Prediction of Spray Penetration for DI Engines by Means of a New Application Tool

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Abstract

An application tool for the prediction of spray in DI combustion Engines has been developed. It is based of empirical equations derived from specialist worldwide during the last decade. The program can easy be modified by own/new equations for spray penetration. The presentation is usable in 2D and 3D as well. The operation of the program is easy and it can even be used by the test bench driver, or the development engineer.
The calculated and tested nozzle versions during an engine test run can by evaluated immediately and ordered by a nozzle form sheet. All nozzle data from the calculated and selected nozzle can be printed into the data sheet. By means of this procedure frequently mistakes during the ordering process can be eliminated.
The described tool was tested by means of a high pressure chamber. The spray penetration was visualized by means of a simple Mie scattering setup. A nanosecond light and a CCD camera with a sophisticated trigger logic was used. The optics will briefly described. The automatically working picture evaluating software will be discussed.

Introduction

During the development of the internal combustion process at the test bench the knowledge of spray penetration would be worthwhile. The Spray penetration directly affects the fuel mixture generation. Therefore the development engineer would get a demonstrative impression of this process immediately during test bench work. After choise of the best suitable nozzle, the nozzle parameter will be provide from the programme to generate a order form. Transmission errors can be avoided by the developed programme.

Spray Penetration Under Diesel Engine Conditions

The investigations of spray penetration have been performed by means of a high pressure injection chamber, see Figure 1.

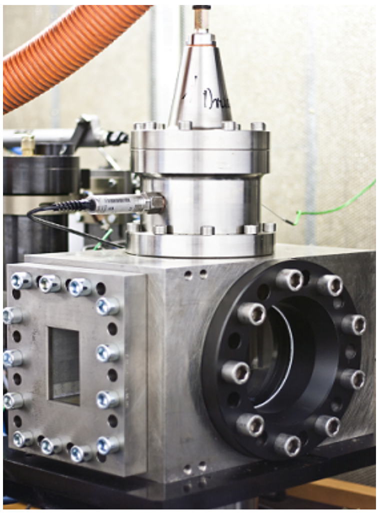

Figure 1. Injection chamber on the injection test bench (gas pressure p_{max} = 25 bar)

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The high pressure injection was carried out by a Truck - Common Rail System, which is in serial production by Deutz. The nozzle investigation was carried out by a choise of nozzles performed by AVL-Schrick.

The exposures of the spray penetration process was done by Mie-Scattering of the fuel droplets. The used flash light had a duration of a few ns and was able to froze the penetration of the droplets to visualize the spray plums. A typical raw exposure presents Figure 2.

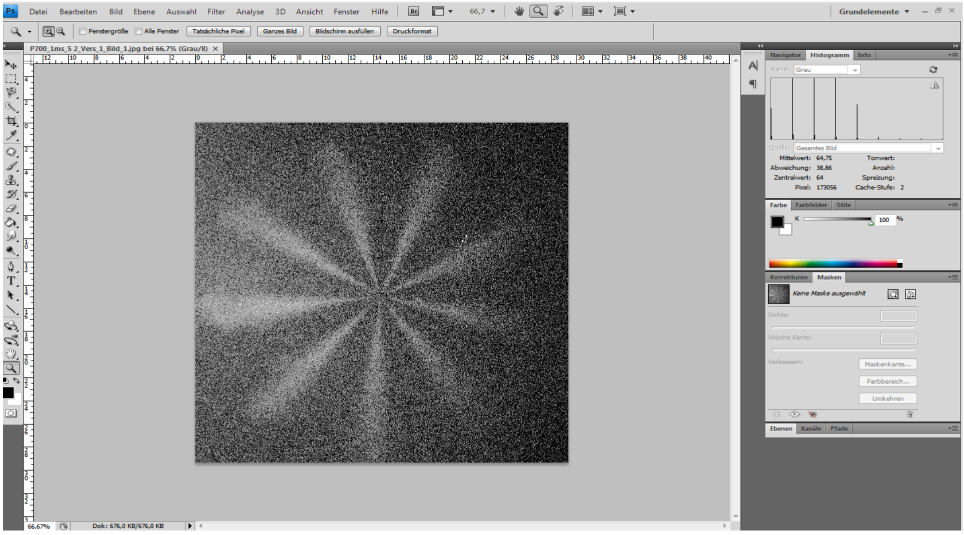

Figure 2. Exposure of the scattered light from fuel droplets (spray plums)

The raw exposures of the spray will automatically elaborated by a particular programme. The programme was developed by a diploma Thesis [1]. In a first step the contour of the spray will be identified. Subsequently the spray penetration (distance between nozzle orifice and spray tip) and the corresponding spray angle will be determined.

