Semi-Empirical Model to Calculate Spray Length Considering Evaporation Effect

A. Flügel*, L. Zigan, I. Schmitz, M. Wensing and A. Leipertz
Lehrstuhl für Technische Thermodynamik (LTT)
Friedrich-Alexander-University Erlangen-Nuremberg
Am Weichselgarten 8, 91058 Erlangen, Germany
and
Erlangen Graduate School in Advanced Optical Technologies (SAOT)
Paul Gordan Str. 6, 91052 Erlangen, Germany

Abstract

In order to improve air/fuel mixture, fulfilling the European Emission Standard and to reduce fuel consumption, injection and combustion systems have to be improved. The understanding of spray formation and evaporation has been the great challenge of last years in modern gasoline direct-injection (GDI) and Diesel engine as well as aerospace technology. For engine development, the most essential spray data are the cone angle, axial and radial penetration under various injection conditions. The purpose of this work is developing a semi-empiric spray model which is able to predict a single jet penetration of a plain orifice injector, typically from a Diesel or GDI atomizer by different temperatures and pressures based on dimensional analysis theorem. Equations were found to prognosticate the spray penetration and an exponent factor which is able to correct the evaporation effect. The results are satisfactory and the improvement of calculation is possible by adding phenomena such as drag force and air entrainment.

Introduction

The spray geometry, velocity and evaporation time are corresponding factors of the air/fuel mixture quality and consequently combustion quality. Great investments have been done worldwide in different diagnostic techniques and computer simulation in order to understand the spray behavior but nevertheless the issue remains. Over the years, injections systems were developed to acceptable level. Nowadays, the search for a better understanding of the spray behavior is looking for the levels required by international standard of pollutants. Therefore, the scientific community uses various research techniques to characterize the spray. Experimental methods are the reference basis of all researches. Ultra fast laser and very sensitive and accurate detectors are utilized to characterize the spray geometry, droplets distribution and their speeds and sizes. Laser-induced fluorescence is also used to detect the evaporation of spray. Mostly due to lack of time for large variety of experiments and the improvement of computer abilities, numerical simulations like CFD has achieved the preference of many researchers, as well as analytical and semi-empirically models, but they should be validated experimentally.

Materials and Methods

The aim of the present work is to formulate a semi-empiric model to predict the penetration of a single jet generated from a plain orifice atomizer. Many different physical parameters such as temperature, pressure and injector geometry as well as fuel physical-chemical properties influence the spray behavior. The combination of all parameters creates a large matrix of possibilities that transforms the spray in a complex problem. The semi-empiric model was developed using the Aimeé method [1], combining dependent and independent parameters.

The method consists of a group of more important variables with strong influence on the spray behavior. This mathematical process reduces the similar physical unit and gives back the Pi-parameters that should be rearranged to get dimensionless equations or desired parameters. The complete physical meaning of the equation is obtained with experimental validation. The comparison with experimental data intends to adjust the model of those phenomena that cannot be quantified by the complexity of the problem.

The experiments were carried out in a spray test bench capable to simulate the thermodynamic conditions of a Diesel engine. The chamber conditions were varied from atmospheric pressure up to 100 bar and from ambient temperature up to 1000 K. The fuel was injected using a piezoelectric-injector under variation of the injection pressure from 800 up to 2000 bar for different fuel temperatures (263 K to 363 K). For the investigation of the spray propagation, the droplets were illuminated from four large windows by four flash lamps and the scattered light was detected by a CCD-camera which was positioned opposite to the injector. For more details about the chamber, its functionality and the experimental setup see [2, 3].

* Corresponding author: alexandre.d.fluegel@ltt.uni-erlangen.de

Results and Discussion

With the Aimeé method two dimensionless numbers were developed consisting of some parameters based on SI units; S (spray length), d_0 (injector outlet diameter), t (time), P (pressure), ρ (density), v (spray velocity), T (temperature), μ (dynamic viscosity) and k (fuel thermal conductivity). One dimensionless number (equation 1) was adjusted to experimental standard condition (ESC) to predict the spray length. At ESC the spray present minimized evaporation and the spray density is reduced due to air entrainment. The multiplication factor 3.5 is a correction calculated from the experimental data. The exponents are a function of the heat transfer and were calculated by the second dimensionless number FZ (equation 2) for constant conditions at ESC. Figure 1 left demonstrates the ESC, as well as the results of the model calculated by equation 1.

$$S = 3.5 d_0^{0.4} t^{0.6} \left(\frac{\Delta P}{\Delta \rho} \right)^{0.3} \quad (1)$$

The FZ number correlates the heat transfer of a quasi-continuum spray medium, and the surrounding gas. Here, the spray is considered as a continuous medium. FZ depends on different variables, whereas the velocity is dominant for the jet development. The initial jet velocity is calculated with the continuity equation combined with the Bernoulli equation. The spray deceleration behaves exponentially mainly due to drag and air entrainment.

$$FZ = \frac{\mu v^2}{k(\Delta T)} \quad (2)$$

The combination of FZ and equation 1 leads to equation 3 which describes the decrease of spray length due to fuel evaporation. For different spray conditions FZ has to be adjusted. In the second experiment, before the combustion takes place, FZ should be thousand times smaller than in ESC concerning the decrease of heat conductive.

$$S_{FZ} = 0.1 d_0^{FZ} t^{(1-FZ)} \left(\frac{\Delta P}{\Delta \rho} \right)^{\left(\frac{1-FZ}{2} \right)} \quad (3)$$

The spray length affected by evaporation can be calculated by eq. 4. Eq. 3 is calculated in the same time interval as ESC and subtracted from spray penetration which is calculated by eq. 1. In figure 1 (right side) a comparison of the model and the measurements are presented.

$$S_{evap} = S - S_{FZ} \quad (4)$$

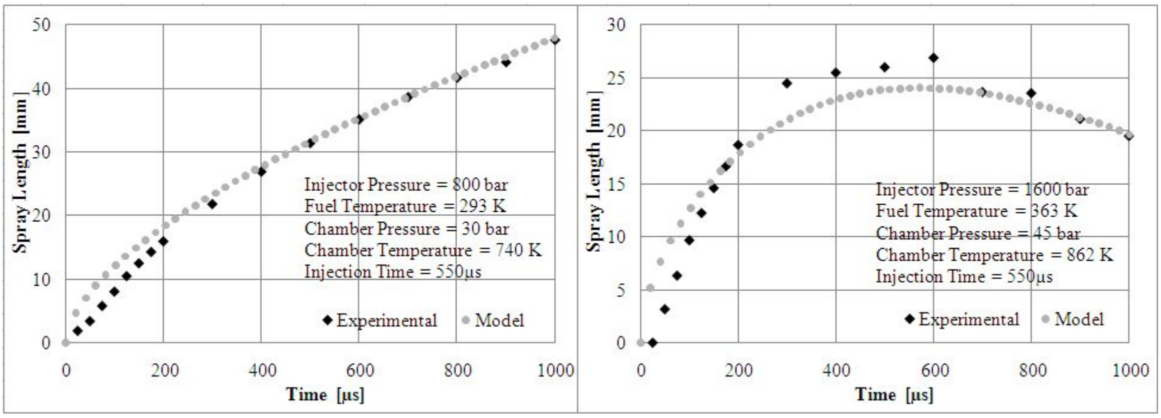

Figure 1. Left shows ESC and Model. Right, spray penetration before combustion with evaporation Model

The model shows a good agreement with experimental data. An additional correction by FZ results from the approximation of a continuum spray. Improvement on S_{FZ} is recommendatory. Implementation of drag and entrainment air would improve the model for a wide temperature and pressure application.

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