Characterization of Fuel Injectors and Urea Dosers

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Outline

- **Spray Characterization Methods**
- **Sample Results**
- **Quality assurance of injectors and dosers**

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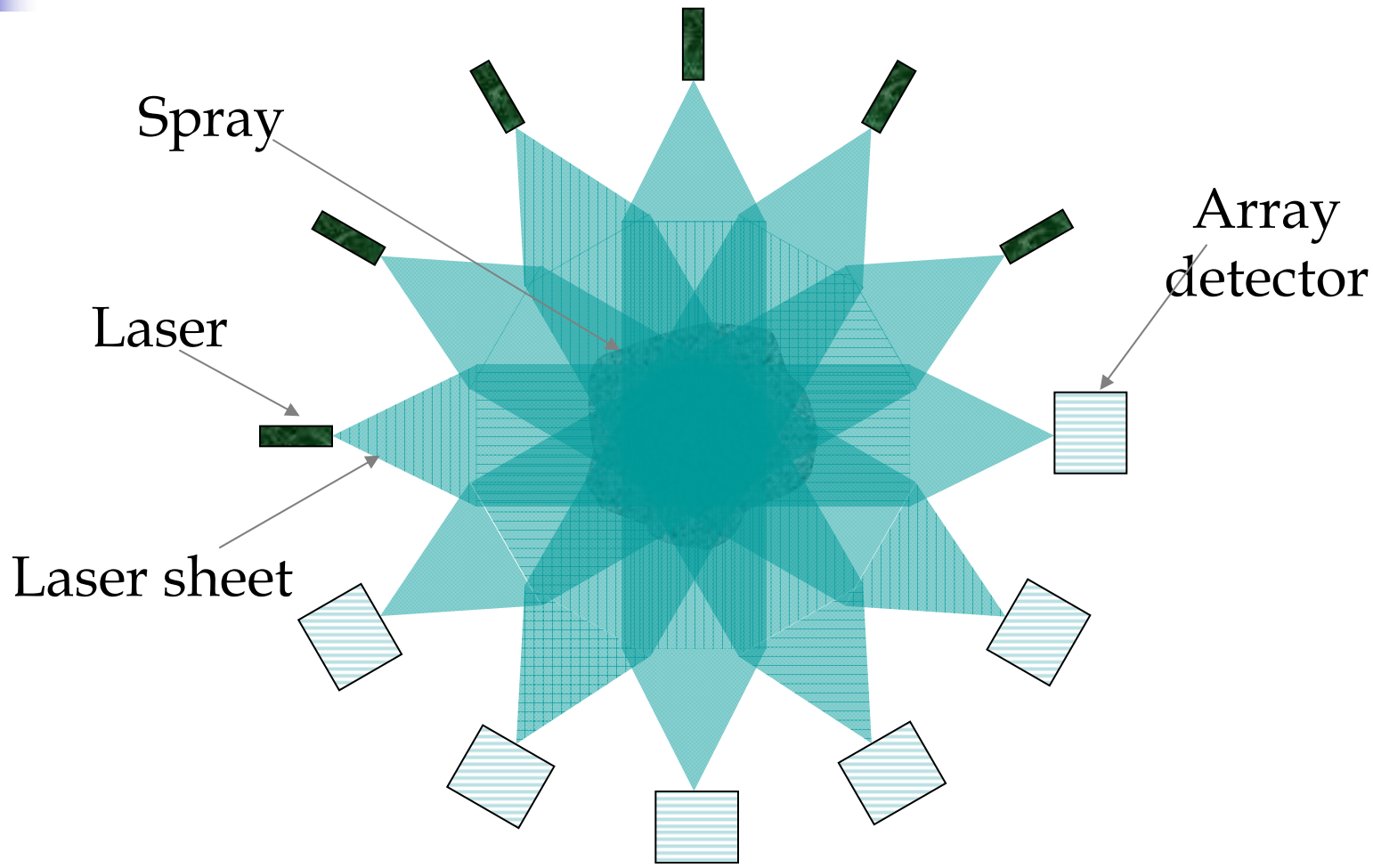
Experimental Techniques

- Extinction tomography for planar drop surface area distribution, plume angles, % split amongst plumes, separation angles, and spray pattern
- Pattern Imaging Velocimetry for planar axial and radial velocities
- Temporally resolved to 100 microseconds

