Giornata Studio “Giorgio Minelli”

LE PROSPETTIVE FUTURE DEI MOTORI A COMBUSTIONE INTERNA

Scuola di Ingegneria
Bologna, 20 Aprile 2018

Politecnico di Bari
Dipartimento di Meccanica Matematica e Management

Sulla propagazione della fiamma, le emissioni gassose e di particolato, il controllo e il monitoraggio della combustione

Alcuni studi teorici, numerici e sperimentali sui motori a combustione interna presso il Politecnico di Bari

Speaker
Elia Distaso

Referenti
Prof. Ing. R. Amirante
Prof. Ing. P. De Palma

Collaborano
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University of Wisconsin-Madison
Engine Research Center – Madison (WI)
Emer. Prof. Rolf D. Reitz

Consiglio Nazionale delle Ricerche
Istituto Motori - Napoli
Dott.ssa Bianca Maria Vaglieco

Agenda

1. **Correlazioni analitiche per il calcolo della velocità di fiamma laminare**
   - Correlazioni per vari combustibili di interesse pratico

     In Cantiere…
2. **Soot formation and oxidation**
   - Investigazioni numerico/sperimentali sulla combustione ossigenata della benzina
   - Ruolo dell'olio lubrificante
     - Campagne sperimentali
3. **Idee sul monitoraggio e il controllo della combustione**
   - Miscele gassose real-time
   - Misura a basso costo della pressione in camera

1 Correlazioni analitiche per la fiamma laminare

- **Correlazioni per vari combustibili di interesse pratico**
  - Metano
  - Propano
  - Miscele binarie Metano/Etano Metano/Propano
  - Miscele ternarie Metano/Etano/Propano come surrogato per il Gas Naturale
  - Benzina

1 Correlazioni analitiche per la fiamma laminare

Formulazioni per combustibili puri

$$\boxed{S_L\left(\phi, T_u, p_u\right) = S_{L0}\left(\frac{T_u}{T_0}\right)^{\alpha}\left(\frac{p_u}{p_0}\right)^{\beta}}$$

$$T_0 = 298\ K$$
$$p_0 = 1\ atm$$

Gülder (1984)

$$S_{L0}\left(\phi\right) = Z\ W\ \phi^{\eta}\ e^{-\xi(\phi-\sigma)^2}$$

Liao (2004)

$$\alpha\left(\phi\right) = a_2\phi^2 - a_1\phi + a_0$$
$$\beta\left(\phi\right) = -b_2\phi^2 + b_1\phi - b_0.$$

Fuel	Z	W $[cm/s]$	η	ξ	σ
CH_4	1	38.85	-0.20	6.45	1.08
C_3H_8	1	42.11	-0.25	5.24	1.10
Gasoline	1	36.82	-0.22	4.86	1.11

Fuel	a_2	a_1	a_0	b_2	b_1	b_0
CH_4	4.9199	10.287	6.9258	1.3712	2.6808	1.7492
C_3H_8	2.7620	5.8808	4.9221	0.9250	2.0000	1.3560
Natural Gas	5.7500	12.150	7.9800	0.9250	2.0000	1.3650
Gasoline	3.2800	7.5200	5.9300	0.9250	2.0120	1.3650

