Transient Characteristics of GDI Injectors using Statistical Extinction Tomography

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Outline

- Background
- Experimental methods
- Results

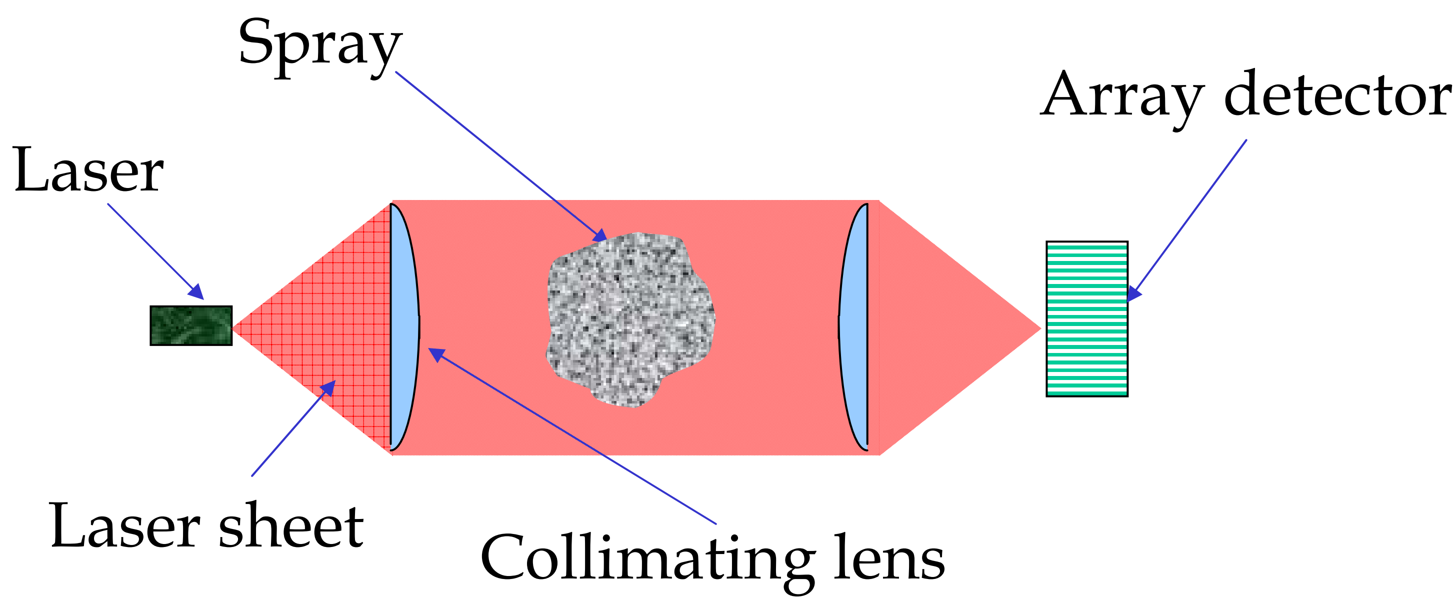
Background

- *Spray characteristics affect engine performance (Speigel and Spicher, 1992, Davy et al., 2000, Zhoa et al., 2002)*
- *Multi-hole configuration better than pressure swirl atomizers (Fujieda et al., 1995; Arcoumanis et al., 1998)*
- *Spray characteristics vary with ambient pressure and fuel temperature (Schmitz et al., 2002; Parish et al., 2010)*

Objective of this study is to investigate the use of extinction tomography to characterize dense multiple plume sprays

Experimental Methods

Optical Configuration



- Single axis extinction measurement at 9.4 KHz
- Planar extinction through 512 parallel paths
- Injector rotated 12 times to obtain multiple view data

Experimental Arrangement

Setscan AP400 patternator

- ***250 mm nominal ID***
- ***100 mm silica windows***
- ***~ 1m high vessel to reduce spray bounce***
- ***Injector rotated by 15 deg for a total of 12 views***
- ***Inert nitrogen atmosphere***
- ***Fuel heated upto 90 ^{O}C***
- ***5 injections per angle***

