IEA 2008, 30th Task Leaders Meeting

DIRECT COMMAND INJECTOR FOR LIGHT DUTY DIESEL ENGINES

L. Allocca, F.E. Corcione, A. Montanaro, G. Valentino

Istituto Motori, CNR – Napoli, Italy

September 14 - 18, 2008 - Capri

GENERAL CONSIDERATIONS

Present and future standard on emissions require advanced strategies to control the combustion process in i.c. engines

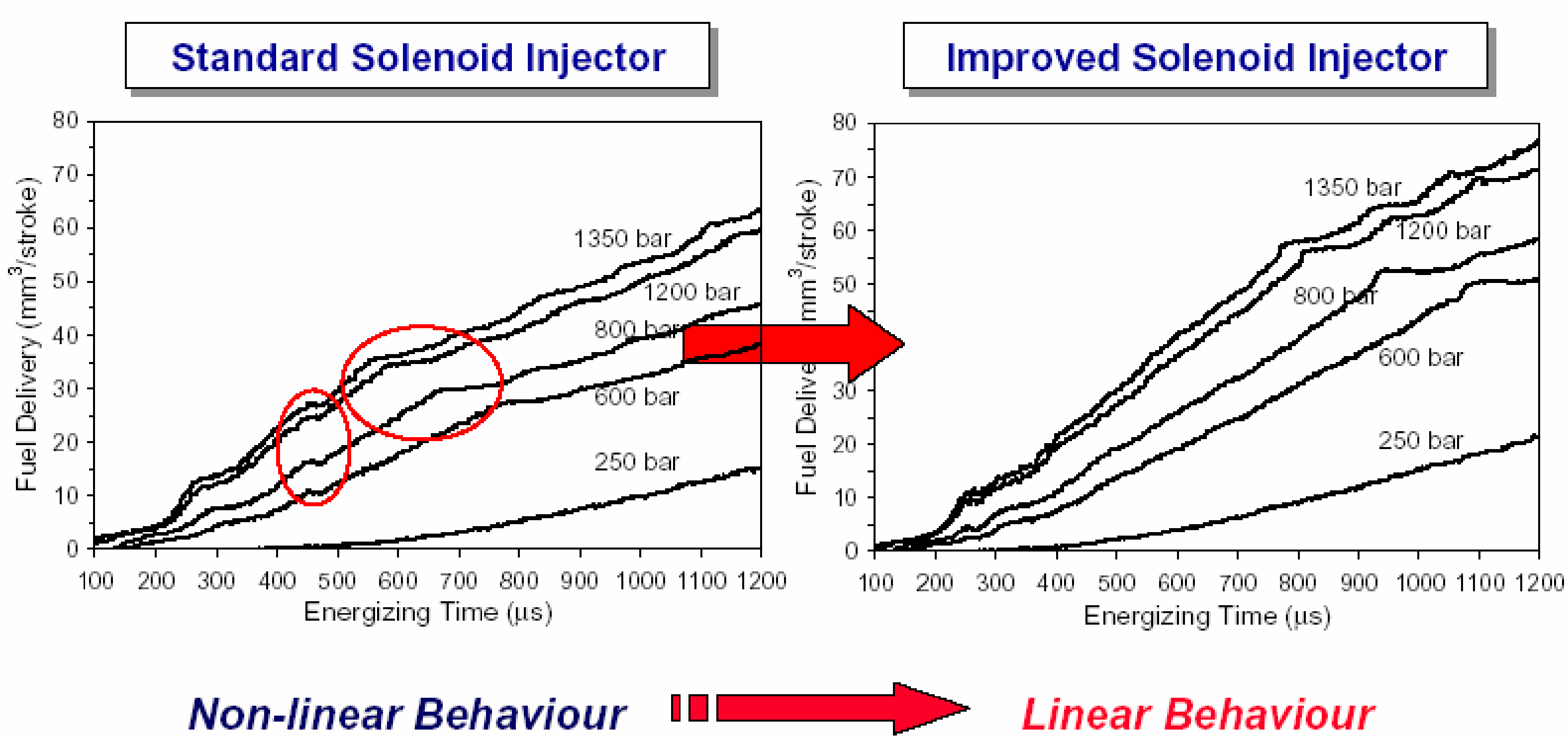
The challenge is in meeting performances and consumption with the more stringent emission regulations

Multinjection strategies allow the reduction of noise and smoke levels, a stable combustion, soot and HC cut

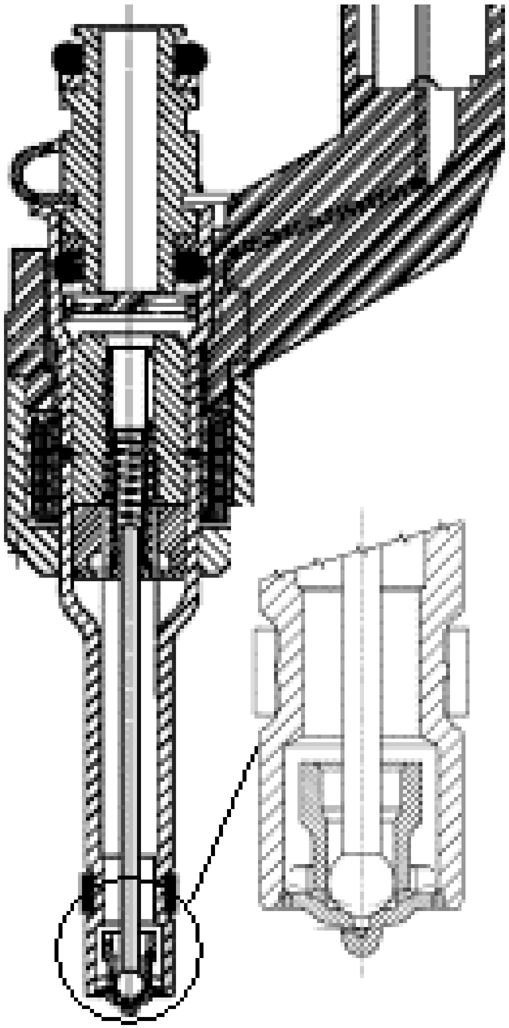
Management of small amount of fuel (less then 1 mg/str) could be required for light duty diesel

Innovative injector, gasoline derived, needle-lift direct-command, has been developed by Magneti Marelli (MM DDI) for light duty diesel engines

Comparison between the solenoid injector of two different generation relatively to the fuel delivery versus opening time. The improved solenoid injector has a better linear behaviour in the range 300 to 1000 μs



Magneti Marelli needle direct command injector



hydraulic and magnetic modifications adapted for the new duty

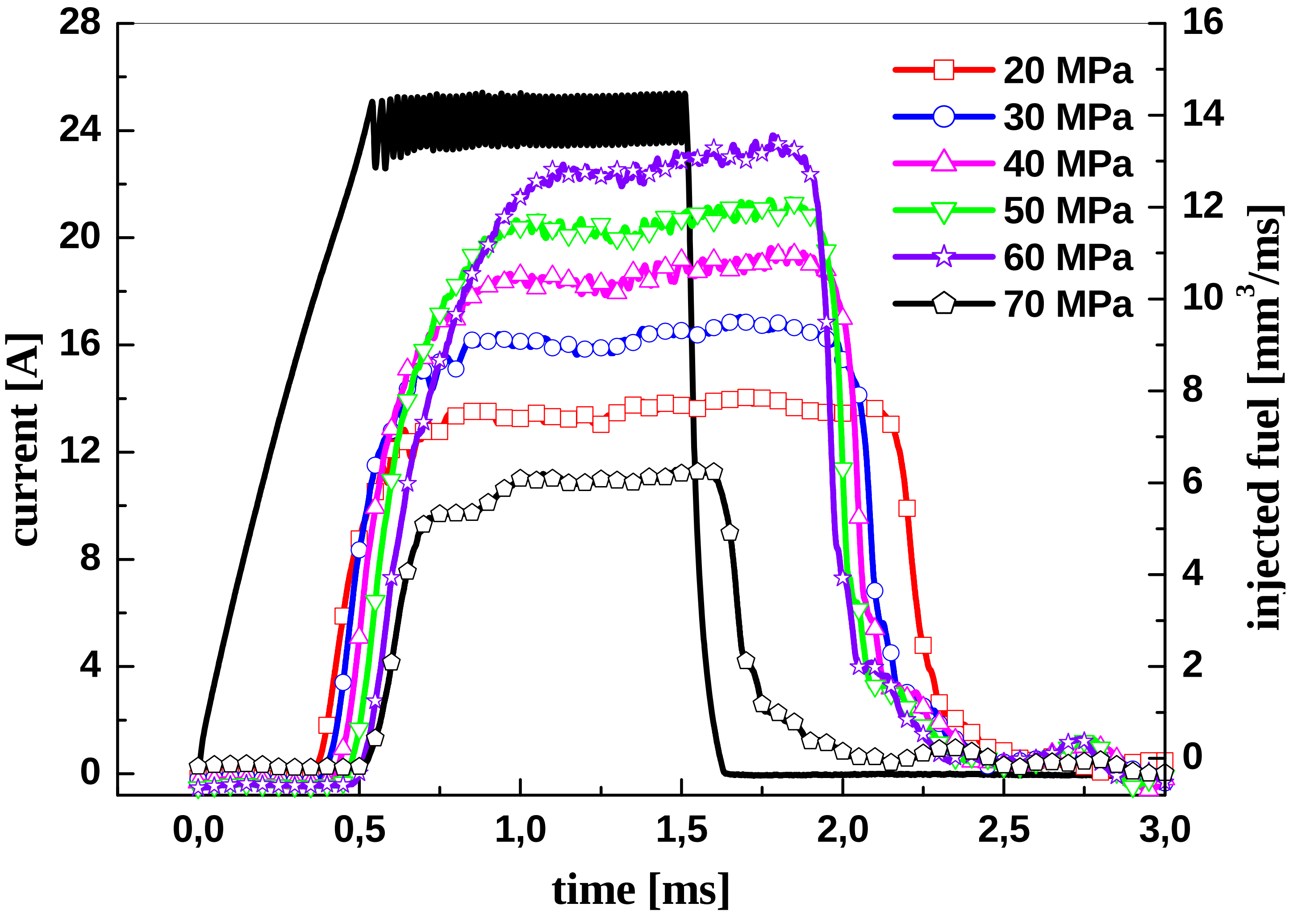
direct command of the injector needle through the solenoid currents

