INFLUENCE OF THROTTLE EFFECTS AT THE NEEDLE SEAT ON THE SPRAY CHARACTERISTICS OF A MULTIHOLE INJECTION NOZZLE

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Abstract
In order to fulfil strict future exhaust emission limits for direct injection (DI) diesel engines as well as demands on low fuel consumption and noise reduction the injection system gains in importance. Multiple injections are already realised by modern injection systems and take significant influence on mixture formation. Except for injection rate shaping effects the fuel flow inside the injection nozzle plays a decisive role for atomisation, distribution and mixing the fuel with air. This paper discusses spray characteristics caused by throttle effects at the needle seat of a multihole injection nozzle of a DI-diesel engine using a new piezoelectrically controlled common rail (CR) injection system. A rapid compression machine (RCM) enables to realise motorlike pressure and temperature conditions combined with optical access through its transparent piston head. By ultra-highspeed-photography the macroscopic spray propagation is geometrically measured. Using a direct-piezoelectrically actuated CR injector it is possible to separate throttle effects at the needle seat caused by varied needle speeds from quasi-stationary partial needle lifts. These effects caused by throttle phenomena at the needle seat are compared with the influence of varied rail pressures on the spray propagation.

Introduction

In DI-diesel engines the fuel atomisation process strongly affects combustion and exhaust emissions. The demands on modern injection systems concerning a minimization of emissions and fuel consumption are significant driving forces for the optimisation of the fuel injection process and the mixing of fuel and air in the cylinder. The way of injecting the fuel into the combustion chamber is of essential importance concerning its local and temporal distribution, evaporation, ignition and finally the combustion process itself. Today high pressure injection systems with hole diameters of about 180 µm and rail pressures of 160 MPa are used. In addition to a further increase of the maximum injection pressure future injection system have to offer a high flexibility of rate shaping as well as high reproducibility. Injection pressure and injection rate exert particular influence on the emissions because both parameters take important influence on the spray parameters like droplet size, spray angle and penetration length and thus on the combustion process. Today multiple injections are already realised by modern injection systems. These small amounts of fuel (e.g. pre-injection < 2mg) implicate an increased significance to partial needle lifts [1]. In the case of partial needle lift the smallest cross sectional flow area relocates from the injection holes to the needle seat. It is known that the strong pressure drop at the needle seat generates clearly different flow conditions inside the nozzle hole. Cavitation effects at the needle seat exert influence on the flow conditions inside the hole and thus on the spray break-up [4, 5].

Experimental Setup

The Institute for Technical Combustion (ITV) at the University of Hanover has developed a new piezoelectrically controlled CR injection system for research. Its fundamental difference to conventional common rail injectors is that the piezo element is directly connected with the needle enabling a highly dynamic and extremely accurate movement and positioning of the needle during the injection (Fig. 1). The system is used to investigate the requirements and the potential of different injection rates and their influence on the fuel disintegration process. Special emphasis is put on the investigation of the spray break-up during partial needle lifts and during the opening and closing processes of the nozzle under motorlike conditions. In order to evaluate the effects of the new injection technology a RCM is