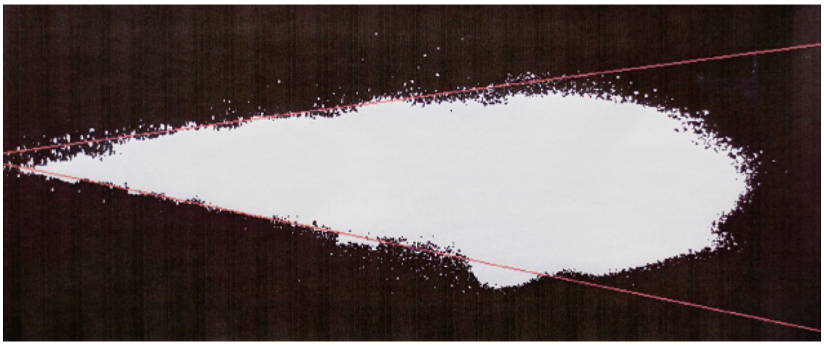

Figure 3. Binary picture for the evaluation of spray penetration and spray angle

For one measurement point of spray penetration or cone angle an average value was calculated by 3 times 20 individual injections at one particular injection time. Each spray plume (8 hole nozzle-> 8 spray plumes) were taken into account.

Finally a curve, e.g. for spray tip penetration (fig. 4), was calculated by 4800 - 5400 individual measured spray plumes.

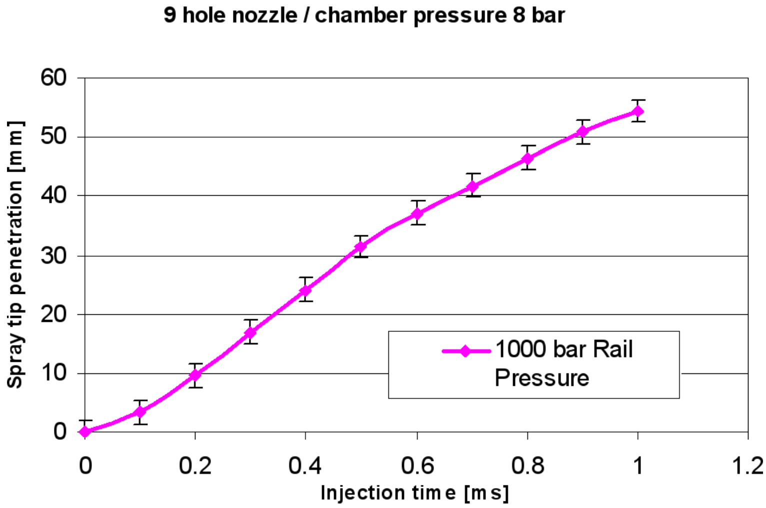

Figure 4. Example of examination of spray tip and cone angle by averaging

Spray tipp penetration and cone angle are dependent on a lot of nozzle and environmental parameter. The dependence is eminently pronounced by the gas density inside the injection chamber, the hydro erosive rounding of nozzle hole inlets and e.g. the Tapering of the holes.

Unfortunately the impact of the nozzle hole tapering could not investigated.

Figure 5 e.g. indicates the behaviour of spray tip penetration in dependence of the chamber density for a chamber pressure of 8 bar under application of a 8-hole nozzle with a hydraulic volume flow rate of Q = 590 ccm/30s (100 bar).