Extinction Tomography (SETscan)



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Principle of Operation

- **Path integrated extinction of laser sheets**
- **Multiple view angles for non-axisymmetric turbulent flows**
- **Multiple slices to obtain high spatial resolution**
- **Local extinction coefficients obtained by statistical tomography (MLE method)**
- **For liquid sprays, the local extinction coefficients is equal to the drop surface areas per unit volume**

Measurement Characteristics

Aerosol limitations	**Unrestricted**
Distance to sample	**Unrestricted**
Probe volume	**Planar**
Size	**Unrestricted**
Number limitation	**Extinction**
Sampling type	**Concentration**
Measured quantities	**Surface area * no. of drops/m^3**
Dynamic range	**Instrument SNR**
Sampling mode	**Instantaneous, time averaged, time resolved**
Sensitivity highest	**Uniform across range**

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Why surface area density

- Total amount of fuel or liquid evaporated is proportional to heat release rate in combustion and solid mass fraction in spray drying.
- Correlation coefficient (R) of different parameters with total fuel evaporated
- Mass flux R = 0.903 Velocity R = -0.239
- Diameter = 0.681 ***Surface area density = 0.961***

For combustion, spray drying, and urea dosing applications, surface area density is optimal method of comparing different nozzles or checking uniformity

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Comparison with Competitive Technology

- Extinction ⇒ Immune to environmental lighting
- Diode lasers ⇒ Class II, No safety issues
- Monolithic ⇒ Out-of-box factory floor deployment
- Adaptive grids ⇒ Alignment of nozzle not critical
- Advanced GUI ⇒ Easily operated by technician
- Reliable ⇒ 100% quality assurance of nozzles

Only quantitative (+/- 2% on absolute values, +/- .5% repeatability) patternator on the market

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Comparison of Methods

Measurement Characteristics	Light Scattering Interferometry	Fraunhofer Diffraction, Ensem	Light Sheet Imaging	Extinction Tomography
Basic Measurement	***Diameter/Velocity***	***Diameter***	***Pattern***	***Surface area***
Accuracy	+/- 20%	+/- 20%	Not quantitative	+/- 2%
Particle Shape Restriction	Spherical	Sphere,Irregular	Spherical	none
Particle Composition	Transparent, Opaque	Better if opaque	None	none
Index of Refraction Dependence	Yes	Partial/none	None	None/Imaginary
Working distance (Trans to Det)	3 m	0.5 m	0.5m	Unlimited
Sample Volume	Small, Point	Line of site	Plane/volume	Plane/volume
Sample Volume Bias	Yes, Correction	None	Yes, Correction	None
Size Minimum, mm	0.3	0.3	3	Unlimited
Maximum size	1,000	500	unlimited	Unlimited
Number Density Maximum	Coincid/extinction	Extinction/MultiScat	Extinction/overlap	Extinction
Number Density Minimum	None	Yes, Low SNR	Blank Images	Low SNR
Sampling Type	Flux Dependent	Concentration	Concentration	N/A
Sampling Mode	Time ave/	Instantaneous/	Instantaneous	Time Ave, Time
	Time Resolved	Time Reolved		Resolved, Instant
Size Dynamic Range	50	50	20	N/A
Particle Velocity	Yes	No	Possible	Possible
Number Density Measurements	Yes	Yes, With extinction	Yes	Yes
Measurement Sensitivity	Highest for largest	Highest for middle	Highest for largest	Uniform across range

Imaging Velocimetry

- **Two types on instruments available for planar velocity estimation in sprays**
- **Planar Particle Imaging Velocimetry and Statistical Pattern Imaging Velocimetry**
- **First type tracks individual particles and determines displacement**
- **Second type tracks flow patterns and determines peak spatial correlations over a fixed time window**

Advantages and Disadvantages of SPIV

Advantages

- **Does not require distinct particles**
- **Works with various types of lighting such as shadowgraphy and natural lighting**
- **Work equally well with dense sprays**
- **High powered lasers not required**