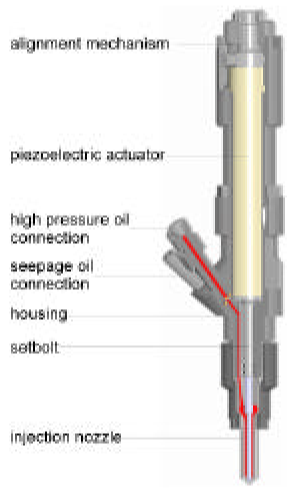
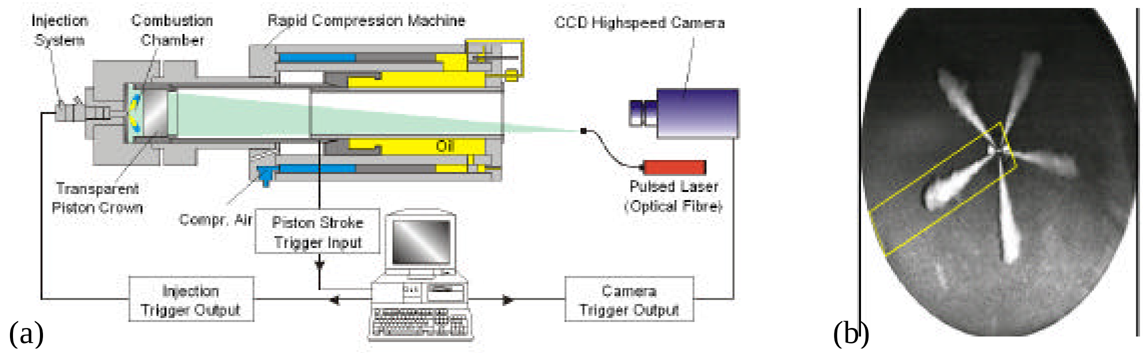


Figure 1: piezo injector [1]

utilised [2], which realises motorlike pressure and temperature conditions and offers an excellent optical access to the combustion chamber with a nearly unconfined view of the spray dispersion [2]. A high speed CCD-camera system with high spatial and temporal resolution in conjunction with laser-pulsed lighting of 20 ns was used for the investigations. Figure 2(a) shows the instrumental setup. According to Figure 2(b) the



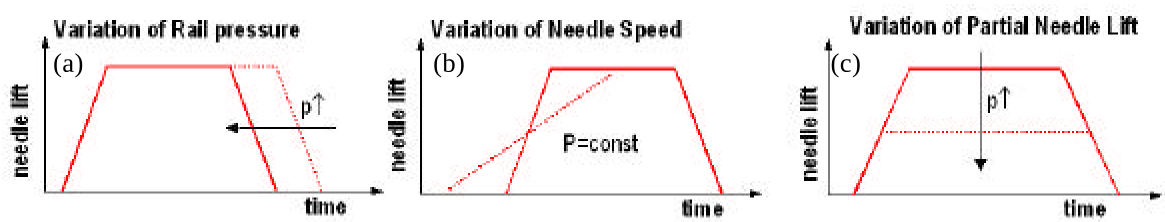
investigated area is concentrated on the marked jet. Preliminary examinations resulted in high reproducibility of the whole system and especially of the optically detected dispersion phenomena.

Figure 2: (a) RCM with measurement instrumentation, (b) investigated area of spray

Operating Conditions

The investigations were made using a sac hole nozzle of a passenger DI-diesel engine, the liquid injected was diesel fuel under suspended combustion (chamber gas: nitrogen). In order to realise constant pressure inside the combustion chamber during the injection the piston moved at top dead centre. This guarantees that the pressure inside the combustion chamber was fixed to 5 MPa with a temperature of 710 K which corresponds to conditions at the beginning of the injection under motorlike conditions. The injected mass was kept constant at 23mg representing a part load of a passenger car DI-diesel engine. In order to estimate the effects of transient and stationary partial needle lifts the following parameters were varied (Fig. 3) and the spray dispersion was geometrically measured. 100% needle lift represents 180μm.

The first parameter, the rail pressure, was varied from 70 MPa to 160 Mpa representing maximum rail pressure of modern CR injection systems (Fig. 3(a)). By using maximum opening speeds of the needle (1 m/s) the influence of the injection pressure was separately examined. The second parameter was the opening speed of the needle, which was varied from 0,18 ms (1 m/s) up to 0,7 ms (0,38 m/s) for total needle lift (Fig. 3(b)). Rail pressure was fixed at 160 Mpa combined with maximum closing speed of the needle. This test enabled a determination of transient dynamical throttle effects at the needle seat. In order to analyse the influence of quasi-static throttle effects at the needle seat on the spray dispersion maximum opening and closing speed of the needle were used during the third experiment while the rail pressure was varied from 70 MPa to 160 Mpa (Fig. 3(c)). The maximum amplitude of the needle lift was reduced with increasing rail



pressure in order to retain fixed fuel mass.