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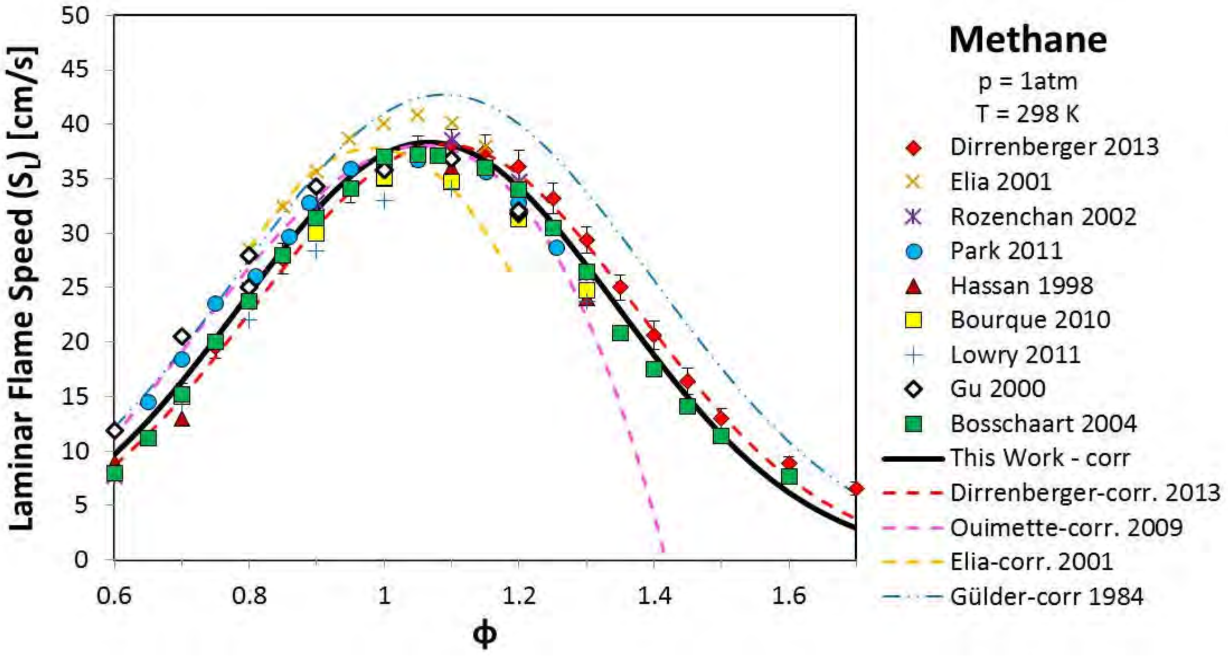
Correlazioni analitiche per la fiamma laminare