Disadvantages

- **Longer computational time required**
- **Minimum 10 KHz camera**

Sample Results

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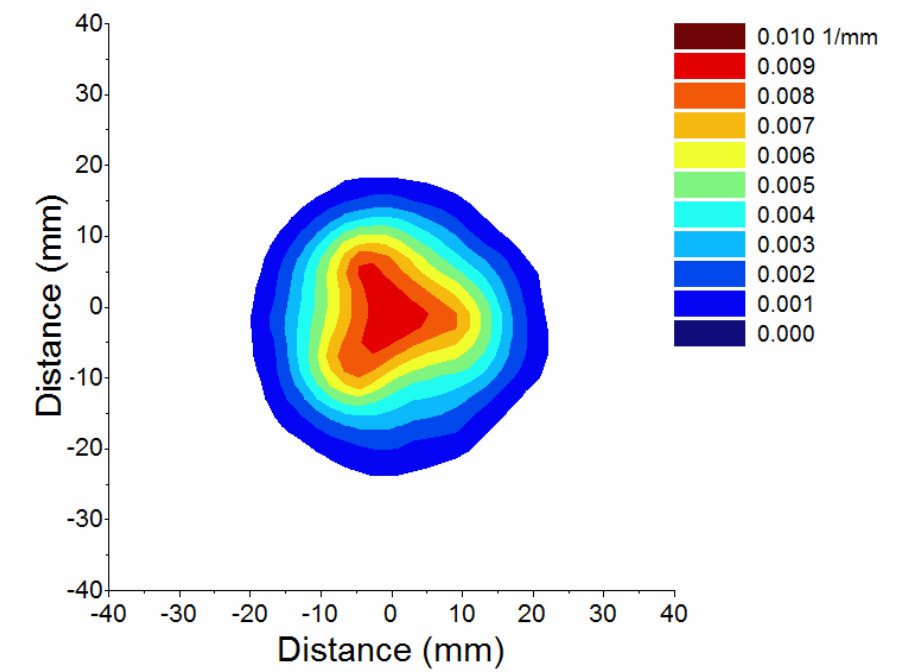
Sample Results Patternator

- Urea doser
- Spray pattern is not very axisymmetric
- 90% of the spray is within a small angle
- Quantitative values of surface area densities



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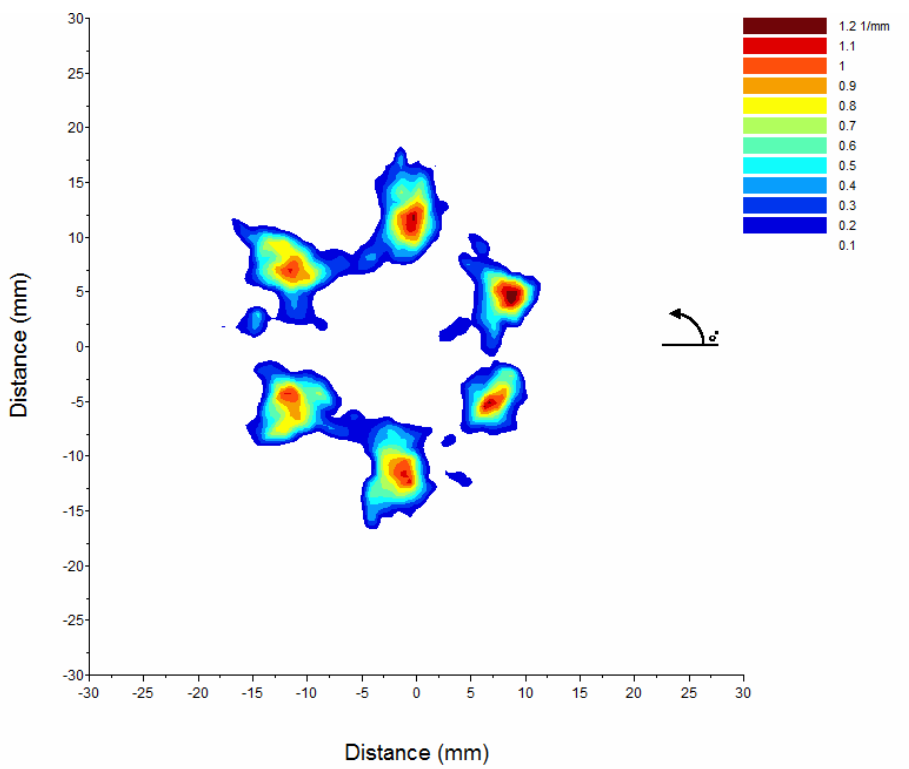
GDI Injector