Figure 3: parameters varied during the investigations

Results

The geometrically measured results are compared with calculation of penetration S and spray angle Θ according to Hiroyasu [3] (Fig. 7, 8).

$$t > t_b: \quad S = 2{,}95 \left(\frac{\Delta P}{r_g} \right)^{0,25} \cdot (D \cdot t)^{0,5} \qquad (1)$$

$$\Theta = 83{,}5 \left(\frac{L}{D} \right)^{-0,22} \left(\frac{D}{D_0} \right)^{0,15} \left(\frac{r_g}{r_l} \right)^{0,26} \qquad (2)$$

nozzle type	Bosch (DLLA 145 P 926
number of nozzle holes	5
nozzle hole angle	72,5°
∅ injection hole (D)	0,164 mm
Injection hole length (L)	0,75 mm
∅ sac hole (D_0)	1,0 mm
sac hole length	1,0 mm
inlet edge	hydro grinded

Table 1: nozzle parameters

Variation of rail pressure:

The realised profiles of amplifier voltage shown in Fig. 4(a) make clear that it is possible to work with constant needle speed combined with maximum needle lift. In order to ensure constant injection mass the injection time at maximum needle lift is adapted to the varied rail pressure. Variation of rail pressure is performed in a wide range of motorlike conditions from 70 Mpa, 100 Mpa to 160 Mpa. Injection rates respond to the control voltage of the piezo actuator (Fig. 4(b)). Except for the closing phase of the needle, differences in injection rates only depend on varied injection pressures. Independent of rail pressure the resulted measured spray angle corresponds to the calculated stationary spray angle Θ of 18,4° (Fig. 6(a)) according to Hiroyasu (2). Utilised calculation parameters of the nozzle geometry conform to Table 1. Figure 6(b) shows that measured penetration accord with equation (1). This first basic experiment shows that the new injection system produces reasonable sprays. The result concerning the influence of rail pressure on spray dispersion represents a good basis for evaluating the effects caused by variation of opening needle speed and partial needle lift.

Variation of opening needle speed:

According to Figure 5(a) the needle speed is varied in a wide range. In order to ensure a best possible comparability of the variations the injected mass is kept constant and maximum needle speed and rail pressure of 160 Mpa corresponding to variation of rail pressure. The lowest needle speed is determined by the demand of realising maximum needle lift, constant injected mass and equal closing needle speeds. Figure 5(b) shows that injection rates distinctly respond to amplifier voltages with comparable maximum injection rates. The geometrically measured results of spray angles clearly depend on the opening speed of the needle (Fig. 7(a)). It is obvious that the spray dispersion is influenced by varied opening speeds. While opening the needle the spray angle nearly doubles for low needle speed (Fig. 7(a)). At the end of the opening process the spray angle converges to the stationary value according to Hiroyasu (2). The measured penetration shows different trend graphs (Fig. 7(b)). For high needle speed it reproduces equation (1). For low needle speed a linear trend is determined.

Variation of partial needle lift:

Reducing the voltage of the piezo actuator effectuates a quasi-static partial needle lift (Fig. 8(a)). Using this phenomenon the complete injection is dominated by the throttle effect at the needle seat. In order to guarantee a best possible comparability to the injection with total needle lift the injection time is kept constant and the rail pressure is increased from 70 Mpa to 160 MPa to ensure a constant injected mass. Maximum needle speed enables to place emphasis on quasi-static effects of partial needle lift instead of transient processes. Figure 8(a) shows that even the partial needle lift is nearly unaffected by mechanical oscillation which could be decisive both for flow effects inside the nozzle and the dispersion of the spray [4, 5]. Moreover Figure 8(b) indicates that injection rates are nearly congruent which underlines the comparability of the geometrical measurement of the spray. Figure 9 generated by photographs of the spray dispersion do not evince any significant influence of the partial needle lift on the geometrically measured penetration. On the other hand Figure 10(a) shows that spray angles in the period of quasi-static partial needle lift are clearly higher compared to the ones at total needle lift. Because the influence of varied rail pressure on the spray angle has already been excluded, this effect is caused by moving the main throttle from the injection holes to the needle seat area. The fluctuating behaviour of the spray angles caused by partial needle lift (Fig. 10(a)) is also pointed up by the spray contours (Fig. 10(b)). It is known that cavitation caused by the pressure drop at the needle seat fluctuates. This unsteady effect is transferred to the fuel flow inside the sac hole and injection holes and thus it consequently results that the break-up of the spray and dispersion also fluctuates [4, 5].