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Principle of Operation

- Path integrated extinction of laser sheets
- 12 view angles, 15 degrees apart
- 5 injection events ensemble averaged at each view angle
- 512 parallel path measurements at each view angle
- Local extinction coefficients in the plane obtained by deconvolution (MLE – Vardi and Lee, 1993)
- For dielectric liquids, local extinction coefficient is proportional to the drop surface areas per unit volume

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Importance of Surface Area Density

Control volume

Drop size varied from 1 to 100 micron
Velocity varied from 1 to 10 m/s
Number of drops varied from 1E5 to 1E7
Calculate evaporation rate

For static drop $$\dot{m} = \frac{4\pi k_g r_s}{C_{pg}} \ln(B+1)$$

For dynamic drop $$\dot{m}_{dynamic} = \frac{N_u}{2} \dot{m}_{static}$$

$$B = \frac{C_{pg}(T_\alpha - T_b)}{h_{fg}}$$

$$C_{pg} = C_{pF}(\overline{T}) \quad \text{and} \quad k_g = 0.4 k_F(\overline{T}) + 0.6 k_\infty(\overline{T}); \quad \overline{T} = (T_b + T_\infty)/2$$

$$N_u = 2 + \frac{0.555 \, Re^{1/2} \, Pr^{1/3}}{\left[1 + 1.232/(Re\,Pr)^{4/3}\right]^{1/2}}$$

*An Introduction to Combustion: Concepts and Applications," Stephen R. Turns, Mc. Graw Hill, 2000

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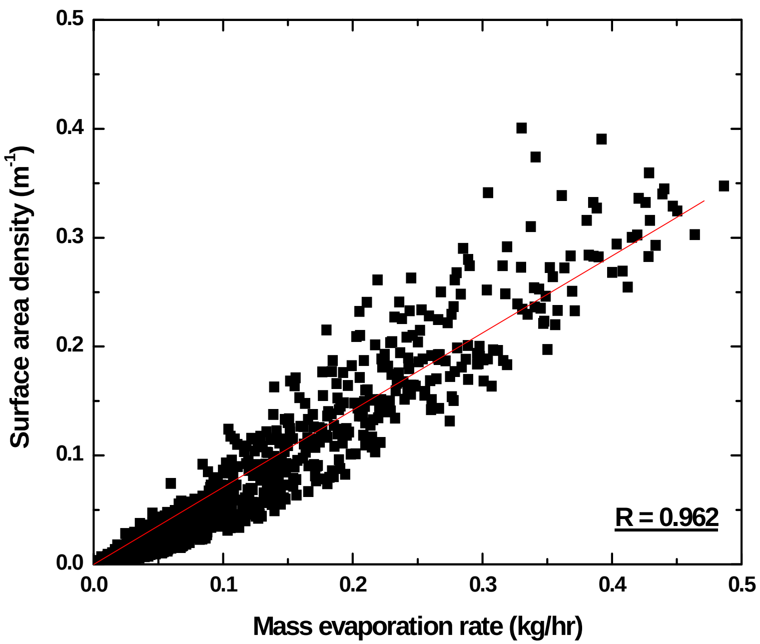
Importance of Surface Area Density



<u>Correlation coefficient (R) of spray parameters with evaporation</u>

Mass flux R = 0.903

Velocity R = -0.239

Diameter R = 0.681

Surface area density R = 0.961

- Total amount of fuel or liquid evaporated is proportional to heat release rate in combustion
- Important for combustion and spray drying