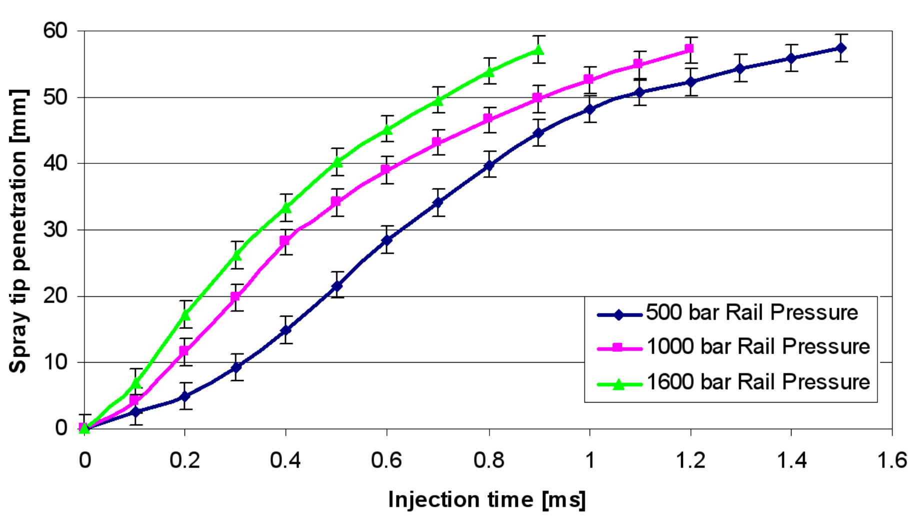

Figure 5. Measured spray tip penetration of a 8-hole nozzle

A numerous number of such measurements provide the following empirical equations under engine like conditions:

$$S = 0.078 \cdot \left(\frac{\Delta p \cdot \rho_F \cdot d_0^2}{\eta_F^2} \right)^{0.3} \cdot \left(\frac{\rho_F \cdot \sigma \cdot d_0^2}{\eta_F^2} \right)^{-0.008} \cdot \left(\frac{\rho_F}{\rho_G} \right)^{0.3} \cdot \left(\frac{l_0}{d_0} \right)^{0.16} \cdot \left(\frac{t^{0{,}05}}{1.5 + \frac{1}{t^{1.3}}} \right) \quad (1)$$

This equation based on a modified equation by Varde and Popa [2]. For the calculation of the spray cone angle an equation made by Hiruyasu and Arai [3] has been enhanced.

$$\Theta = 83.5 \cdot \left(\frac{l_0}{d_0}\right)^{-0.22} \cdot \left(\frac{d_0}{d_s}\right)^{0.15} \cdot \left(\frac{\rho_G}{\rho_F}\right)^{0.17} \cdot \left(\frac{\Delta p}{1000}\right)^{0,12} \tag{2}$$

These equations will fit very well for light duty engines with a stroke volume of approximately 1-2 L.

Further methodes of resolution (empirical/semi empirical) are given by: Wakuri [4], Lustgarten [5], Sitkei [6], Dent [7], Reitz/Bracco [8], Yule [9], Yokoka/Matsuoka [10].

Simulation Programme

Primary aim of the described work was the development of a user orientated simulation programme, easy to use, providing simulation results directly during engine test bench work to assist the engineer. The derived nozzle parameter from experimental work at the test bench should be automatically transferred into an order form of the nozzle.

The accuracy of the simulated results should be sufficient for engineers work. But the results must be visualized immediately for the calculated working point. By this means the simulation work assist the development work at the bench.

If the spray parameter for a particular application have been fixed/defined and given as input into the programme, further calculations at the same engine required not a new input. For a new start of injection the new crank angle must be given to the programme. Figure 6 represents the spray penetration of one jet at 2 degree CA after top dead center. The spray plume has not reached the wall of the cavity. Already now the range of impact between spray jet and wall is denoted.

The order form of the nozzle supplier will be automatically filled with the determined nozzle parameter. Transmission errors can be avoided by means of the procedure.