Conclusions

The piezoelectrically controlled CR injection system of the ITV represents a research instrument that enables separate evaluation of the investigated parameters. The results of the examinations indicate a significant influence of throttle effects at the needle seat on the spray characteristics. Effects generated by pressure drop at the needle seat have a much bigger influence than a variation of injection pressure. Both throttle effects at the needle seat caused by opening the needle and during quasi-stationary needle lift show a distinct influence on the spray angle. Geometrically measured penetration and spray angle with total needle lift and maximum needle speed correspond to calculations according to Hiroyasu under comparable conditions. It is known that pressure drop at the needle seat caused by partial needle lifts generates cavitation phenomena which move into the sac hole and influence the flow inside the injection holes. In spite of a steady partial needle lift, clearly fluctuating spray angles and spray contours underline the result that cavitation phenomena caused at the needle seat generate fluctuation inside the injection nozzle which are decisive for the spray break-up and dispersion.

References

[1] Meyer, S., Krause, A., Krome, D., Merker, G.P., *Ein flexibles Piezo-Common-Rail-System mit direktgesteuerter Düsennadel*, Motortechnische Zeitschrift, 02/2002

[2] Dorer, F.S., *Kompressionsmaschine zur Simulation von Brennraumvorgängen in Wasserstoff-Großdieselmotoren*, Dissertation, Technische Universität München, 1999

[3] Hiroyasu, H.; Arai, M., *Structures of Fuel Sprays in Diesel Engines*, SAE- Paper 900475, 1990

[4] Busch, R., *Untersuchungen von Kavitationsphänomenen in Dieseleinspritzdüsen* Hannover, 2000

[5] Blessing, M., König, G., Krüger, C., Michels, U., Schwarz, V., *Analyse von Strömungs- und Kavitationsvorgängen in Dieseleinspritzdüsen und deren Wirkung auf die Strahlausbreitung und Gemischbildung*, 5. Intern. Symposium für Verbrennungsdiagnostik der AVL Deutschland, Baden-Baden, 06./07.06.2002

