

Time and Spatially Resolved Measurements of the Interaction of Combusting Diesel Spray and Walls with Elevated Temperatures

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ABSTRACT

The interaction between a combusting diesel spray and a wall at temperatures of 700K and 735K was investigated in a combustion chamber using optical measurement techniques. The temperatures were chosen as they appear in the range of the maximum piston surface temperatures of the latest production engines. Combustion was investigated with a dual camera setup, which is designed to take simultaneous pictures of the UV flame luminosity (FL_UV) and the visible flame luminosity (FL_VIS). The FL_UV is used to measure lean or stoichiometric combustion. The FL_VIS is capable of detecting the thermally excited soot. Mie scattering is used to study the liquid fuel phase.

It was found that there is almost no FL_VIS signal visual in the 700K case, but a very strong signal in the 735K case. In general, one might expect that higher wall temperatures lead to an improved mixture formation and, consequently, lower soot production. However, the opposite was detected. The reason for this is that the ignition delay is much larger at the colder wall and, therefore there is more time for premixing. Also the FL_OH signal is much weaker at the lower wall temperature. This can be explained by the fact that the OH-radical is not only a marker of lean combustion, but also a marker of soot oxidation.

In addition, the ignition delays are compared at different measurement settings. It can be assumed that the ignition delays are shorter in the hot wall cases and also shorter at the higher ambient gas pressures. The comparison between unaffected spray and wall-influenced spray shows that ignition delays for the unaffected spray cones are always smaller or equal to those for wall-influenced ignition. Moreover, the differences between ignition delays tend to be smaller at the higher wall temperatures.

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INTRODUCTION

In the past decade, automobile manufacturers have been increasingly moving towards downsized engines. The reason for this is that downsized engines offer considerable advantages in fuel efficiency and, therefore have lower CO₂ emissions. However, there is less space for the propagation of fuel and combusting flames to spread out without being influenced by comparatively cold cylinder and piston surfaces. To achieve future pollutant limit values it is

necessary to understand the mechanisms that take place in the combustion chamber. The spray-wall- and the flame-wall-interaction is an important part of that, since it has major impact on the premixing, the flame propagation and the emissions [1, 2, 3, 4]. The influence can be either positive or negative [5, 6]. If liquid fuel film is present on the wall of the combustion chamber, the emissions of unburned hydrocarbons (UHC) and soot increase significantly. This can be explained by the poor evaporation of the fuel film, insufficient mixing of the fuel with oxygen and

consequently, a very sooty combustion. A positive effect of the spray-wall-interaction can be explained in cases of enhanced evaporation and mixing. If droplets hit the wall with high kinetic energy, the droplets are shattered into small droplets in certain circumstances. The increased surface and interaction with the swirl flow enhance the evaporation and the mixing process of the fuel. In order to explain the physical context, the impingement of a single droplet shall first be explained. Figure 1 shows the dependency of the evaporation time on the wall temperature (T_W).

In this paper, the influence of wall temperature on elevated levels of impinging diesel spray and combusting diesel spray and walls is investigated time and spatially resolved. To the best of our knowledge these measurements have been carried out for the first time using cutting-edge diesel engine conditions.

Dependency of the Evaporation Time on the Wall Temperature

In Fig.1 the dependency of the evaporation time on the wall temperature is shown. The boiling temperature is marked with T_B . The Nukiyama temperature (T_N) is the temperature at which the heat flow between the wall and the fluid is at maximum. For this reason the evaporation time is at a minimum.