Risultati

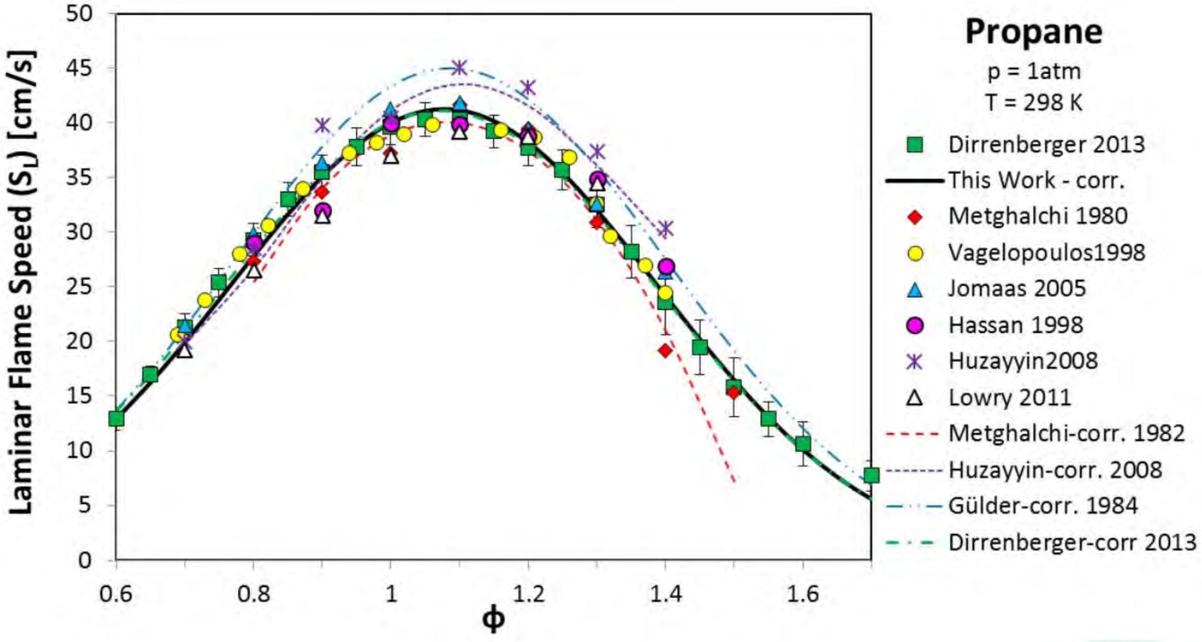
$$p_0 = 1\ atm$$
$$T_0 = 298\ K$$

$$S_{L0}(\phi) = \ Z\ W\ \phi^{\eta}\ e^{-\xi(\phi-\sigma)^2}$$

Methane



Propane



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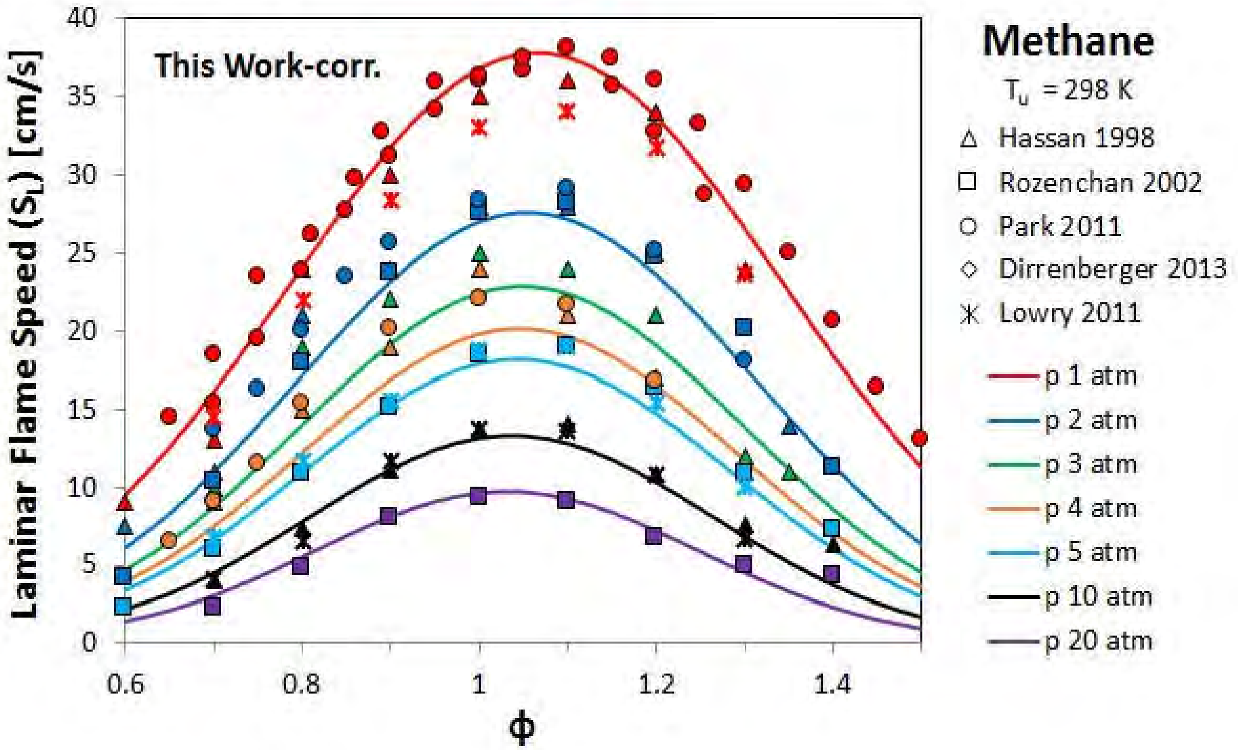
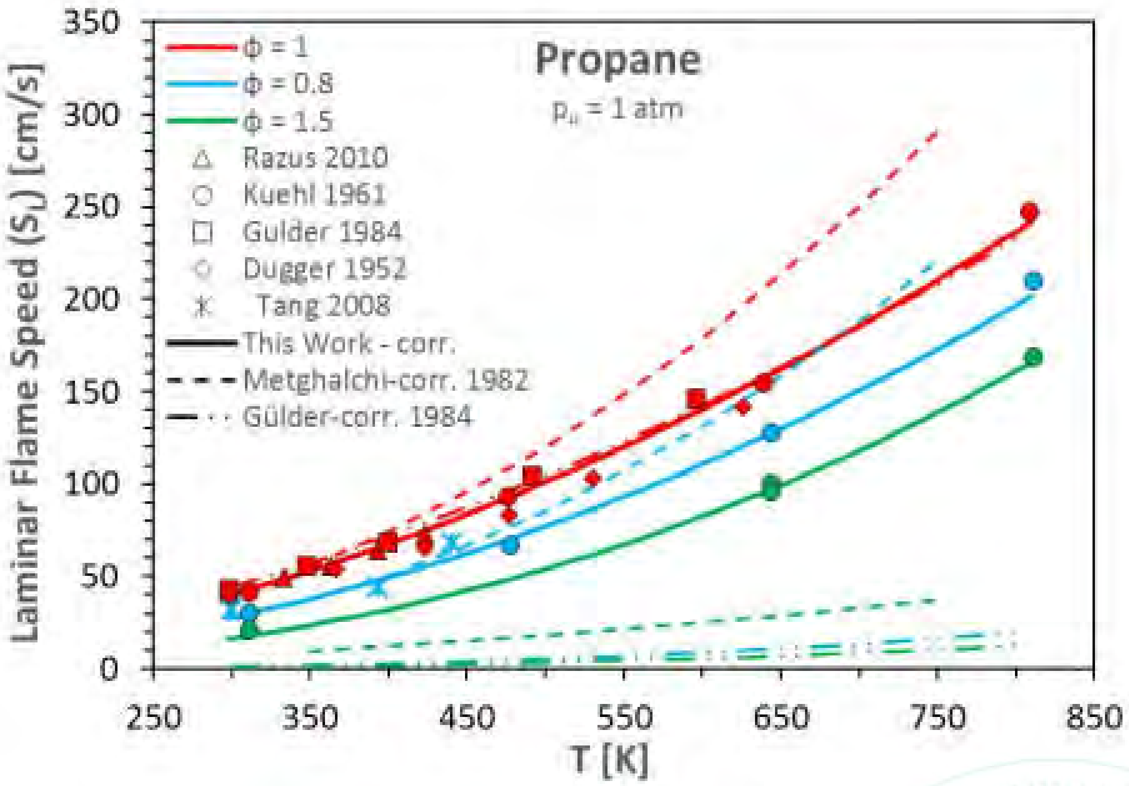
1 Correlazioni analitiche per la fiamma laminare