low losses in the hydraulic circuit

reduced dimensions with potential use in small engine layout

simple internal structure of components and manufacturing with a strong reduction of the costs

Current command and fuel injection rate signals



AIMS OF THE PRESENT WORK

An investigation on a MM DDI injector has been carried out to evaluate the performances and the assessment of the spray behavior in a wide range of conditions for different injection strategies

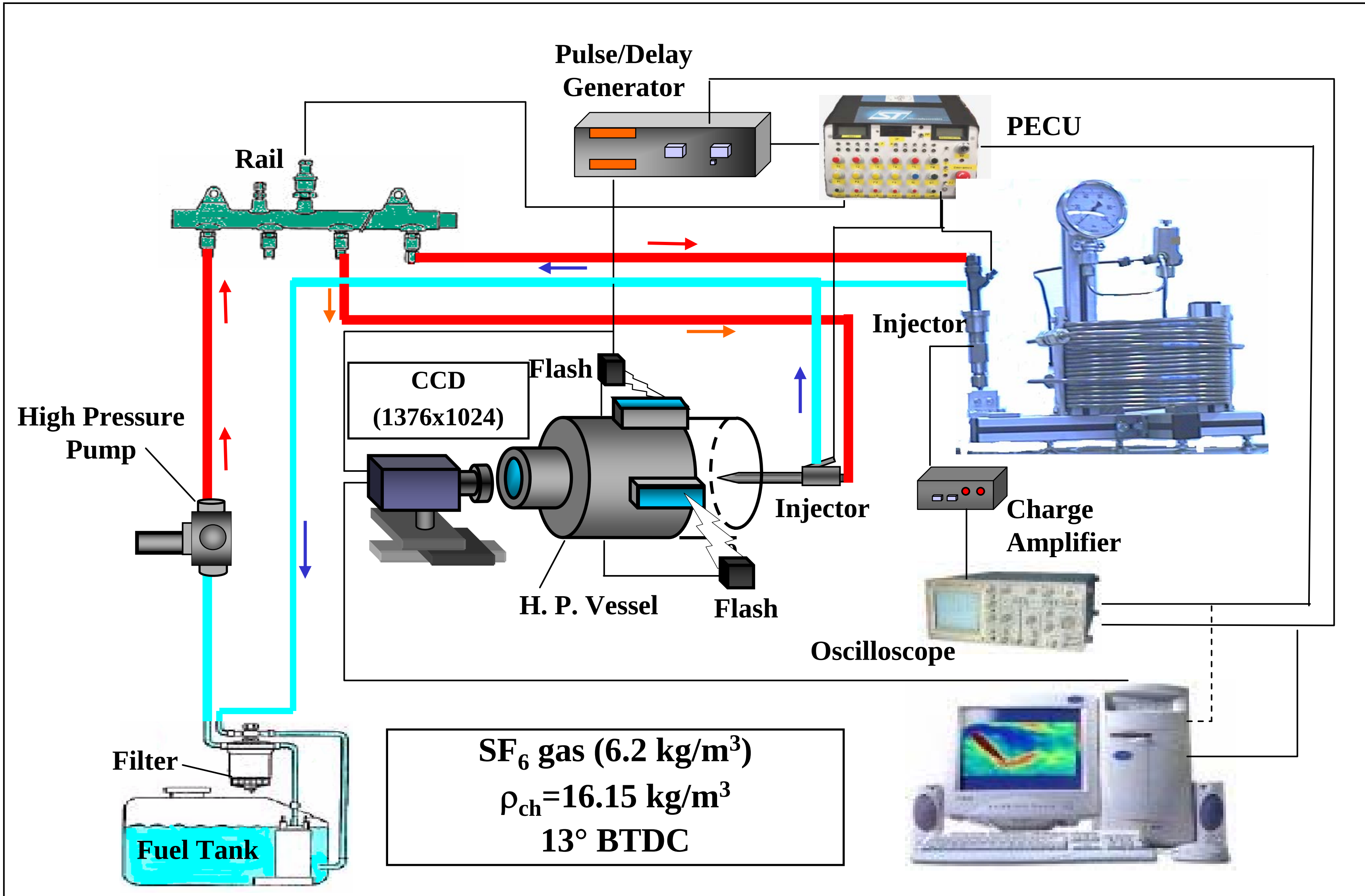
Comparison with the recent generation of multinjection hydraulic-guided commercially-available injector devices

Characterization of jets both in non evaporating and evaporating conditions at typical diesel-like gas density conditions in quiescent ambient

Operative Conditions

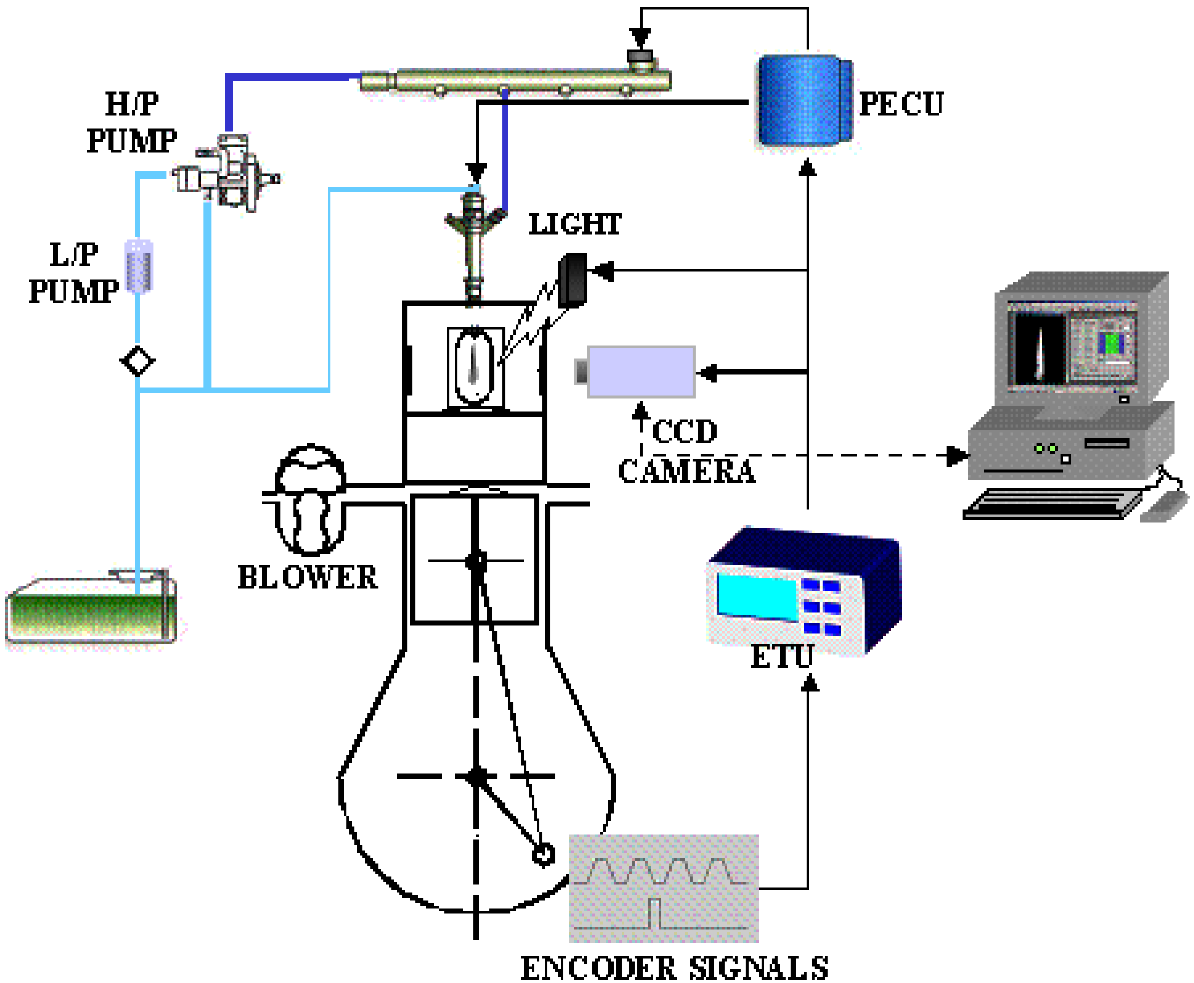
- **Programmable Electronic Control Unit for setting the injection strategies**
- **Three strategies: single, double (pilot + main) and triple (pilot + split main)**
- **Magneti Marelli injector: 5 holes, 150° spray angle, 0.12 mm nozzle diameter**
- **Bosch injector: 5 holes, 150° spray angle, 0.13 mm nozzle diameter**
- **Flow rate measurements by AVL Fuel Gauge Meter**
- **Images techniques for spray morphology**