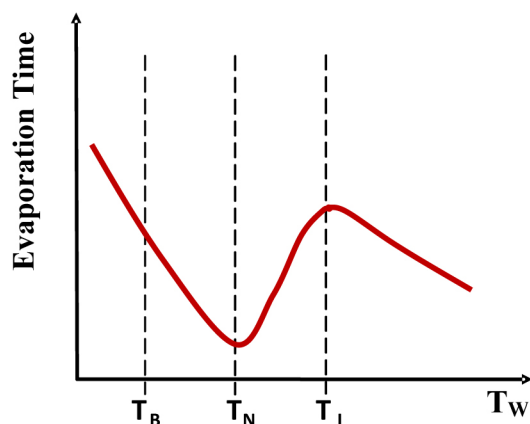


Figure 1. Dependency of the evaporation time on the wall temperature

Yusmady et. al observed minimum evaporation points for diesel at roughly 630K wall temperature at ambient pressure [7]. Stanglmaier et al. found that the temperatures described are shifted to higher values at increased ambient pressures [8]. At Leidenfrost temperature (T_L) there is an isolating vapour film between the droplet and the wall. Therefore, evaporation time has a local maximum. Huang et.al. [9] tested different fuels in a Direct Injection Spark Ignition engine test. They found that the most volatile fuel, which has its T_L close to the piston temperature produces high UHC. Fuels with T_B near the temperature of the pistons produced much lower UHC.

Weber Number

For the characterization of the spray-wall-interaction under engine-like conditions the Weber (We) number has to be considered:

$$We = \frac{u_{dr}^2 * d_{dr} * \rho_{fl}}{\sigma_{fl}} \quad (1)$$

Depending on the We number different behaviour can be observed at wall temperatures higher than T_L (Fig. 2). If the We number is smaller than 10, an elastic rebound of the droplet can be observed. In the range between a We of 10 and 100 a development of single secondary droplets occurs. For We numbers higher than 100 the impacting droplet bursts on the surface. If the T_W is lower than T_N , wall wetting occurs both for low and for high We . The only difference is that for high We numbers small satellite droplets are formed.

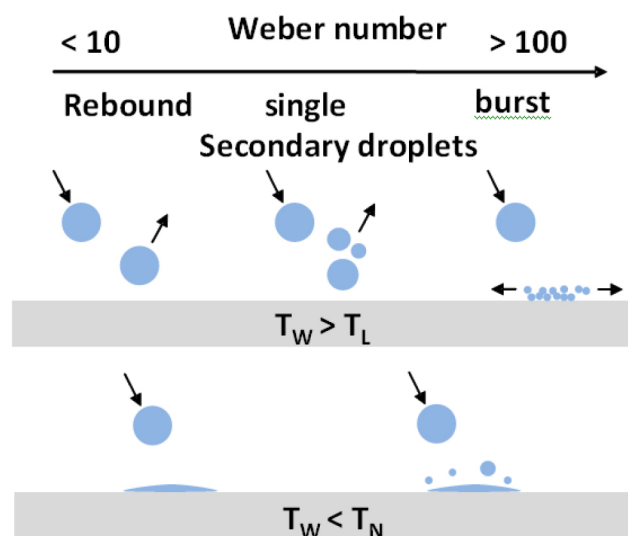


Figure 2. Characteristic arrays of droplet impact with a flat and dry wall dependent on the Weber number at surface temperatures higher than T_L [10]

Spray-Wall-Interaction in Diesel Engine Like Conditions

It is possible to draw inferences about the behaviour of a spray from the behaviour of single droplets. But it has to be considered that the physical background is much more complicated for a spray. Different droplets have different diameters, velocities and We numbers. Furthermore, the influence of ambient conditions like inconsistent turbulent flows, heterogeneous temperatures and pressures have to be considered (Fig 3).