Risultati

<u>P and T influence</u>

$$\alpha(\phi) = a_2\phi^2 - a_1\phi + a_0$$
$$\beta(\phi) = -b_2\phi^2 + b_1\phi - b_0.$$





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1 Correlazioni analitiche per la fiamma laminare

Formulazioni per miscele binarie e ternarie

Gülder (1984)

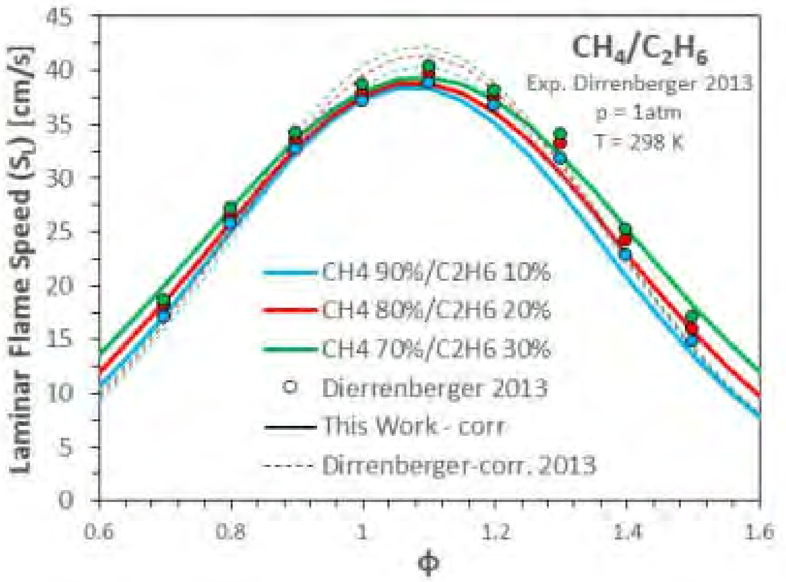
$$S_{L0}\,(\phi) = \;Z\;W\;\phi^{\eta}\;e^{-\xi(\phi-\sigma)^2}$$

Dirrenberger (2013)