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Test Matrix

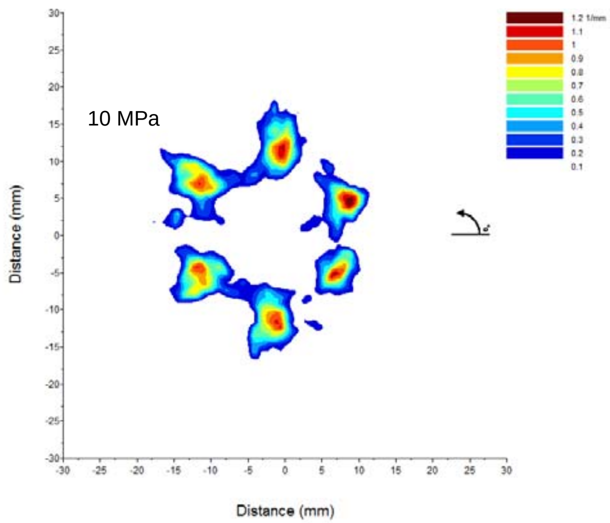
Test Conditions	Ambient Pressure (kPa)	Fuel Temperature (^oC)	Injection Pressure (MPa)
1	101	20	15
2	40	90	5
3	60	60	5
4	60	60	10
5	101	20	10
6	40	90	2

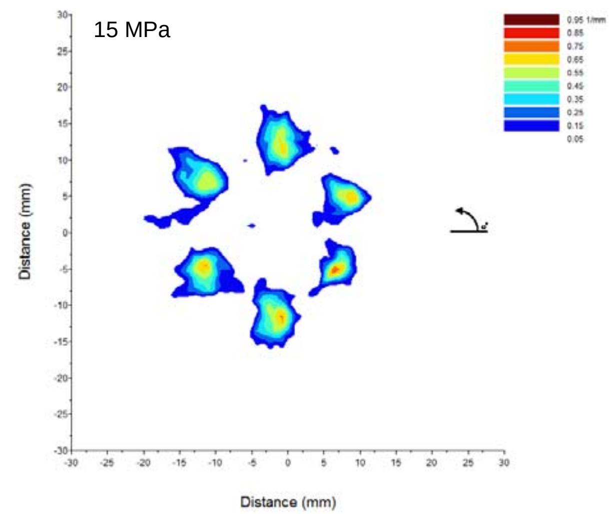
Injection at higher temperatures and lower than atmospheric pressures to simulate engine conditions. All tests carried out with calibrated gasoline-E10

Results

Six Plume Injector (20^{O} C)

1.035ms





Plume ID	Center R (mm)	Center θ (deg)	Center X (mm)	Center Y (mm)	Contour Area (mm^2)	Plume Angle (deg)	Peak Area (mm^{-1})	Total Area (mm^2)	% in Plume
1	12.1	19.8	8.0	5.1	33.2	7.4	0.69	11.3	13.2
2	11.8	77.5	-0.9	12.5	45.5	8.7	0.69	16.3	19.0
3	10.6	142.1	-11.8	7.5	43.6	8.5	0.69	14.7	17.1
4	10.3	218.0	-11.6	-5.3	47.4	8.9	0.75	15.4	17.9
5	12.6	278.0	-1.7	-11.5	44.8	8.6	0.71	16.4	19.0
6	11.8	330.8	6.8	-4.7	27.5	6.8	0.83	9.4	11.0
Total (plume separation at 15.9%)								83.5	97.2