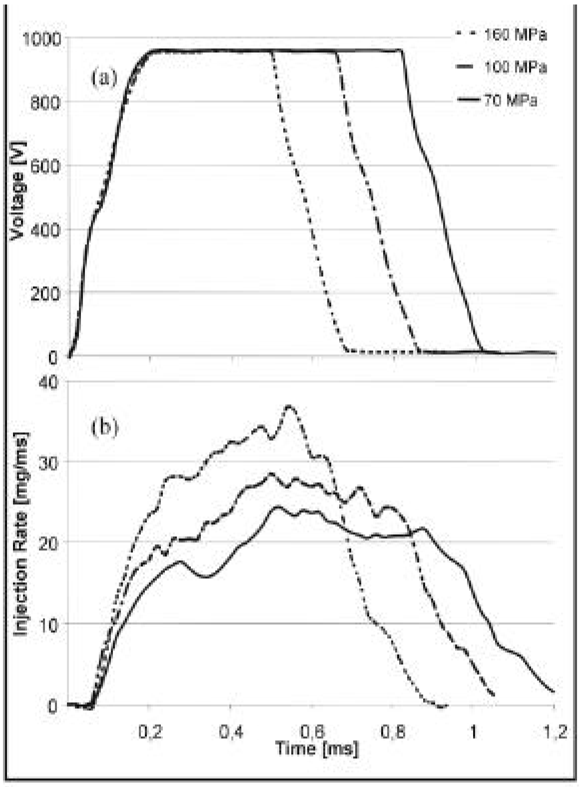


Figure 4

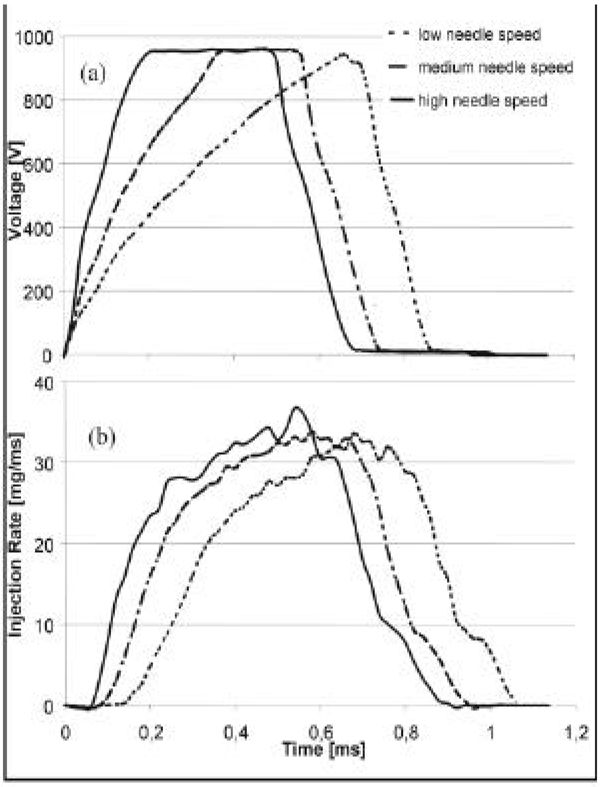


Figure 5

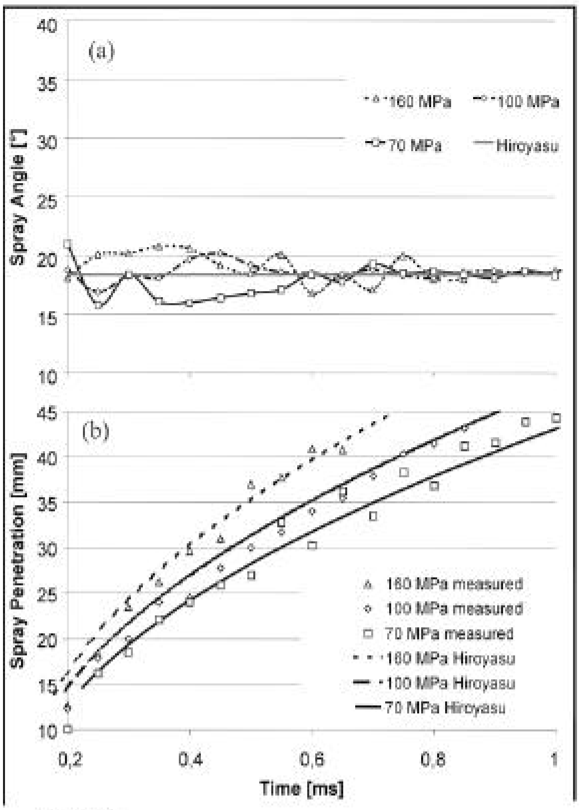
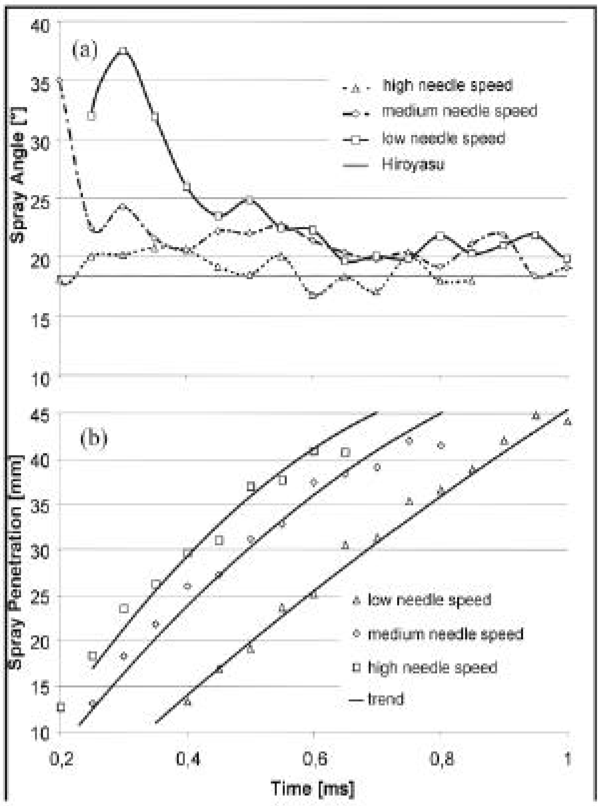