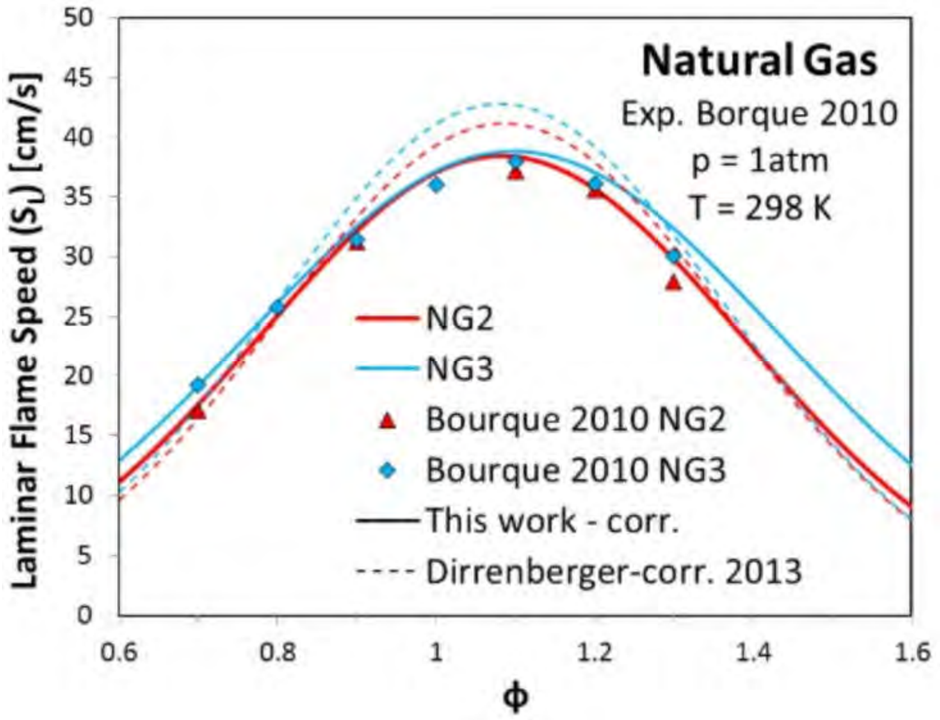
$$S_{L0}\,(\phi,\chi) = \;(1+\nu\chi^{\tau})\;W\;\phi^{\eta}\;e^{-\xi(\phi-\sigma-\Omega\chi)^2}$$

This work (2017)

$$\boxed{S_{L0}\,(\phi,\chi) = \;(1+\nu\chi^{\tau})\;W\;\phi^{\eta(1-\chi)^{\varepsilon}}\quad e^{-\xi(\phi-\sigma-\Omega\chi)^2}}$$



Miscele Binarie



$$\boxed{S_{L0}\,(\phi,\chi_1,\chi_2) = \;(1+\nu{\chi_1}^{\tau_1})\,(1+\nu{\chi_2}^{\tau_2})\;W\;\phi^{\eta(1-\chi_1)^{\varepsilon_1}(1-\chi_2)^{\varepsilon_2}}\quad e^{-\xi(\phi-\sigma-\Omega_1\chi_1-\Omega_2\chi_2)^2}}$$

Gas Naturale

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1 Correlazioni analitiche per la fiamma laminare