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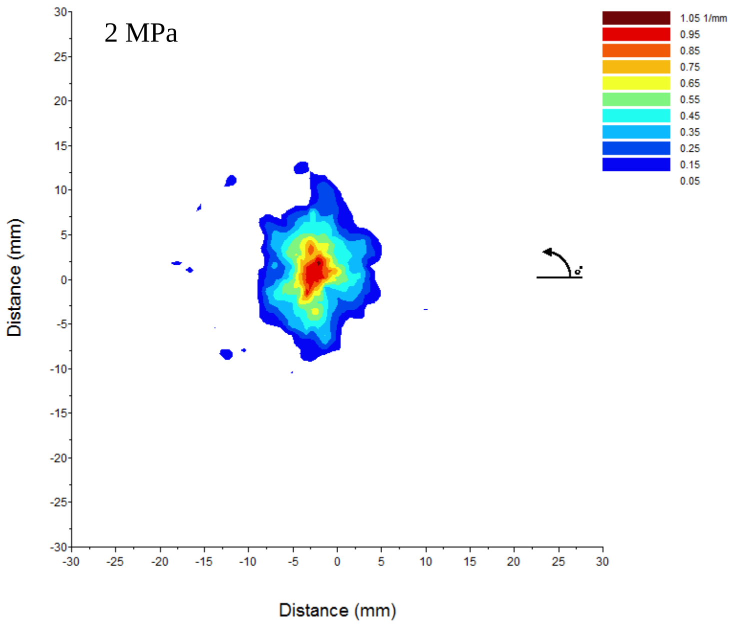
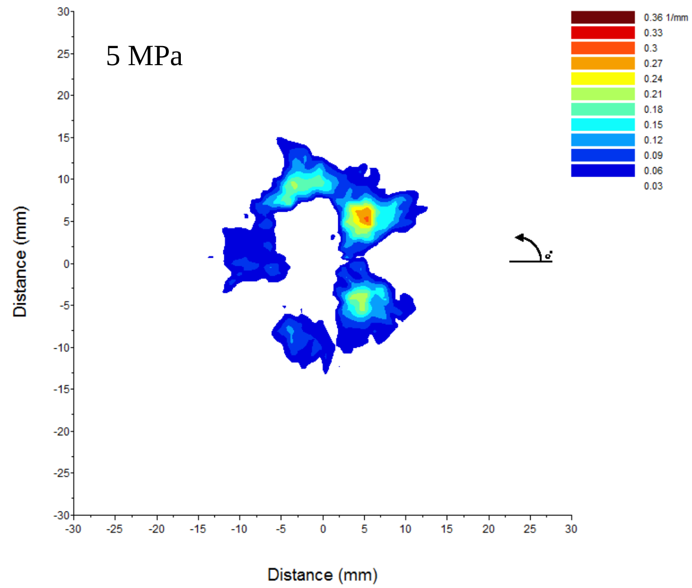
Six Plume Injector (90^O C)





- Individual plumes not visible at low ambient pressures and high fuel temperatures