Non evaporating experimental set-up

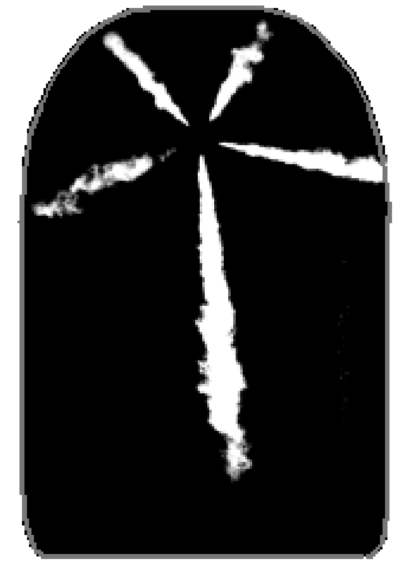


SF_6 gas (6.2 kg/m^3)
ρ_{ch}=16.15 kg/m^3
13° BTDC

Evaporating test engine set-up



ENGINE SPECIFICATIONS	
Single cylinder 2-stroke	
Bore	150 mm
Stroke	170 mm
Connecting rod	360 mm
Displacement	3000 cm^3
Combustion chamber	Quiescent
Geometric compression ratio	10.1:1
Air supply	roots blower
Intake air pressure	0.217 Mpa

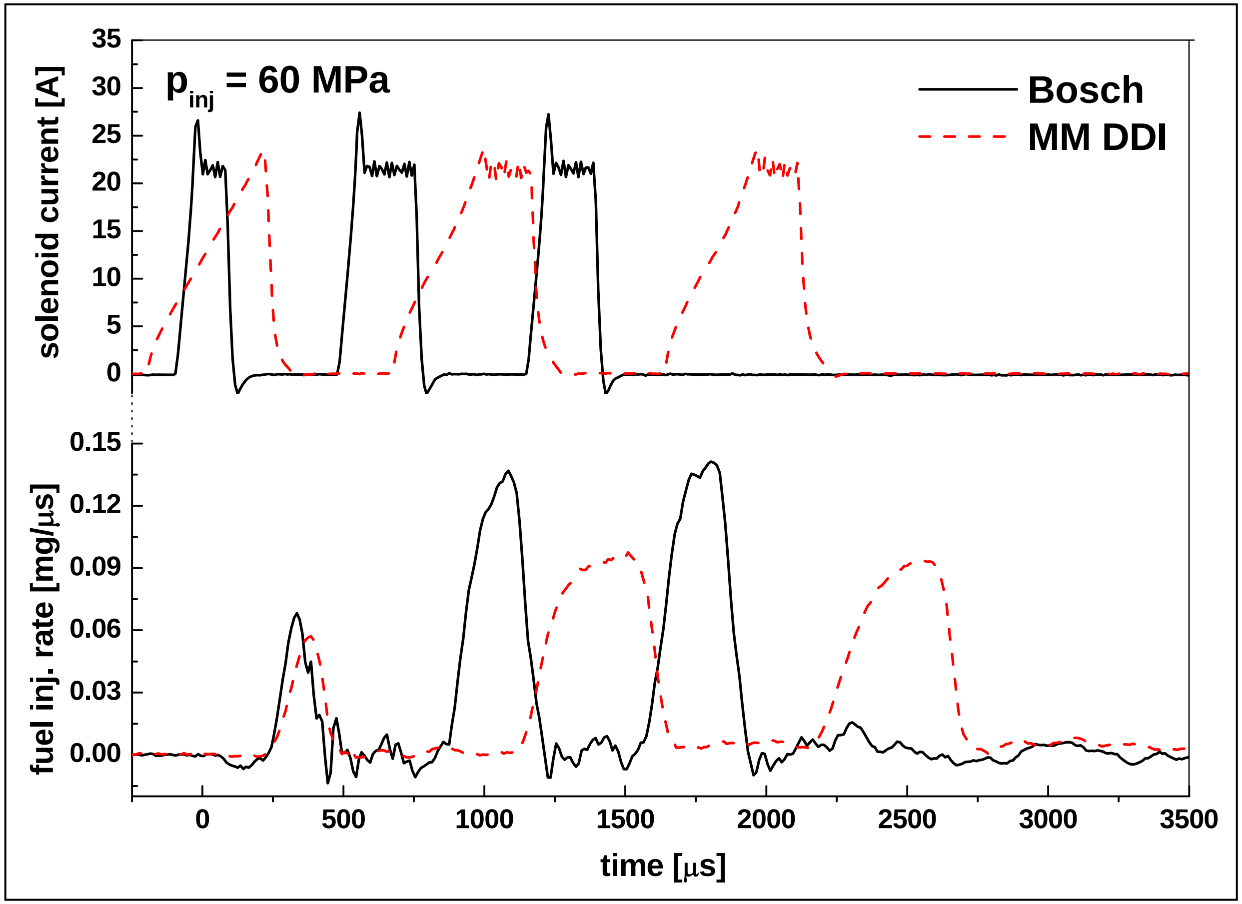


Adopted strategies and relative delivered quantities for MM DDI and Bosch injectors at p_{inj}= 60 MPa

	MM DDI - P_{inj}= 60 MPa		
	Single	Double	Triple
pilot [μs] - [mg/str]	[910]-[6.53]	[450]-[0.28]	[450] - [0.26]
dw_1 [μs]		[400]	[400]
$main_1$ [μs] - [mg/str]		[780]-[6.15]	[570] - [3.25]
dw_2 [μs]			[400]
$main_2$ [μs] - [mg/str]			[550] - [3.07]
$Q_{TOT.}$ [mg/str]	[6.53]	[6.43]	[6.58]

	BOSCH - P_{inj}= 60 MPa		
	Single	Double	Triple
pilot [μs] - [mg/str]	[460]-[6.79]	[150] - [0.36]	[150] - [0.30]
dw_1 [μs]		[400]	[400]
$main_1$ [μs] - [mg/str]		[410] - [6.21]	[320] - [2.89]
dw_2 [μs]			[400]
$main_2$ [μs] - [mg/str]			[280] - [3.28]
Q_{TOT} [mg/str]	[6.79]	[6.57]	[6.47]

Energizing solenoid currents and corresponding fuel injection rates comparison for the two injectors