Mean plume angles (deg.)	% area in plume
10.89	19.32
5.73	4.69
11.53	21.71
10.48	17.91
11.51	23.06
9.35	12.93
Mean centroid (x, mm)	**Mean centroid (y, mm)**
3.26	-5.69
-4.84	14.28
-22.13	1.97
-29.04	-10.75
-15.37	-18.49
0.10	-20.01



Reliable data with multiple orifice injectors

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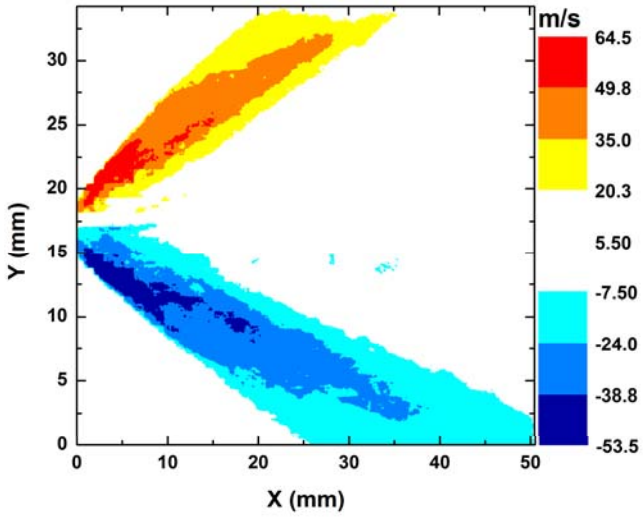
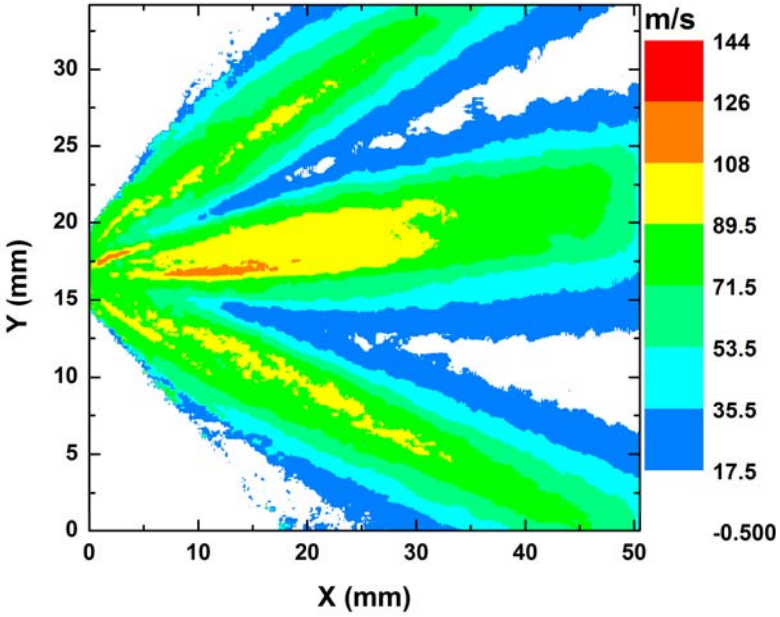
Sample Results SPIV