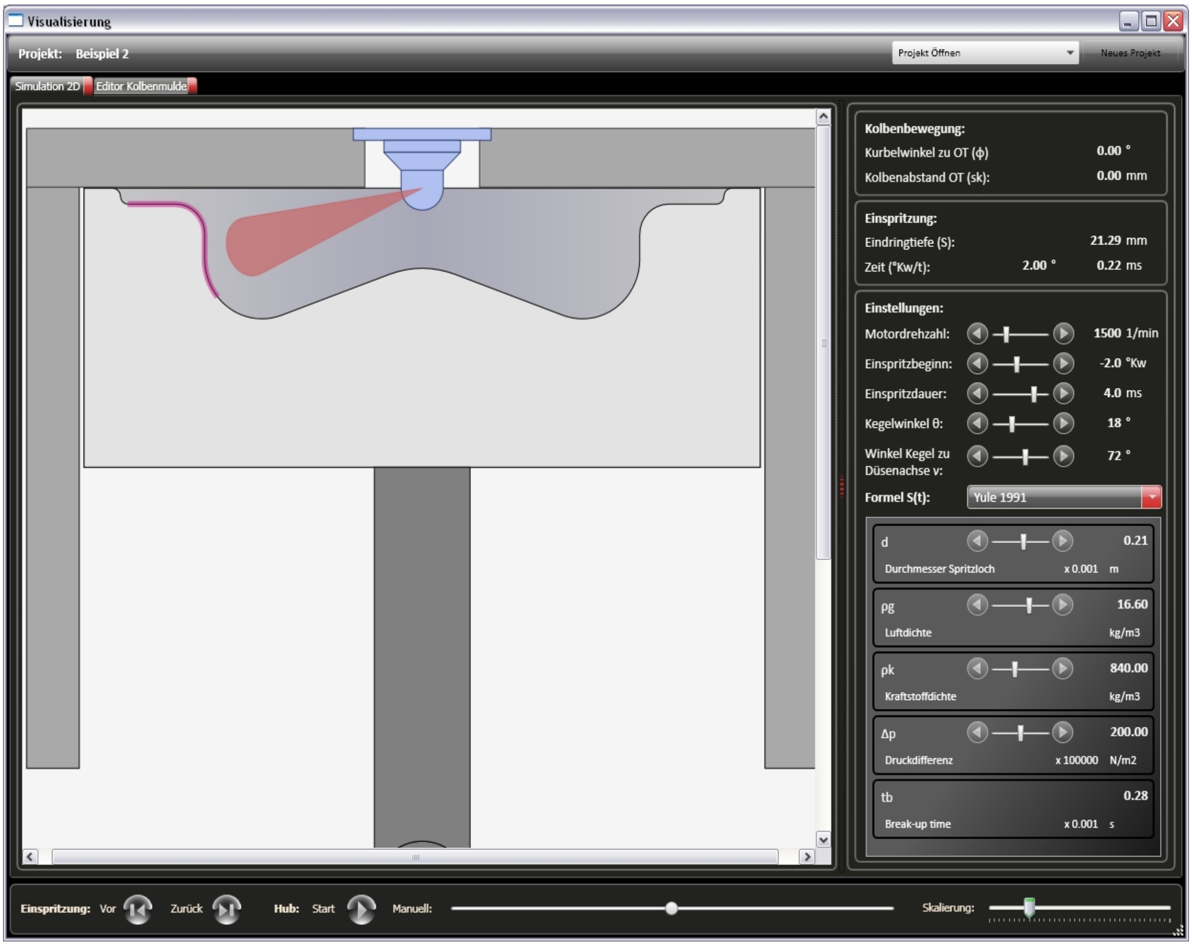

Figure 6. Spray penetration during piston movement (2D)

For a better understanding of the spray penetration process and the spray/wall interaction the spray penetration process and the piston movement can be animated in 3D, as shown in Figure 7 by four steps.