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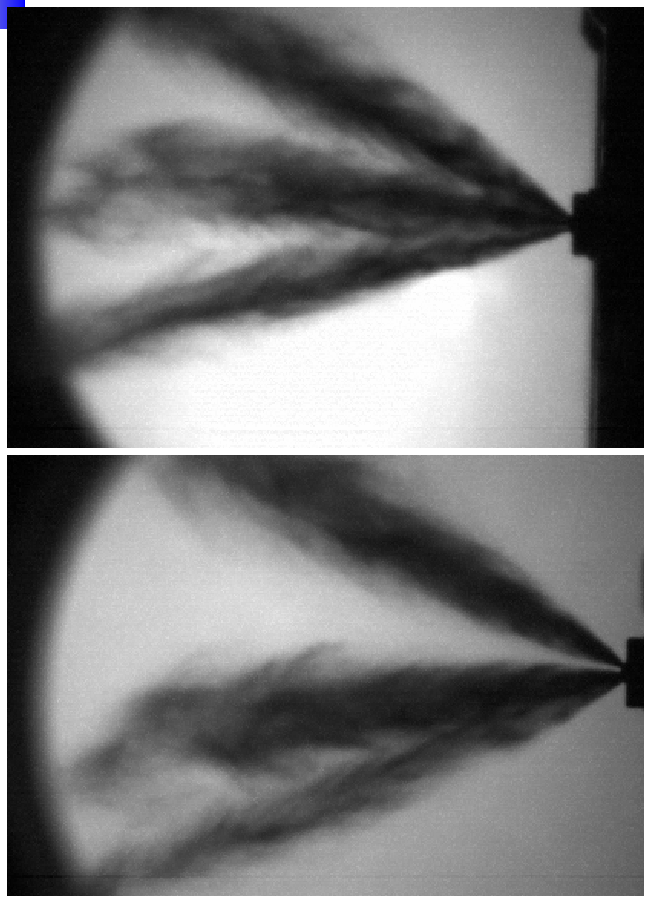
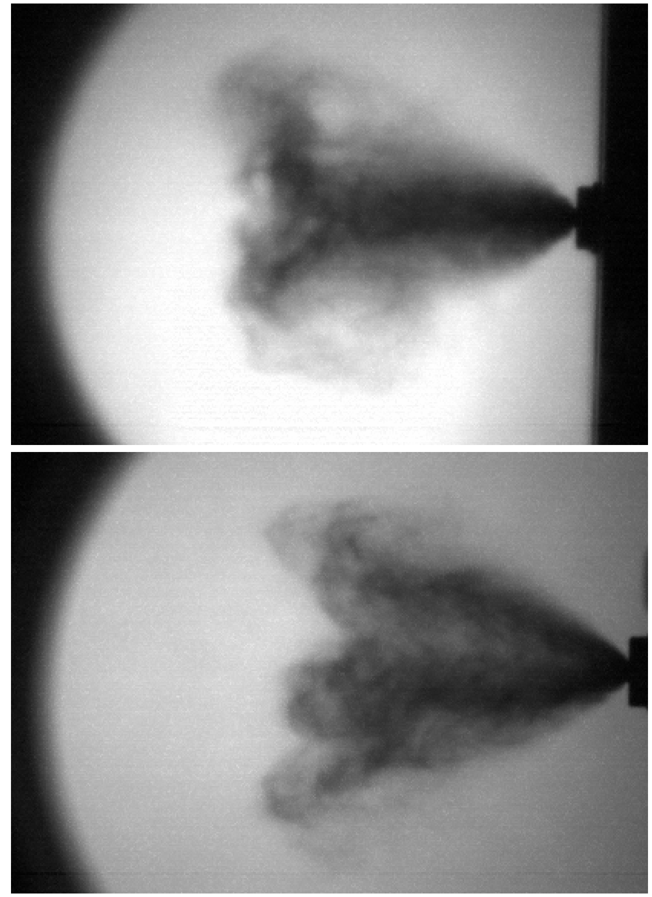
High Speed Video



Six

Five



10 MPa, 20 ^{O}C, 101 KPa

2 MPa, 90 ^{O}C, 40 KPa

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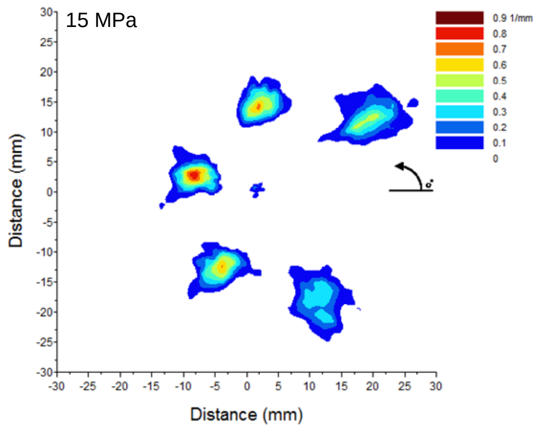
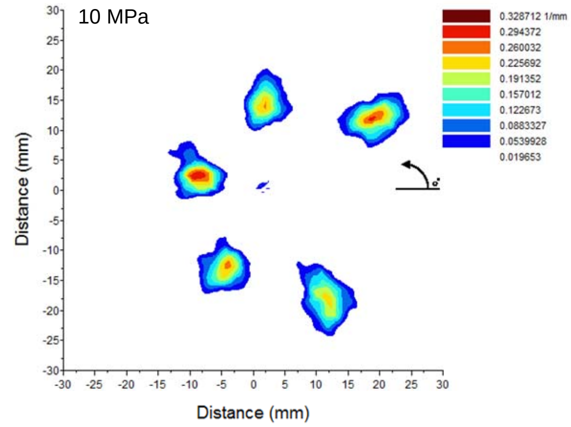
Five Plume Injector (20^{O} C)