Figure 6



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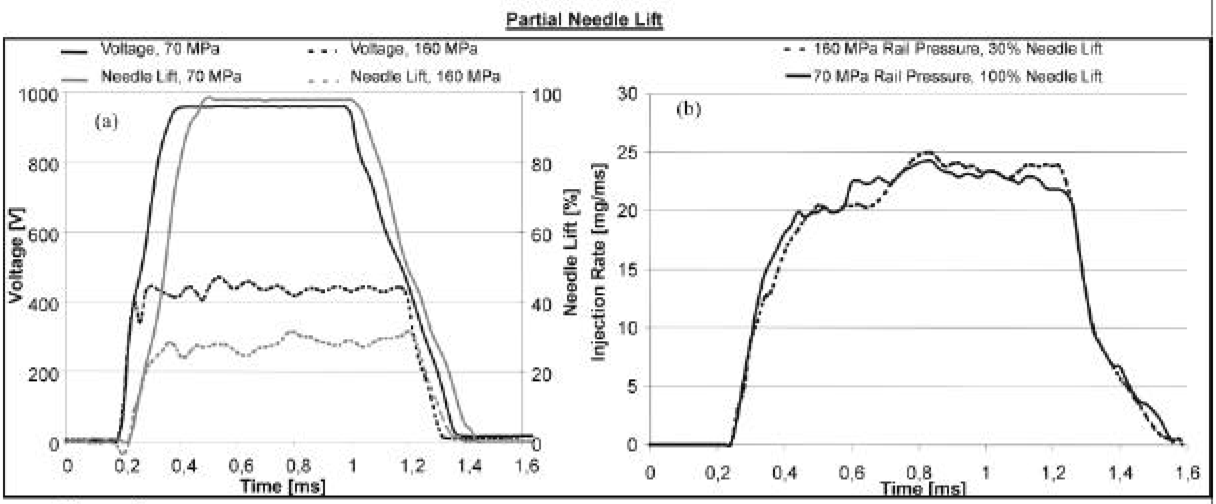