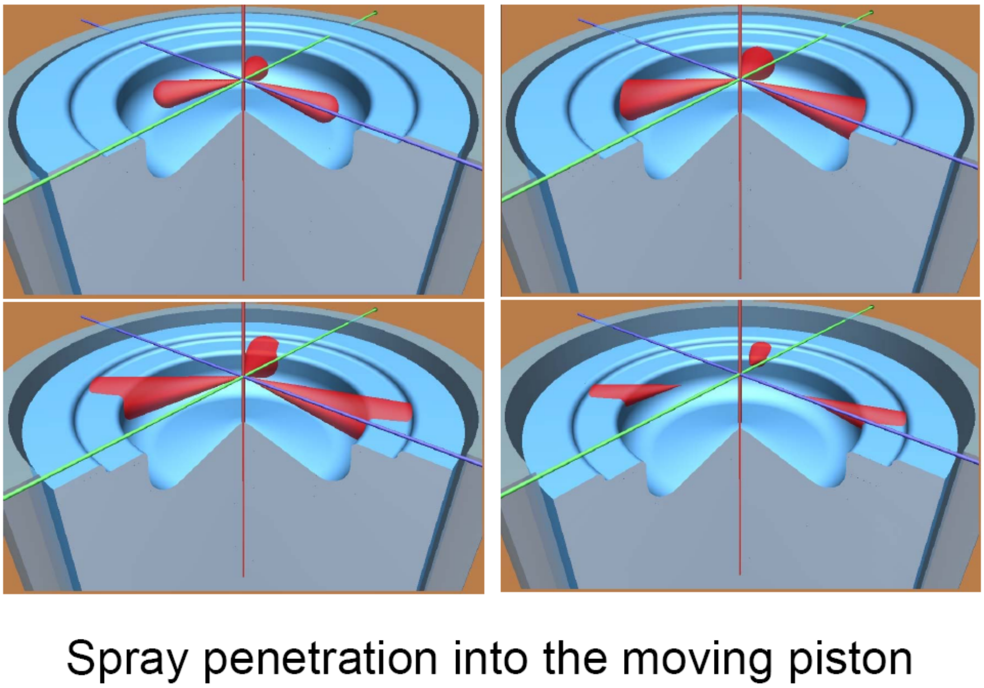

Figure 7. Sequence of spray penetration

Conclusion

Under consideration of Diesel engine injection conditions of truck engines with a stroke volume between 1-2 l pro cylinder empirical equations have been derived to describe the spray penetration behaviour. A typical injection test bench was used to drive a commercial truck CR injection system. The spray penetration and corresponding cone angle were observed by means of an injection chamber with optical access.

The new derived empirical equations were implemented in a simulation programme. The programme provides a well impression of the spray penetration during the piston is moving. The spray/wall interaction is displayed.

The calculation of the visualization of the spray penetration process and the piston movement simultaneously to the engineers development work at the test bench provides the practical use of this tool. After definition of the nozzle, the nozzle parameter can transferred to the order sheet of the supplier.

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References

[1] Baasner, Gunnar; Entwicklung einer automatischen Bilderfassung und – Datenauswertung von Kraftstoffsprays, FH-Köln, Inst. für Fahrzeugtechnik, Köln, 2009
[2] Varde, K.S., Popa, D.M.;Diesel Fuel Spray Penetration at High Injection Pressures SAE 830448, 1983
[3] Hiroyasu H., Arai M. ; Structures of Fuel Sprays in Diesel Engines, SAE 900475, 1990
[4] Wakuri, Y., Fujii, M., Amitani, T., Tsuneya, R.; Studies of the Penetration of Fuel Spray in a Diesel Engine, Bulletin of J.S.M.E., Vol. 3, No. 9, p. 123 1960
[5] Lustgarten, G.; Modelluntersuchung zur Gemischbildung und Verbrennung im Dieselmotor unter Anwendung der Modelltheorie, Diss. ETH Zürich, 1973
[6] Sitkei G., Kraftstoffaufbereitung und Verbrennung bei Dieselmotoren, Springer Verlag Berlin, 1964
[7] Dent J.C., A Basis for the Comparison of Variuos Experimental Methods for Studying Spray Penetration, SAE 710571, 1971

[8] Reitz.R.D., Bracco F.V., Mechanism of Anatomization of a Liquit Jet, The Physics of Fluid Vol. 25, No 10, S. 1730-1742,1982
[9] Yule, A.J.; The Structure and Dimensions of the Time Dependent Break-Up Zone of Diesel Sprays., ICLASS-94, Rouen, 1994
[10] Yokoka K., Matsuoka S., An Experimental Study of Fuel Spray in a Diesel Engine Trans. JSME, Vol 43 No. 373 pp. 3455ff, 1977