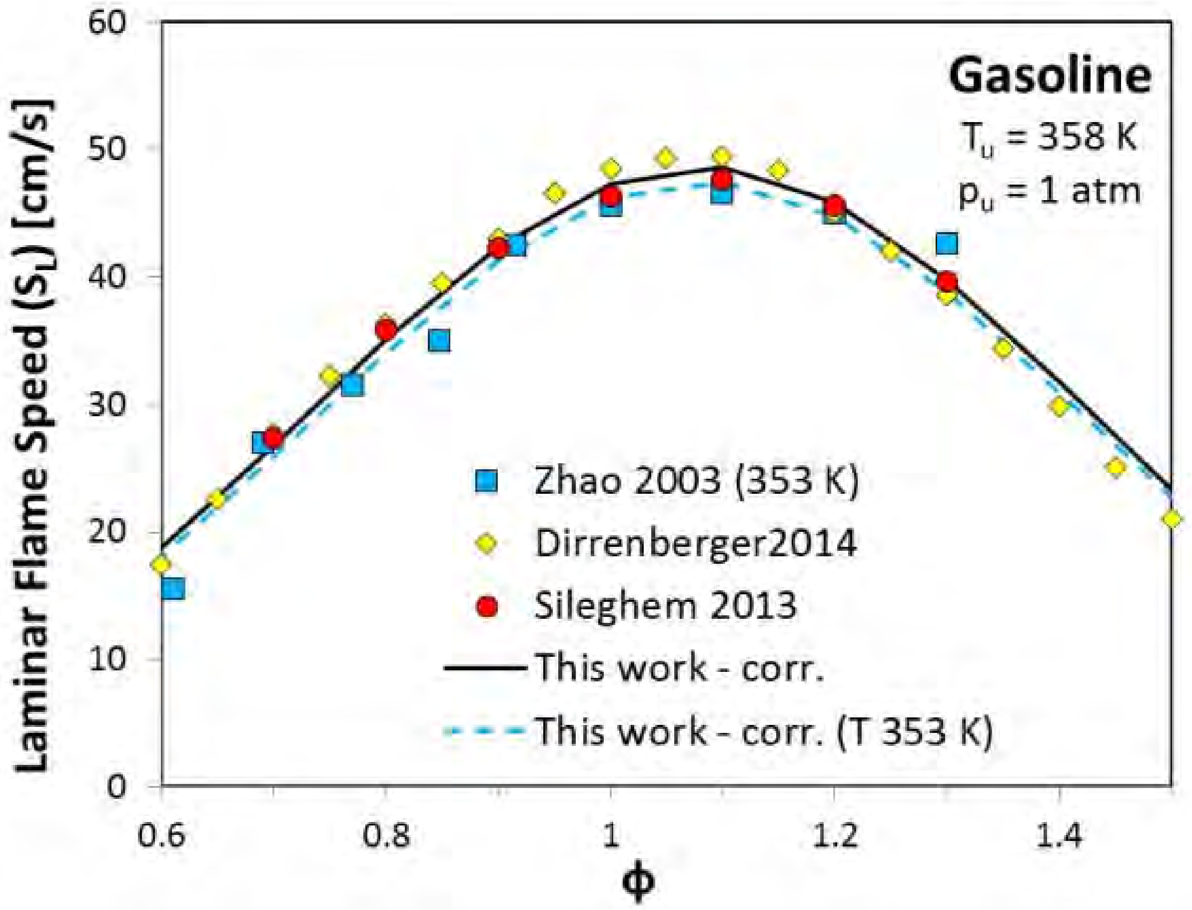
Risultati

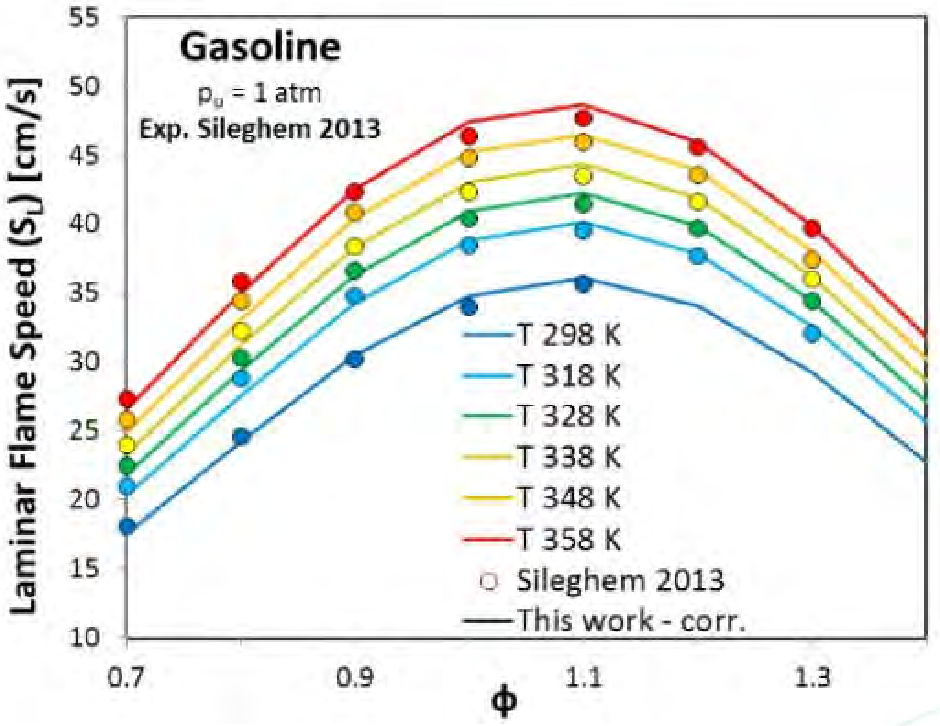
Gasoline

$$S_L(\phi, T_u, p_u) = S_{L0}\left(\frac{T_u}{T_0}\right)^{\alpha}\left(\frac{p_u}{p_0}\right)^{\beta}$$

$$S_{L0}(\phi) = Z\,W\,\phi^{\eta}\,e^{-\xi(\phi-\sigma)^2}$$

$$\alpha(\phi) = a_2\phi^2 - a_1\phi + a_0$$
$$\beta(\phi) = -b_2\phi^2 + b_1\phi - b_0.$$