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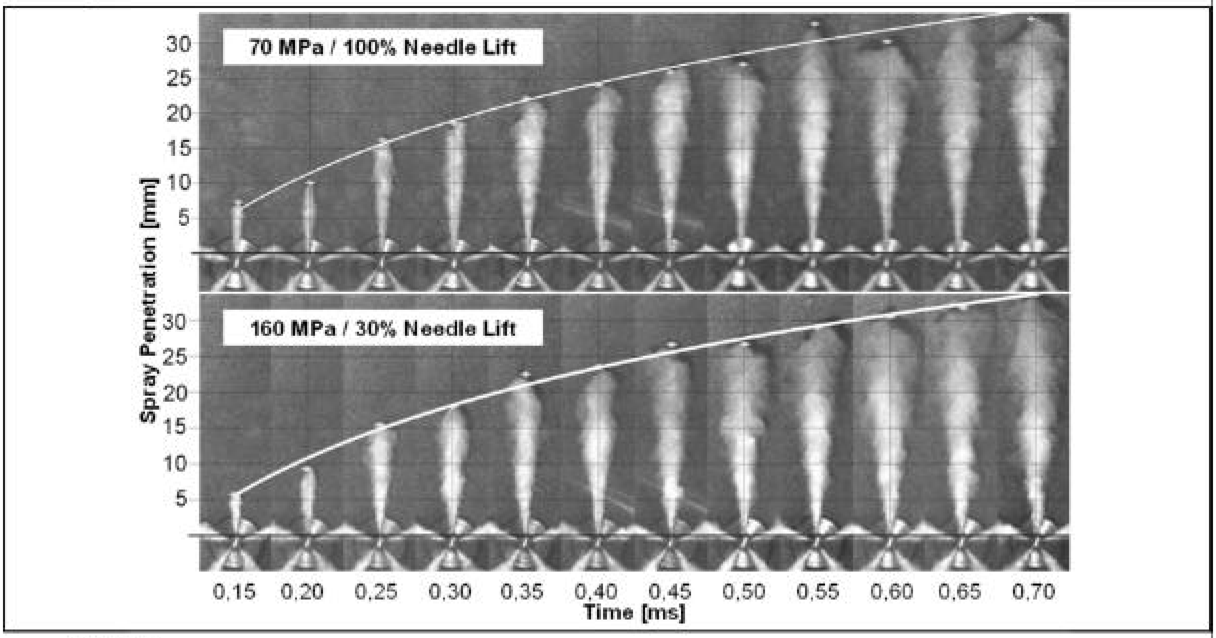

Figure 9

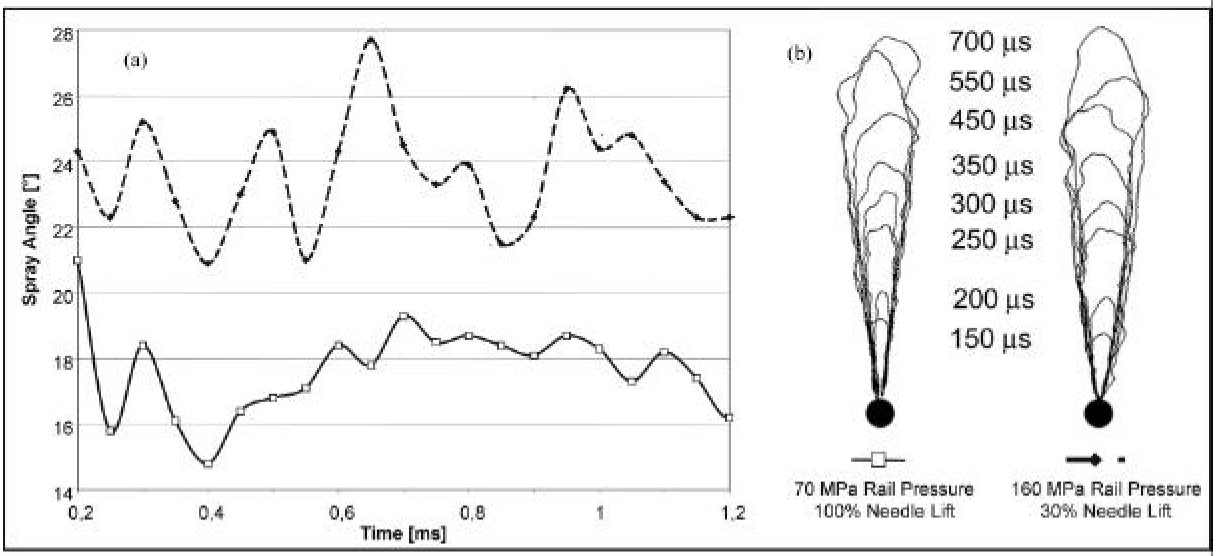

Figure 10