GDI Injector at 20 MPa

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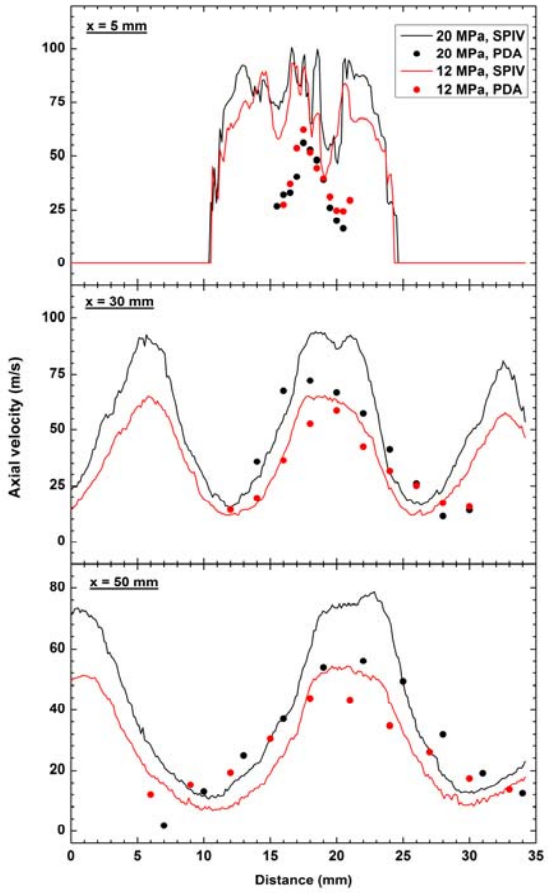
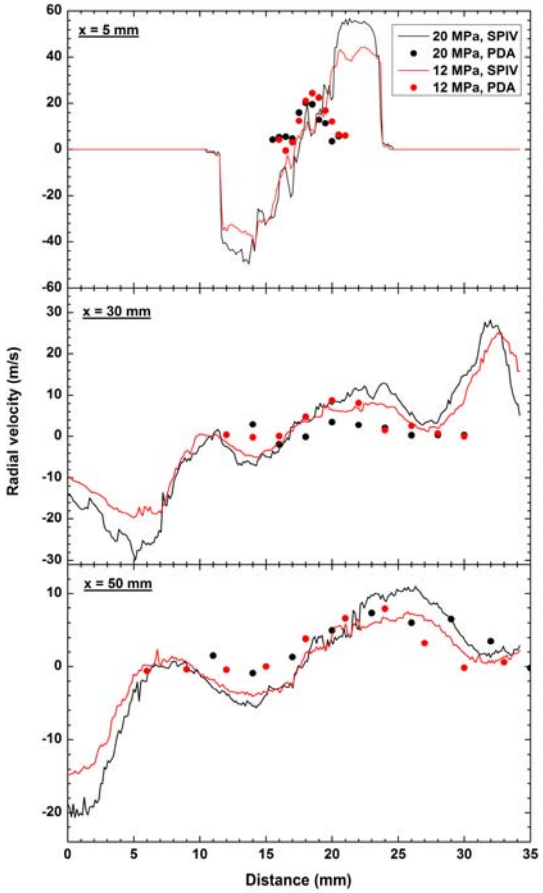
Comparison with PDA





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Quality Assurance of Nozzles

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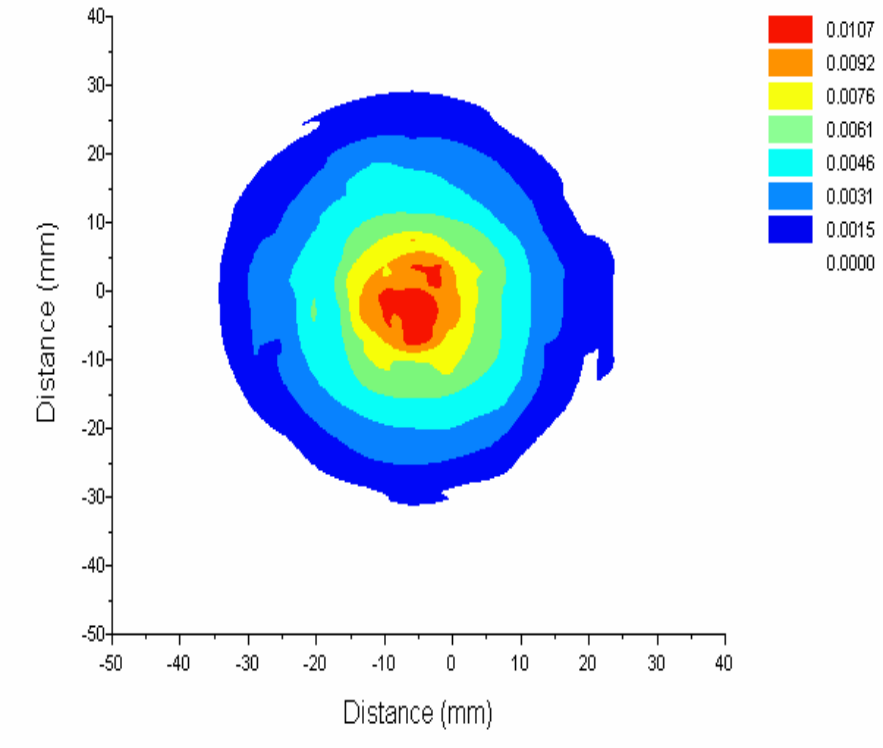
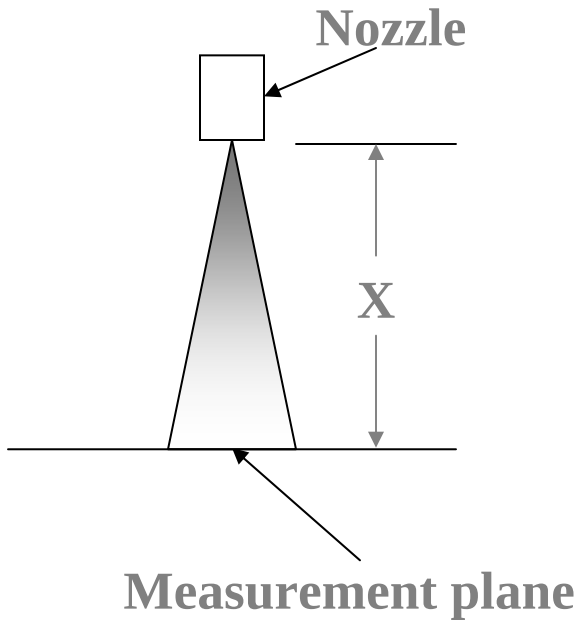
Quality Control Objectives