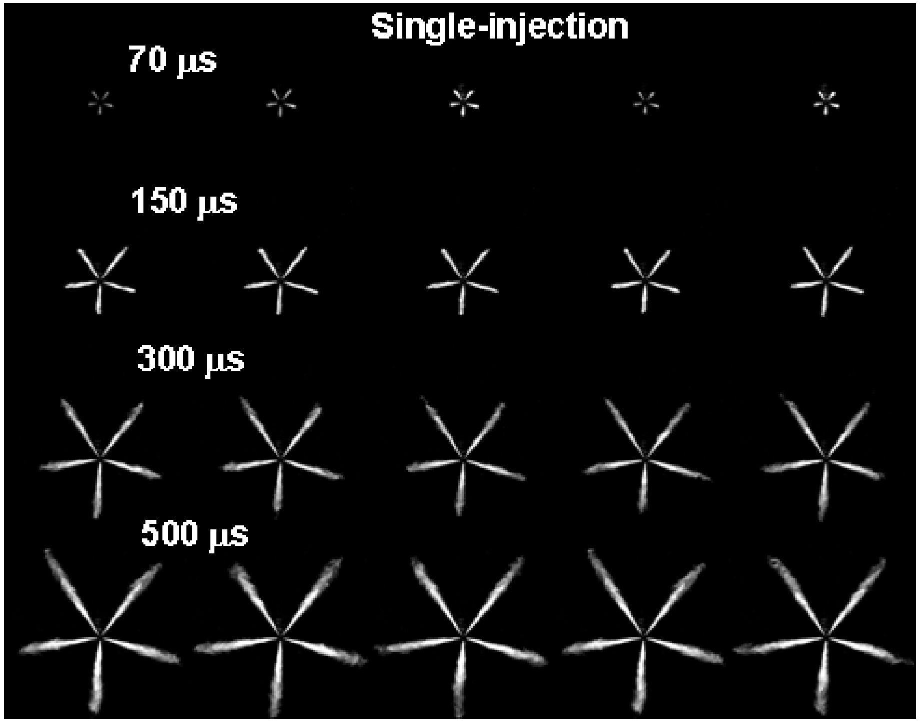


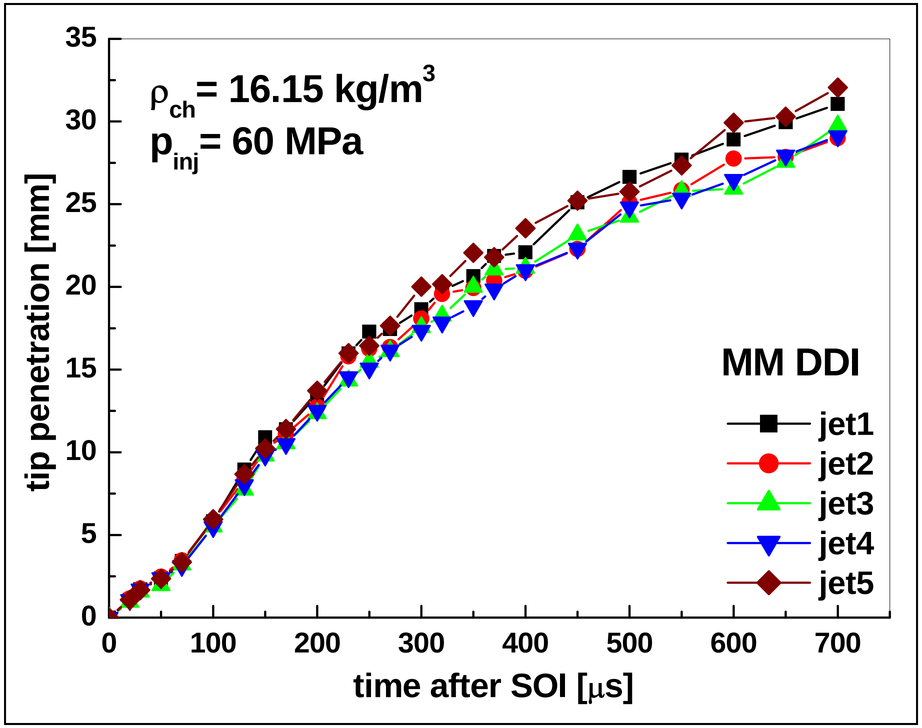
Adopted strategies and relative delivered quantities for MM DDI and Bosch injectors at p_{inj}= 50 MPa

	MM DDI - P_{inj}= 50 MPa		
	Single	Double	Triple
pilot [μs]-[mg/str]	[860]-[6.52]	[420]-[0.33]	[415] - [0.27]
dw_1 [μs]		[400]	[400]
$main_1$ [μs]-[mg/str]		[690]-[6.08]	[480] - [3.09]]
dw_2 [μs]			[400]
$main_2$ [μs]-[mg/str]			[440] - [3.18]]
$Q_{TOT.}$ [mg/str]	[6.52]	[6.41]	[6.54]

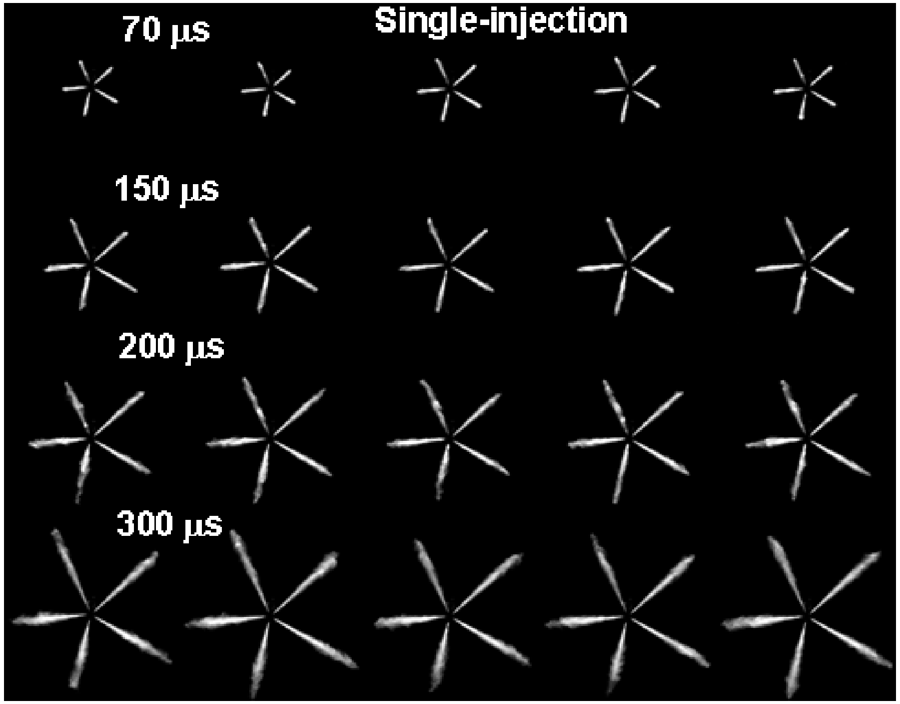
	BOSCH - P_{inj}= 50 MPa		
	Single	Double	Triple
pilot [μs]-[mg/str]	[500] - [6.47]	[170]-[0.35]	[170]-[0.32]
dw_1 [μs]		[400]	[400]
$main_1$ [μs]-[mg/str]		[460]-[6.41]	[330]-[2.93]
dw_2 [μs]			[400]
$main_2$ [μs]-[mg/str]			[300]-[3.25]
Q_{TOT} [mg/str]	[6.47]	[6.76]	[6.50]

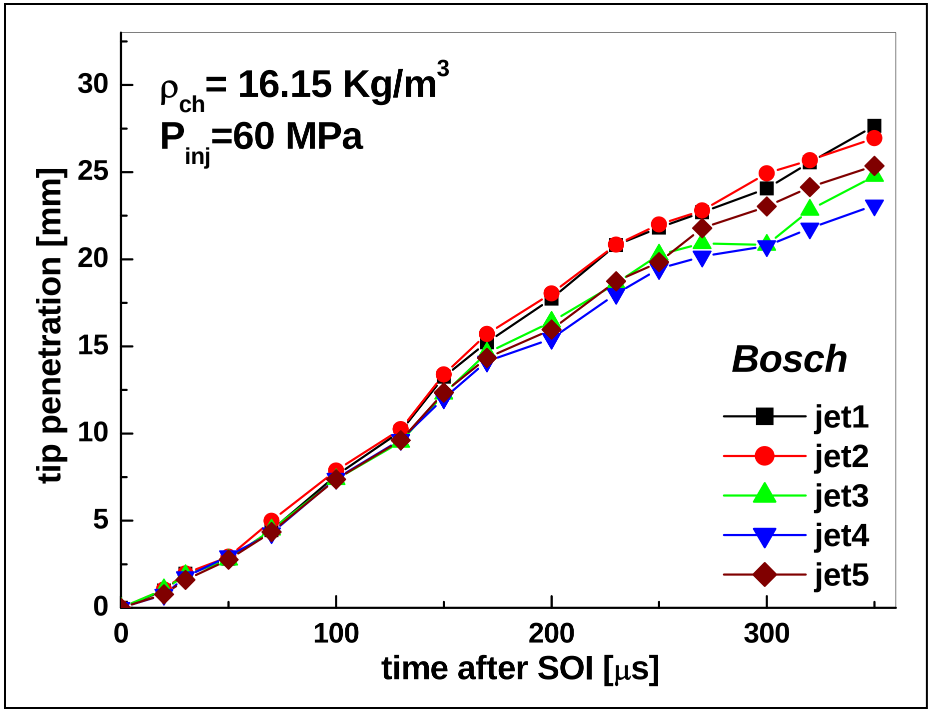
Jet dispersion for MM DDI injecting 6.5 mg/str