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1 Correlazioni analitiche per la fiamma laminare

Amirante, R., Distaso, E., Tamburrano, P., & Reitz, R. D. (2017). **Laminar flame speed correlations for methane, ethane, propane and their mixtures, and natural gas and gasoline for spark-ignition engine simulations**. *Int. Journal of Engine Research*, *18*(9), 951-970. doi:10.1177/1468087417720018

In cantiere…

- Allargamento ed aggiornamento del database di dati sperimentali di letteratura
- Idrocarburi oltre i C_3
- Combustibili ossigenati (Metanolo, etanolo, ….)
- Influenza di inerti (EGR, N_2, ….)
- Influenza di presenza di acqua
- Altre miscele binarie (metano/idrogeno, H_2/CO, propano/butano, …)
- Miscele a più di 3 componenti
- Correlazioni per il Syngas
- Benzina come miscela e non combustibile puro

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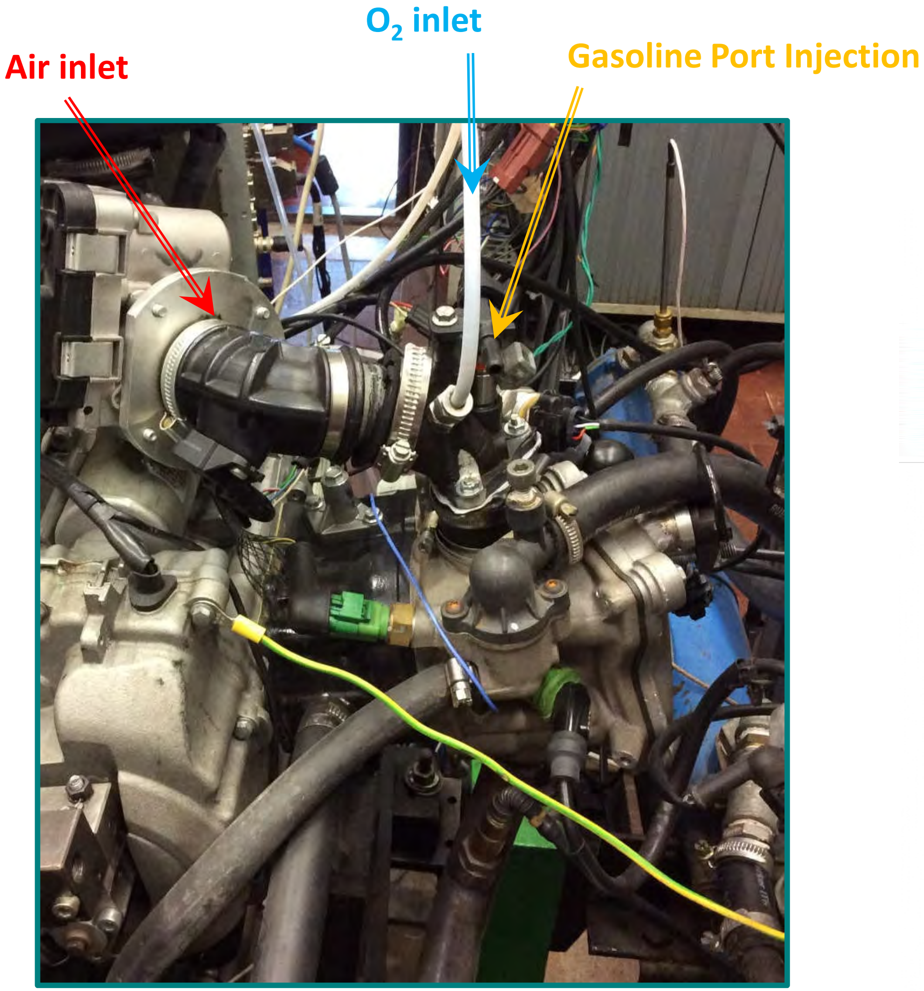
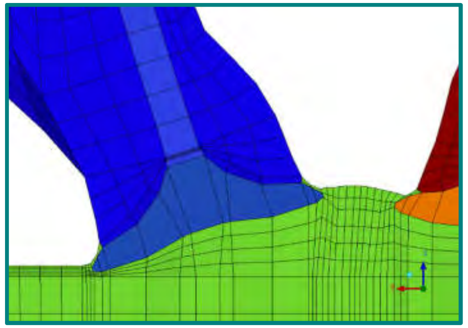
2 Soot formation and oxidation