1.035ms





Plume ID	Center R (mm)	Center θ (deg)	Center X (mm)	Center Y (mm)	Contour area (mm2)	Plume angle (deg)	Peak area (mm-1)	Total area (mm2)	% in plume
1	22.7	35.6	18.5	13.2	108.8	26.5	0.31	10.7	22.2
2	14.9	86.1	1.0	14.9	89.3	24.1	0.26	8.3	17.1
3	9.3	165.8	-9.0	2.3	103.4	25.8	0.32	9.3	19.3
4	13.6	253.4	-3.9	-13.0	99.8	25.4	0.28	8.6	17.8
5	21.3	305.6	12.4	-17.3	131.3	29.0	0.26	10.9	22.6
Total (plume separation at 5.3%)								**47.8**	**99.1**

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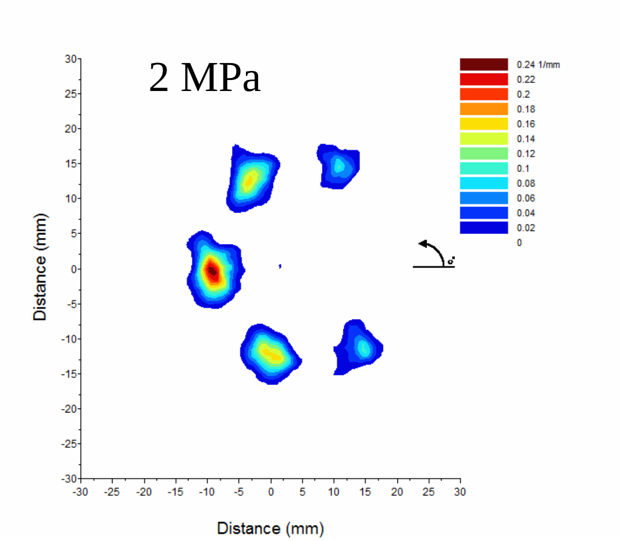
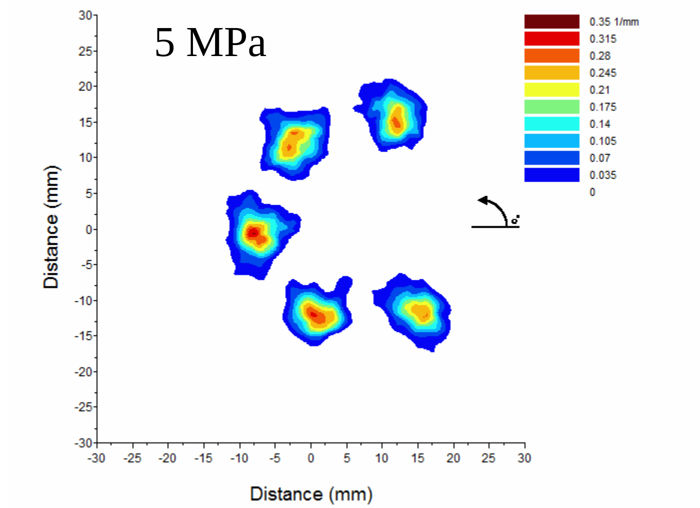
Five Plume Injector (90^{O} C)