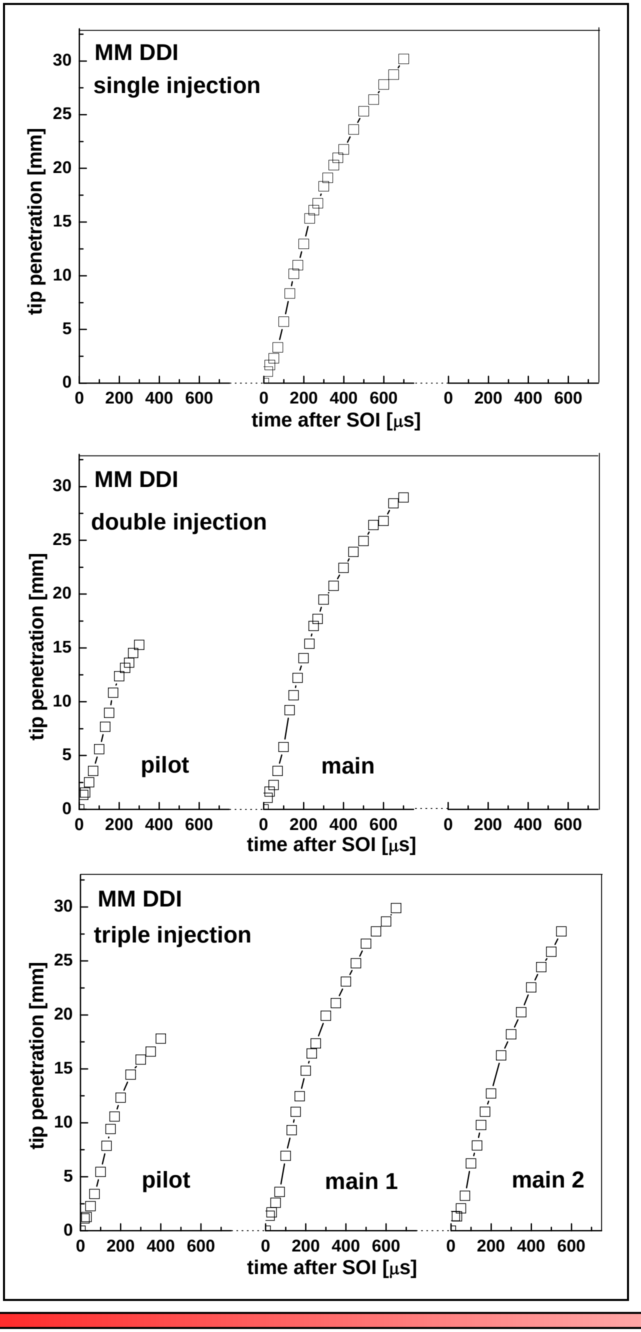


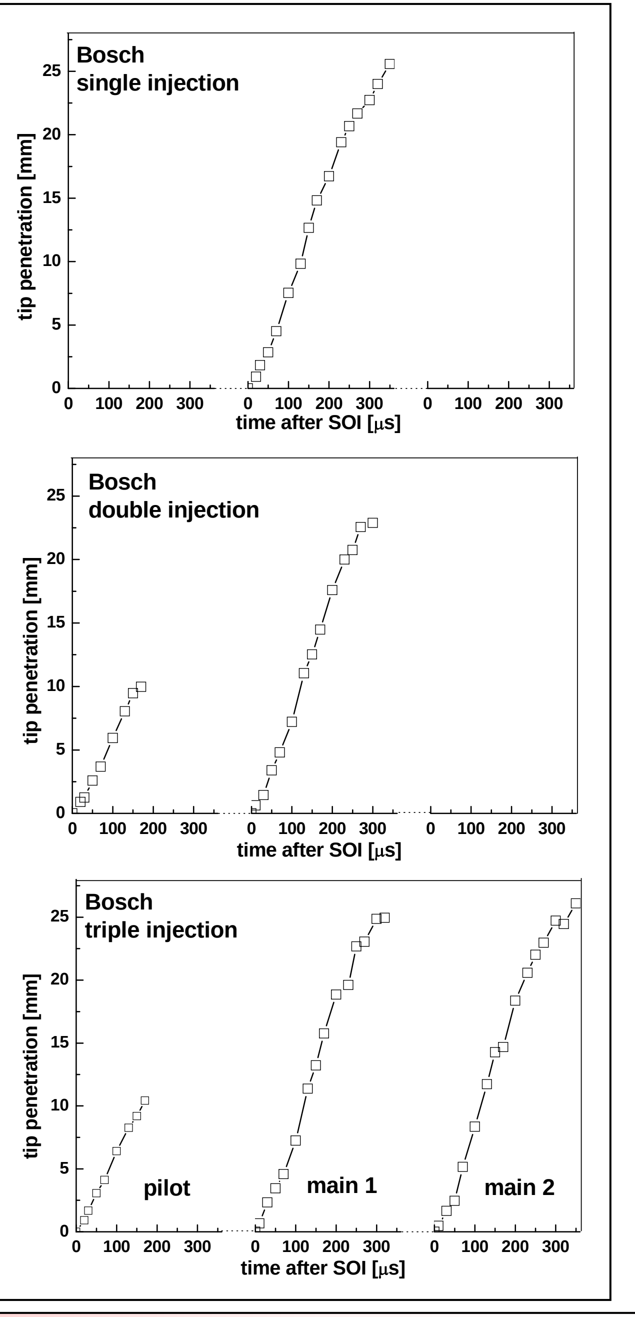


Jet dispersion for Bosch injecting 6.5 mg/str






MM DDI
single injection
double injection
triple injection
pilot
main
main 1
main 2
tip penetration [mm]
time after SOI [µs]


Bosch
single injection
double injection
triple injection
pilot
main
main 1
main 2
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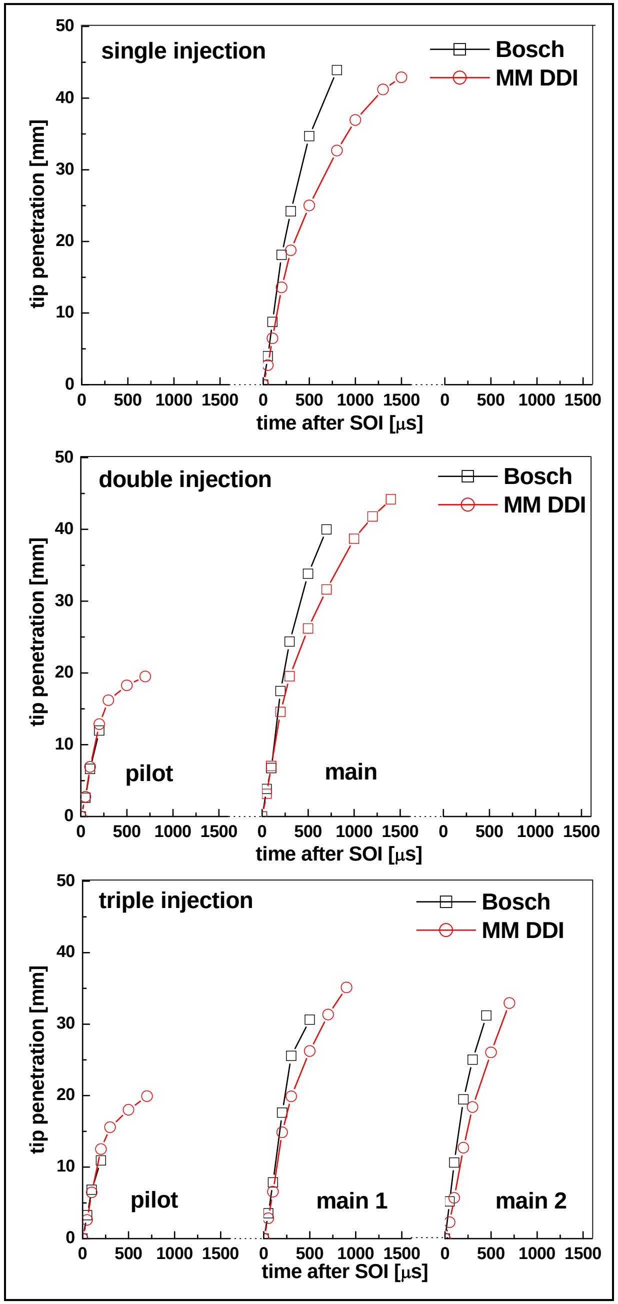