- Define QC parameters
- Set tolerance limits
- Generate master template
- Compare each nozzle with master template
- Accept/reject nozzle based on patternation result

Sample QC parameter (1): Spray Angle





One of over 100 QC parameters used by the SETscan patternator

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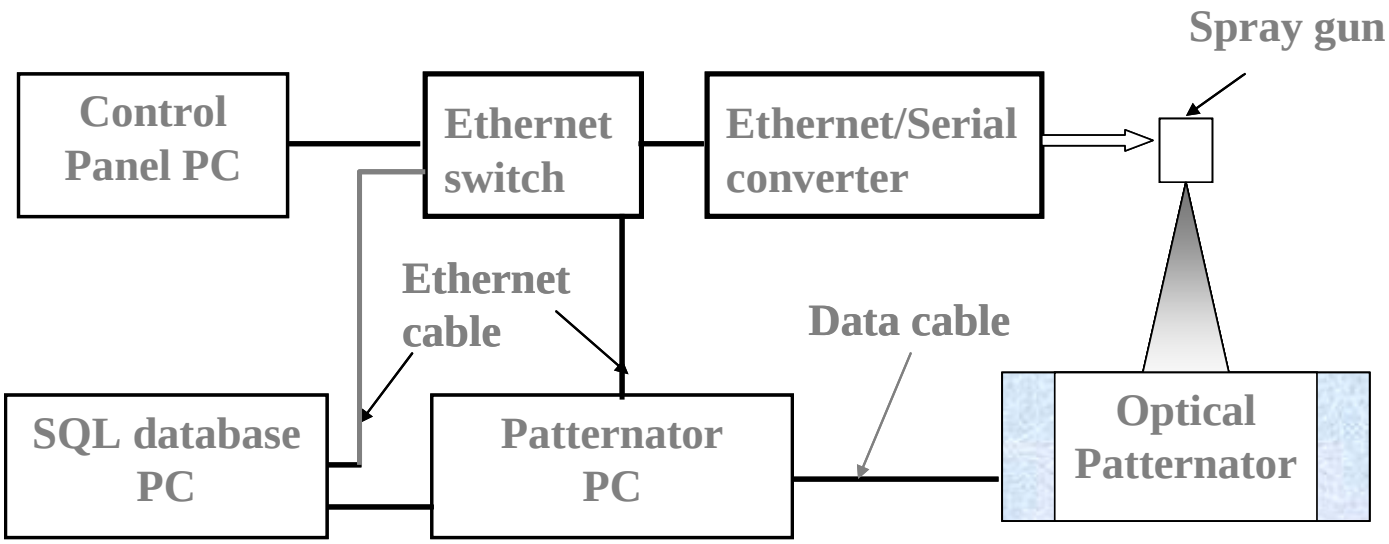
Quality audit configuration