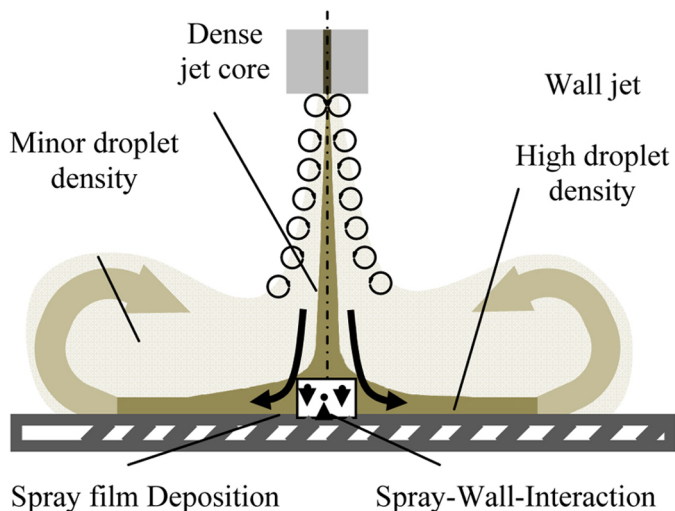


Figure 3. Spray-Wall-Interaction model for diesel like conditions [11]

Even before the impact of the spray on the wall, small vortex structures occur next to the dense jet core. After the impact, a wall jet with high droplet density is formed parallel to the wall. Under certain conditions a spray film is formed. Most droplets are transported in a radial movement after impact, until the wall jet breaks down into a vortex structure. This vortex structure is formed immediately after impact and is considered to be the follow-up of the vortex structures at the spray front. Droplets with different masses are separated by the centrifugal force. The droplet density at the center of the vortex is low. Afterwards the size of the vortex structure increases and moves in radial direction away from the impact point.

Schünemann [12] studied the influence of the injection pressure (p_i) on the Spray-Wall-Interaction in diesel engine like settings (Table 1) using Mie-scattering and phase-doppler-anemometry. It was shown that at higher injection pressures the droplet diameter decreases due to higher primary atomization, and the droplets move with higher velocities. Near the wall there are approximately as many droplets flying towards the wall, as droplets moving the other way. This indicates that there is a reflection of droplets at the wall. At higher injection pressure, the wall jet vortexes move faster at a higher rotational speed.

Lower wall temperatures cause low gas temperatures above the wall, consequential there are higher gas densities and viscosities. The droplet sizes are significantly increased due to slower evaporation, and have higher forces of inertia. As a result, the radial droplet velocity is higher and causes a higher rotational speed of the wall jet vortex in the cold wall case.

Table 1. Test conditions used by Schünemann

Injection pressure in MPa	40 / 80 / 120
Wall temperature in K	393 / 623
Chamber temperature in K	653
Nozzle-wall distance in mm	20
Injected fuel quantity in mm ³	40

Meingast et al. [6] also performed studies about the consequences of an elevation of the injection pressure at diesel engine conditions (Table 2). Mie scattering and PDA measurements were performed to determine a decrease in droplet diameter, an increase in droplet velocity, and an improved mixture with higher injection pressure.

Table 2. Test conditions used by Meingast

Injection pressure in MPa	Up to 135
Wall temperature in K	600
Chamber pressure in MPa	5

Egermann and Taschek [13] examined the effect of a rail pressure variation on the air-fuel-ratio using spontaneous Raman scattering. The measurements were done under typical diesel engine conditions (Table 3).

Table 3. Test conditions used by Egerman and Taschek

Injection pressure in MPa	80 / 135
Wall temperature in K	423 / 553
Chamber pressure in MPa	5
Chamber temperature in MPa	723

The measurements were done at a distance of 2mm above the wall, directly above the impact region as well as inside the wall jet. They found out that by an increase of the rail pressure the mixture formation is significantly improved. If the same fuel mass is injected at different p_i , the increased turbulent mixing between fuel vapour and ambient air, and the shorter injection duration are responsible for a faster mixture formation at higher p_i .

The influence of the wall temperature is also investigated in [6], [11] and [13]. In [6] and [11] smaller droplets and an improved mixture formation have been found with higher wall temperature. This is a consequence of the faster evaporation after the spray impact. Furthermore, it is observed that the wall temperature has only little influence on the local air-fuel ratios [13], when it is raised from 423K to 553K. Propiolek [14] verified at p_i of 110bar and ambient conditions of 1bar and 298K that there is no wall wetting at T_w higher than T_L .