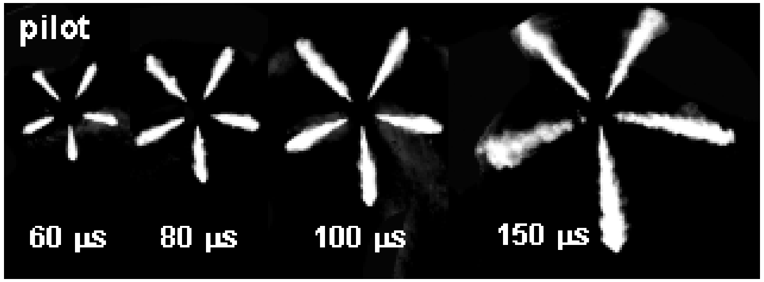
Bosch vs MM DDI tip penetration for the three injection strategies

All the injection strategies have highlighted a reduced penetration speed for the MM injector compared to the Bosch one.

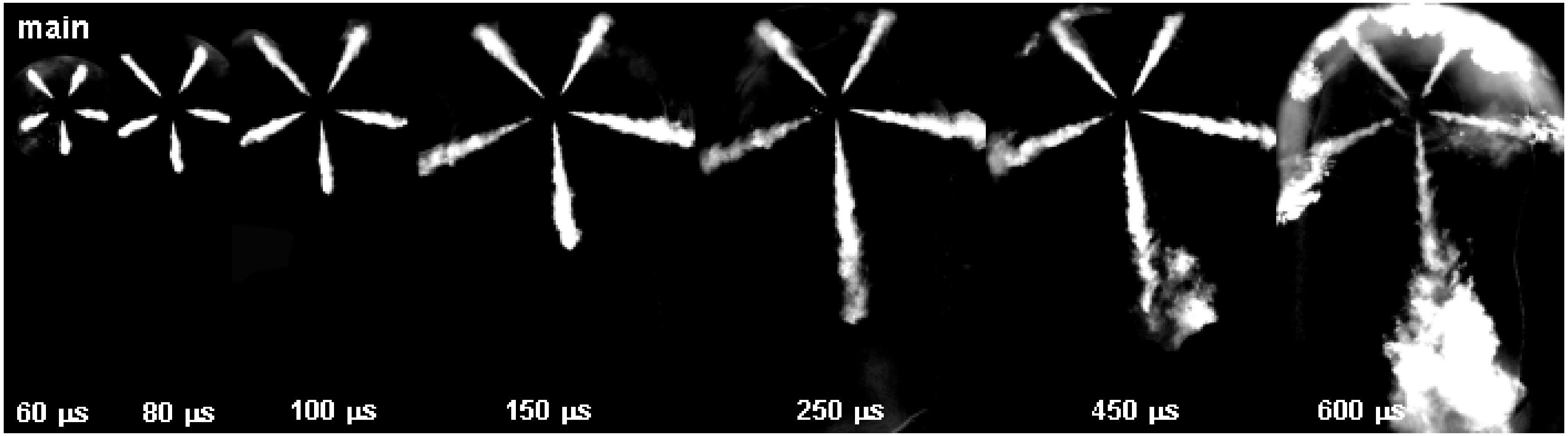
Spray-cone angle comparison

Cone angle - P_{inj}= 60 MPa - ρ_{ch} = 16.15 kg/m^3		
	BOSCH	MM DDI
Single [deg]	9.3	12.9
Double [deg]	9.3	12.2
Triple [deg]	9.7	12.5

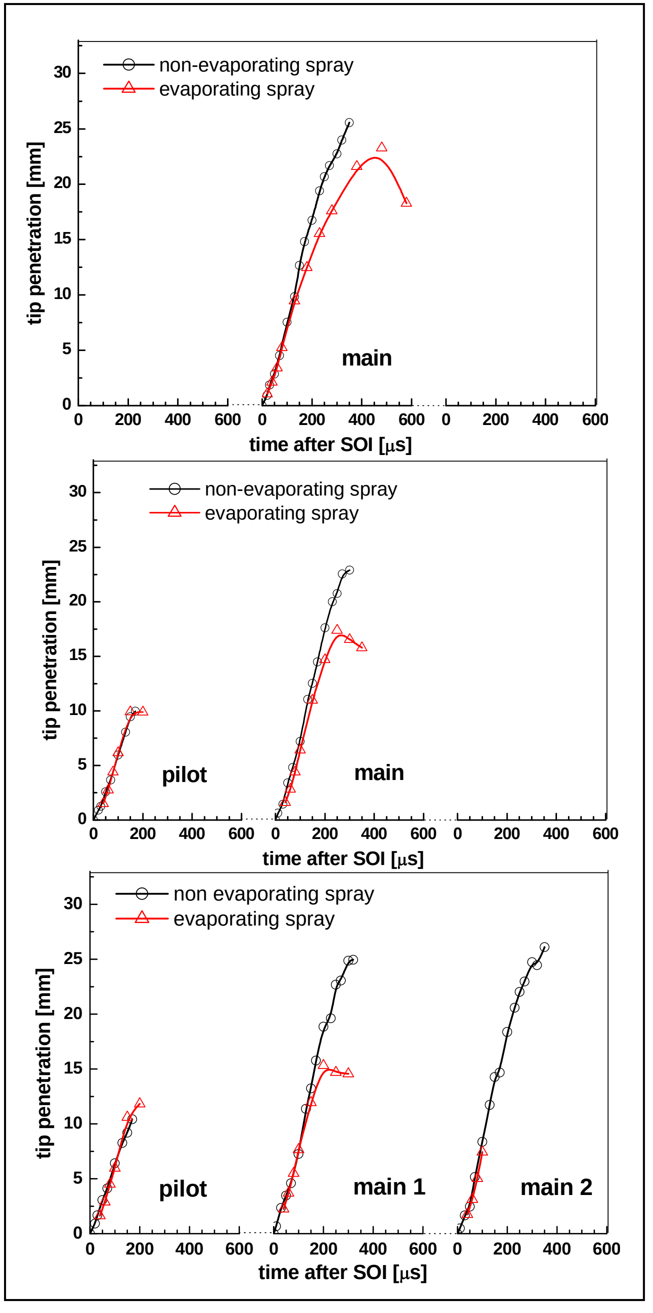
EVAPORATING CONDITIONS (Bosch injector)



Uniform behavior of each single jet, good stability also for small amount of delivered fuel



The oval shape of the optical access allows to follow the full penetration only for one jet (averaged on 5 shots)



Tip penetration comparison for **Bosch injector** at 60 MPa in non evaporating and evaporating conditions

The plots show a perfect overlapping trend for the non evaporating and evaporating sprays up to 150 µs.

