

Fig. 4. Temperature gradients along the injector axis for different measurement

4. Conclusions & Future perspectives

- Even small changes in fuel temperature result in a significant influence on the injection pressure of a PLN system. This is mostly the consequence of the temperature depending bulk modulus and viscosity of the fuel.
- The injected fuel temperature can be estimated more accurately, knowing the gradients inside the injector and the relation between fuel, chamber and coolant temperature.
- The measured fuel temperatures were for steady state conditions. The influence of combustion needs to be investigated. The same method can be applied to estimate the fuel temperature as accurately as needed.

5. References

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