- **Plumes still distinct at higher temperatures and lower ambient pressure**

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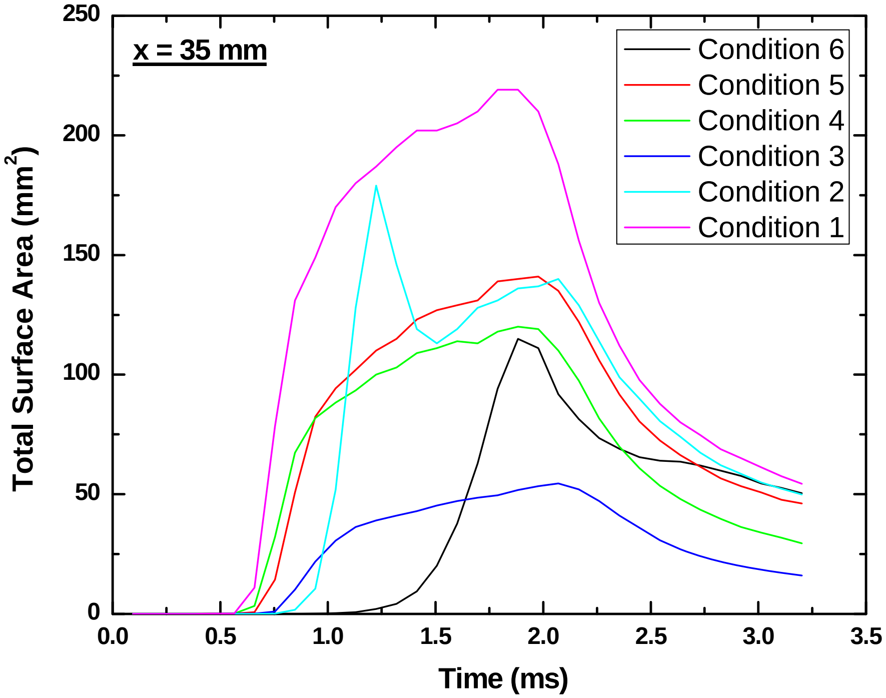
Transient Total Surface Areas



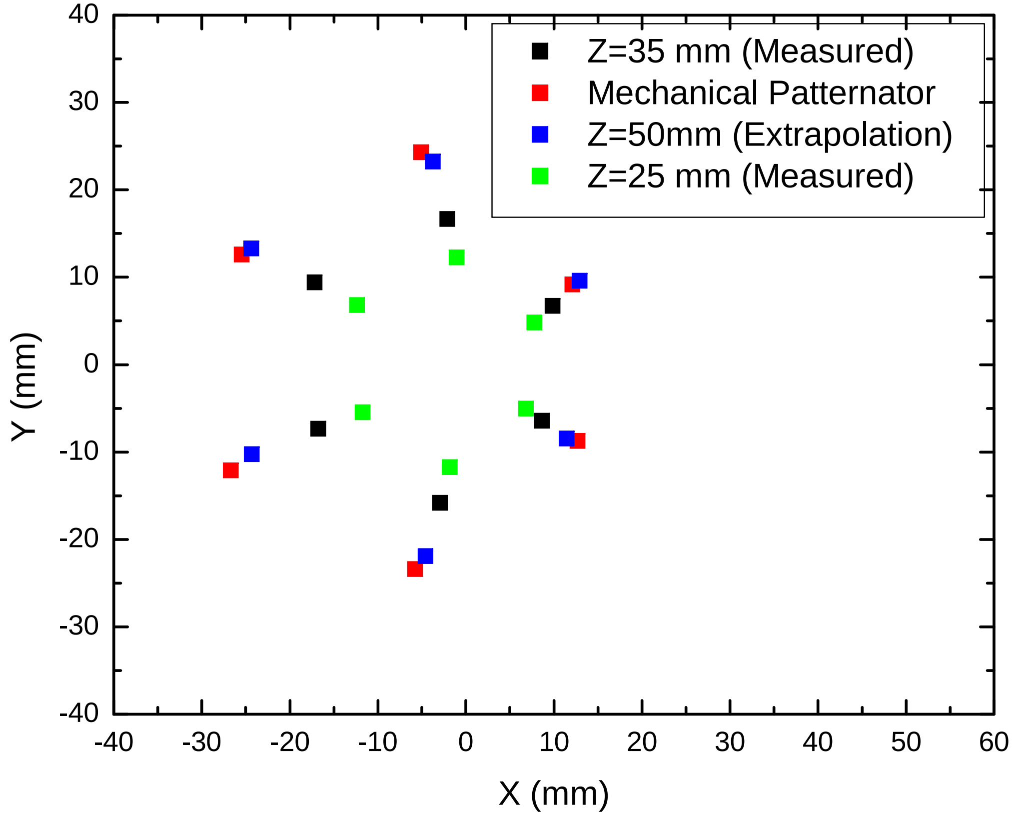
20 ^{O}C (1 and 5)