During the early stage, both conditions show the same linear slope indicating that the fuel jet momentum is the main parameter controlling the process

At later time, the liquid penetration, for evaporating sprays, slows down because of the evaporation process and the incipient combustion

CONCLUSIONS

Innovative, gasoline-derived, needle direct command injector has been tested for supplying fuel to light duty diesel engines in multiple strategy mode

The tests have been carried out at typical diesel-like gas density conditions in quiescent ambient

Injection rate behavior and spray morphology have been measured for single, double (pilot + main) and triple (pilot + split main) injection strategies

Behavior and performances have been compared with the last-generation commercially-available hydraulic-command injector (Bosch) for multiple injections

CONCLUSIONS (cont.'d)

Both the injectors have shown a good stability for small amount of delivered fuel with a uniform evolution of each jet

The innovative injector confirms the capability to make consecutive injections and to control double and triple injections with short dwell time

The two injectors have shown different penetrations due to diverse fuel injection rate, consequence of their peculiar working mechanisms

The Bosch injector delivers an equivalent amount of fuel in a shorter time compared to the Magneti Marelli

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THANK YOU FOR YOUR ATTENTION

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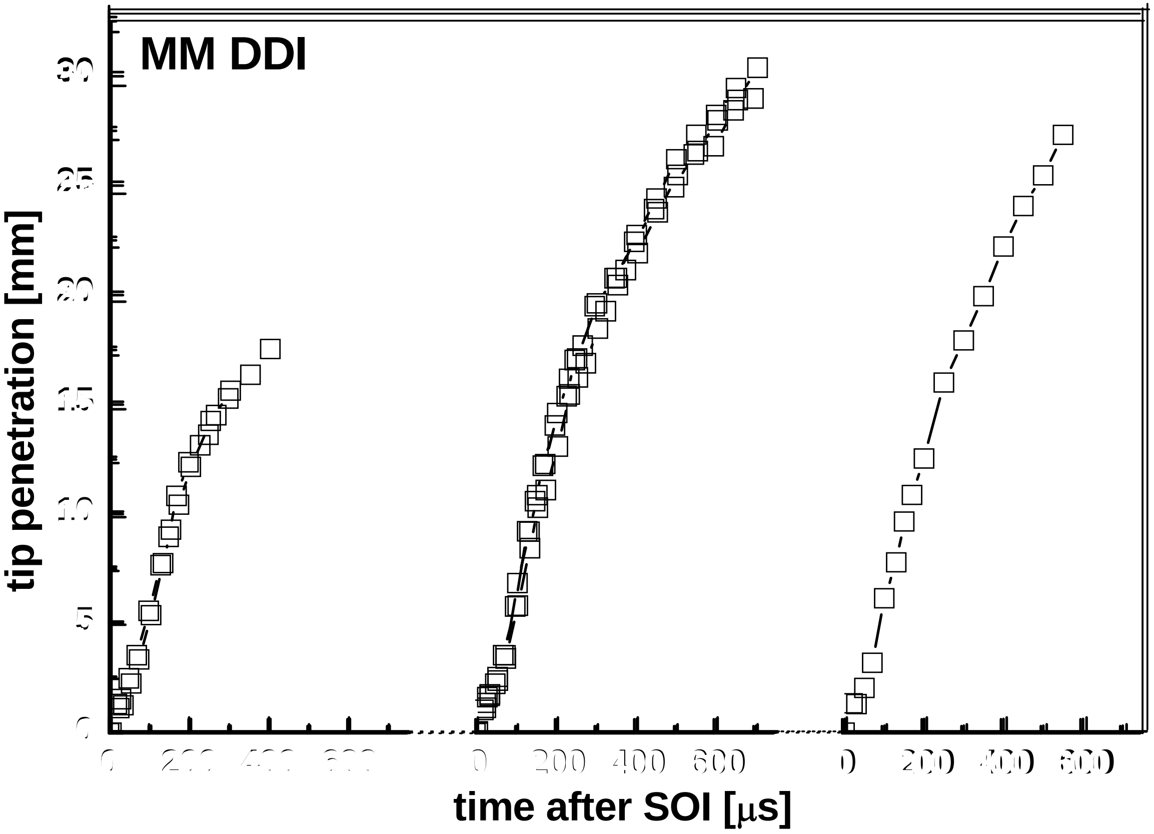
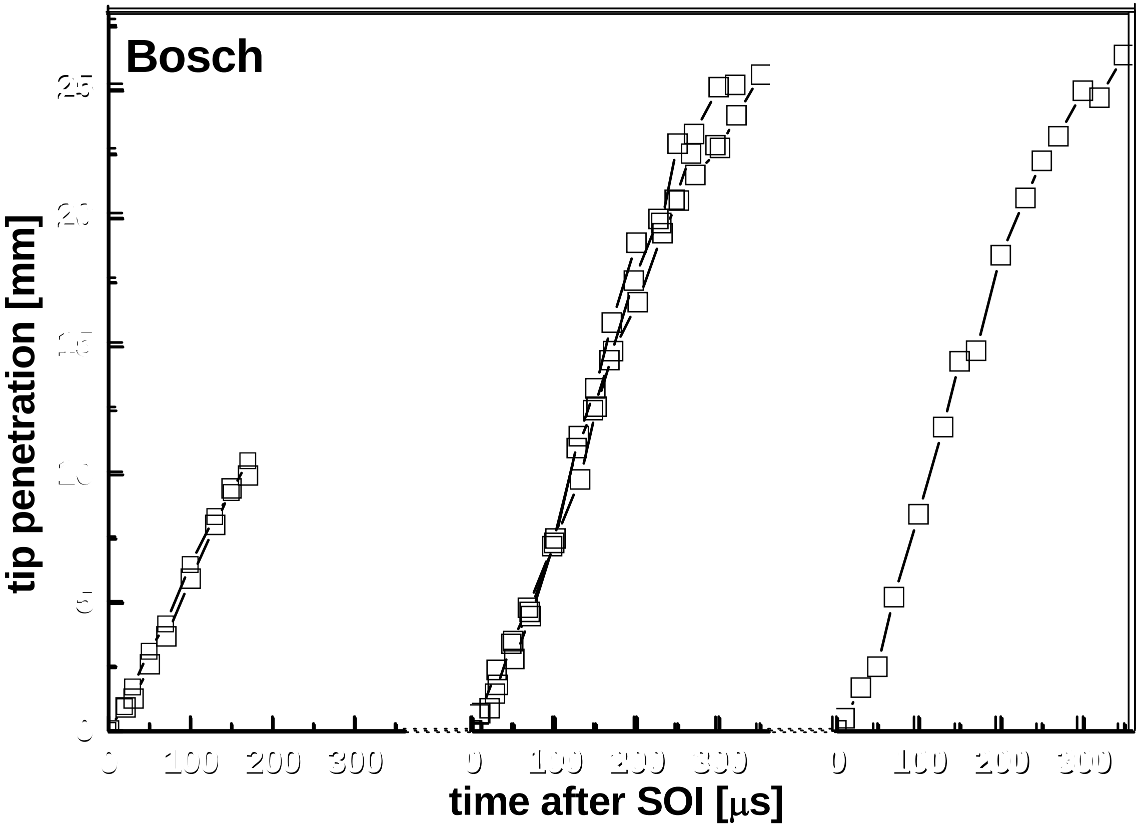
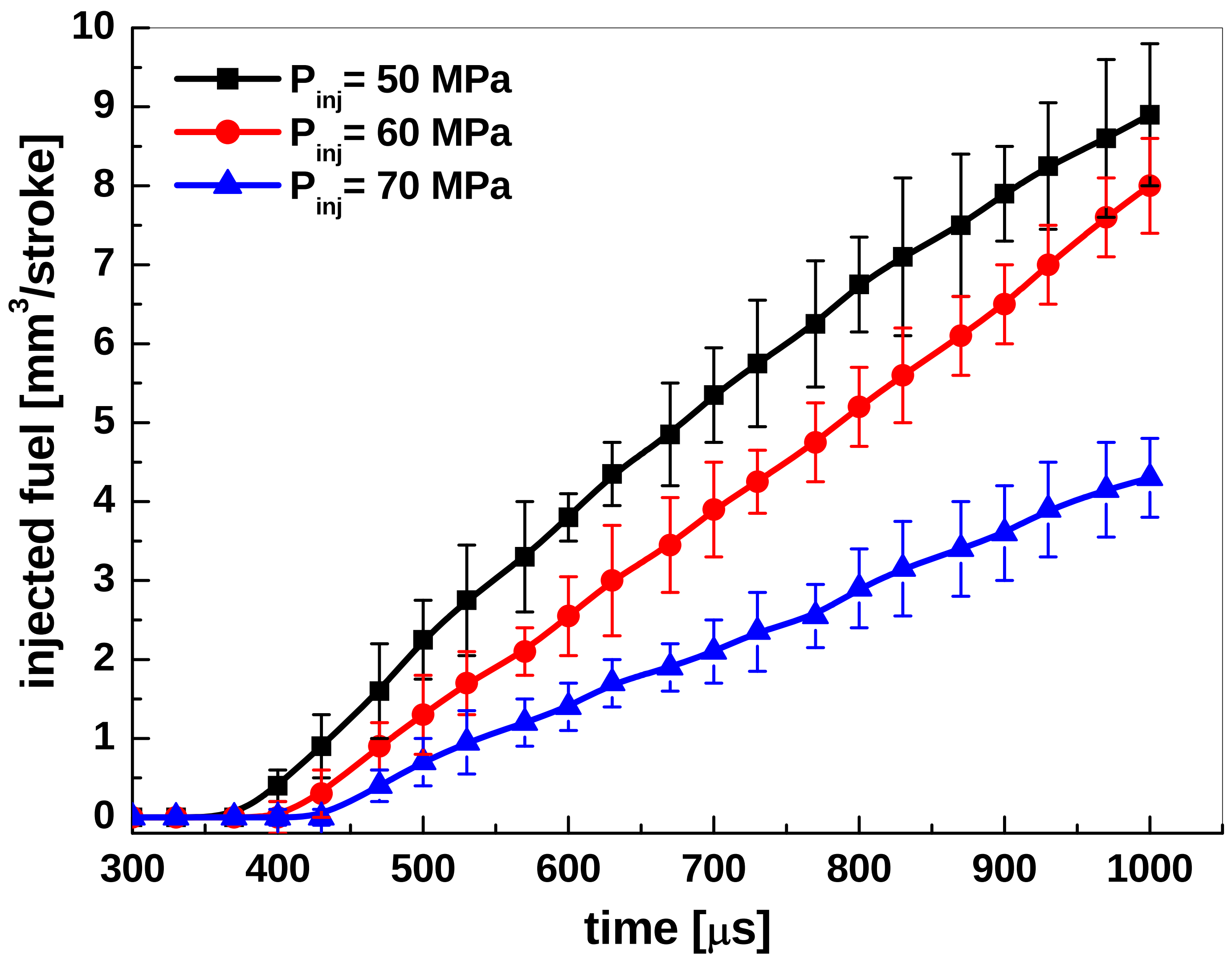
MM DDI tip penetration for the three injection strategies