Over 3000 nozzles or injector audited in one day
Rapid turn over with minimal supervision by technicians
Average system downtime < 3 day per year

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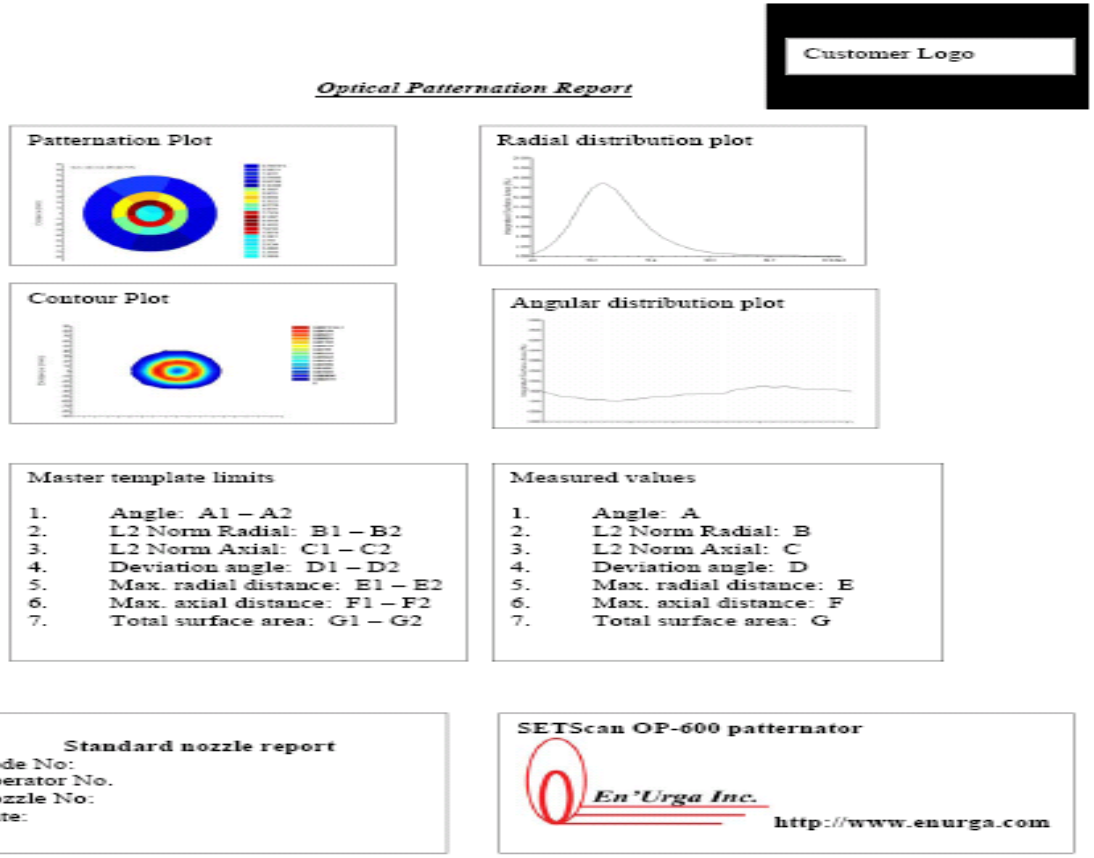
Sample Report Generated by SETscan



Traceable warehoused data for all injectors and dosers

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Sample Installation (OP-600)

- 2 computer QA system
- Automatic nozzle mounts
- Booth by Alsmatik
- QA software by En'Urga
- Multiple types of nozzles
- ROI < 1 year

Photograph: Courtesy Danfoss S/A

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Selected Customers

Abbott	General Motors	Hitachi
Bend Research	Cummins	AVL
Pfizer	Emcom Technologies	FEV
S.C. Johnson & Son	Faurecia	Nordson
Catalytica Energy	Donaldson	Delavan
Delphi	Proctor & Gamble	Woodward
Ricardo	Honeywell	Tenneco
Continental	Bombardier	Synerject
Eaton	Rolls Royce	Danfoss
Columbian Chemical	General Electric	Boston Scientific
United Technologies Aerosapce System	Dow Agrosciences Laboratories	Vertex Pharmaceuticals
Toyota	Bosch LLC.	3M