60 ^{O}C (3 and 4)

90 ^{O}C (2 and 6)

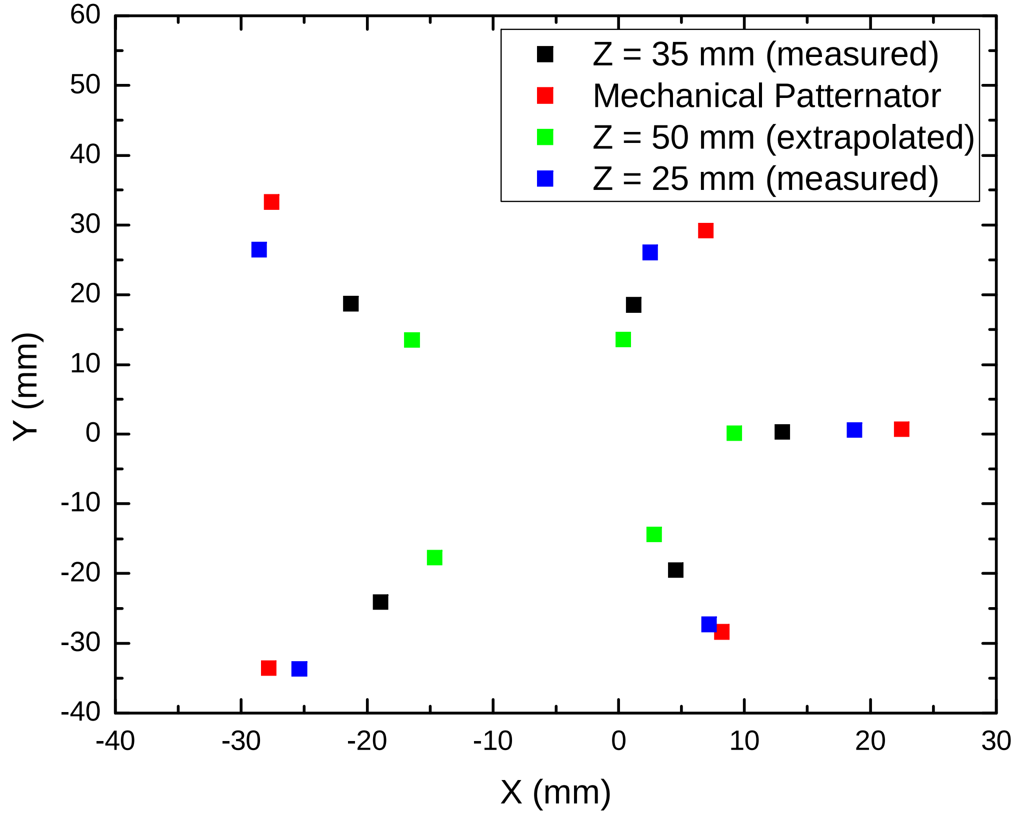
- **Profiles similar for same temperature and ambient pressures**
- **Lower injection pressures shows delay in peak values and lower peak values**
- **Injection temperature changes profile significantly**

Comparison with Mechanical Patternator



Centriods from mechanical patternator is slightly further away

Comparison with Mechanical Patternator



Centriods from mechanical patternator is slightly further away

Conclusions

- The peak surface area density increasing with increasing injection pressure.
- There is a merging of the plumes at higher temperatures and lower ambient pressures.
- The centroid locations obtained from the mechanical and optical patternator were in good agreement for both the injectors tested in this study
- The centroid locations do not vary much with pressure
- Extinction tomography is useful to characterizing the fuel spray from GDI injectors

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