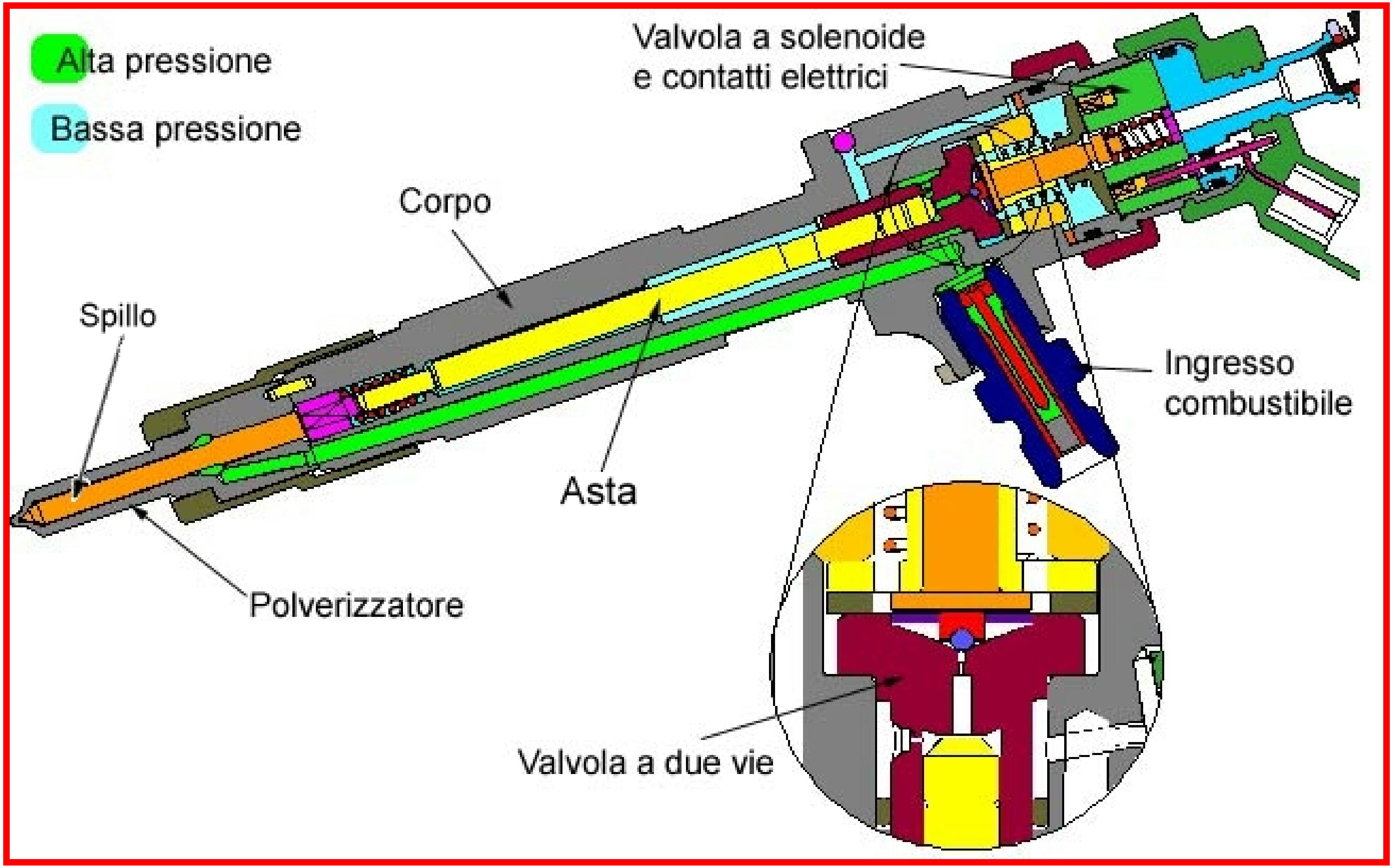
Bosch tip penetration for the three injection strategies



Delivered fuel amount versus injection duration



Inner hydraulic circuit injector

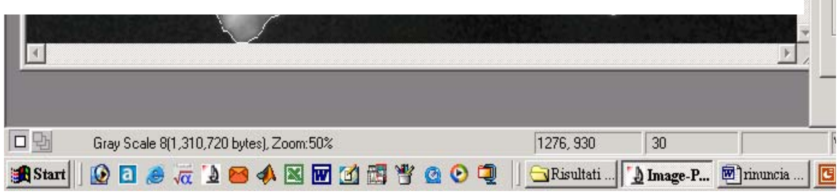


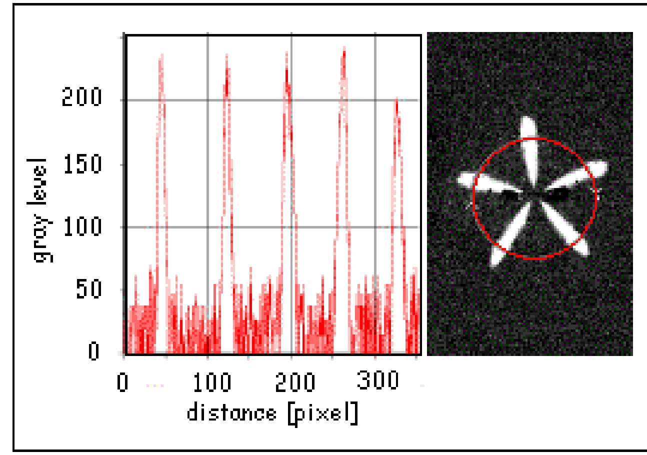
Images Processing

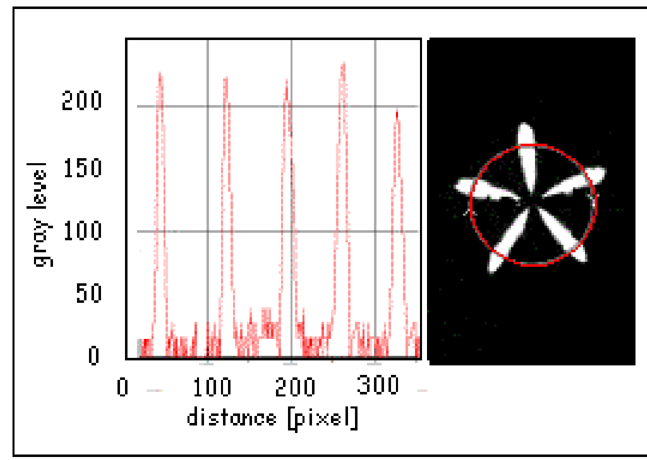
The processing procedure has been divided into:

- ➢Background subtraction
- ➢Image filtering
- ➢Fuel spray edges determination

A median filter has been applied to remove impulse noise from the spray image







Histograms of gray levels before (top) and after (bottom) the filter application

The sprays images have been proce
Image Pro Plus to extract the main pa