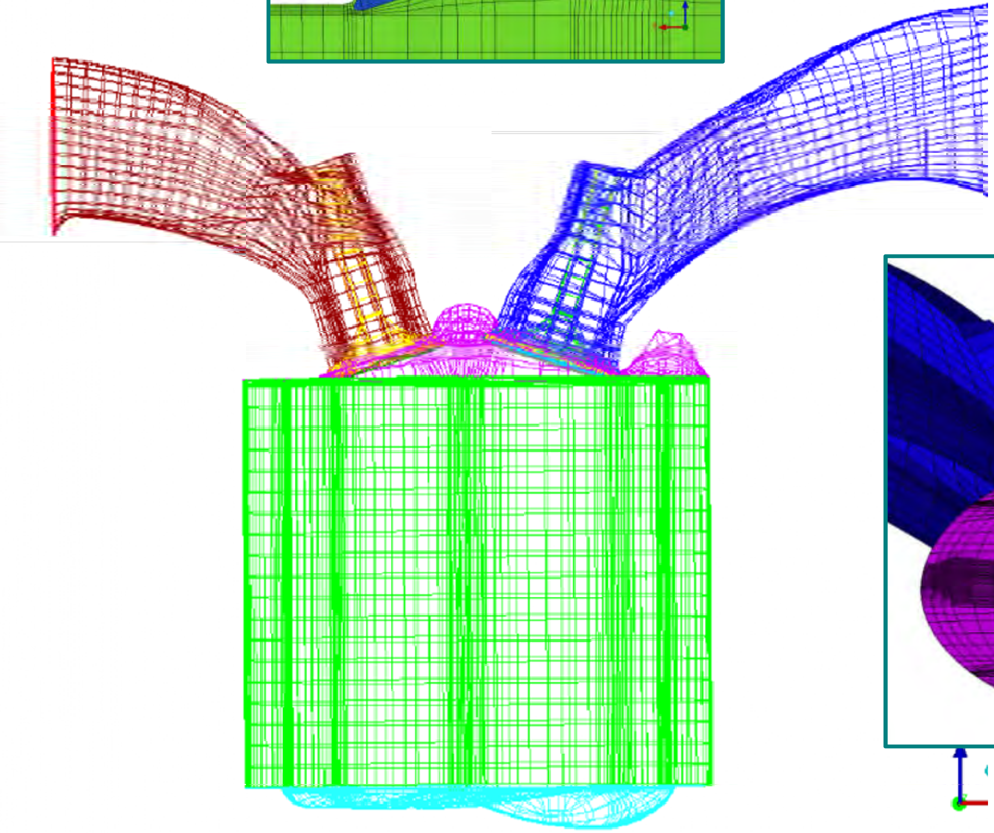
- **Investigazioni numerico/sperimentali sulla combustione ossigenata della benzina**
- **Ruolo dell’olio lubrificante**
    - Campagne sperimentali

2 Combustione ossigenata della benzina

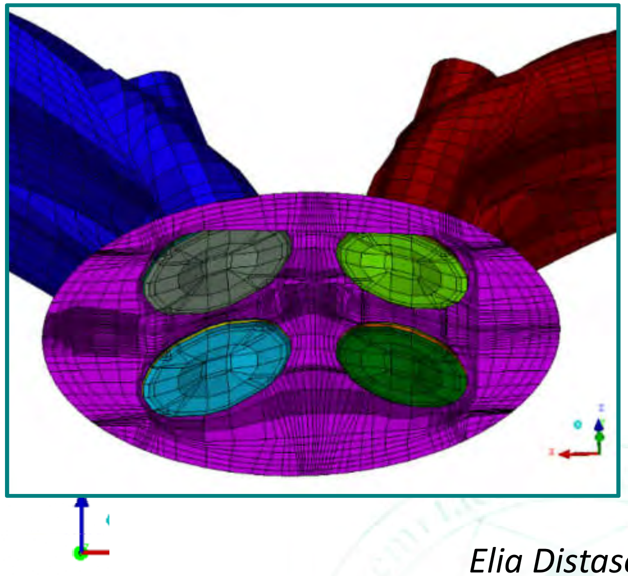
Soot Formation and Oxidation







Multi-dimensional KIVA3v-Release 2 CFD code



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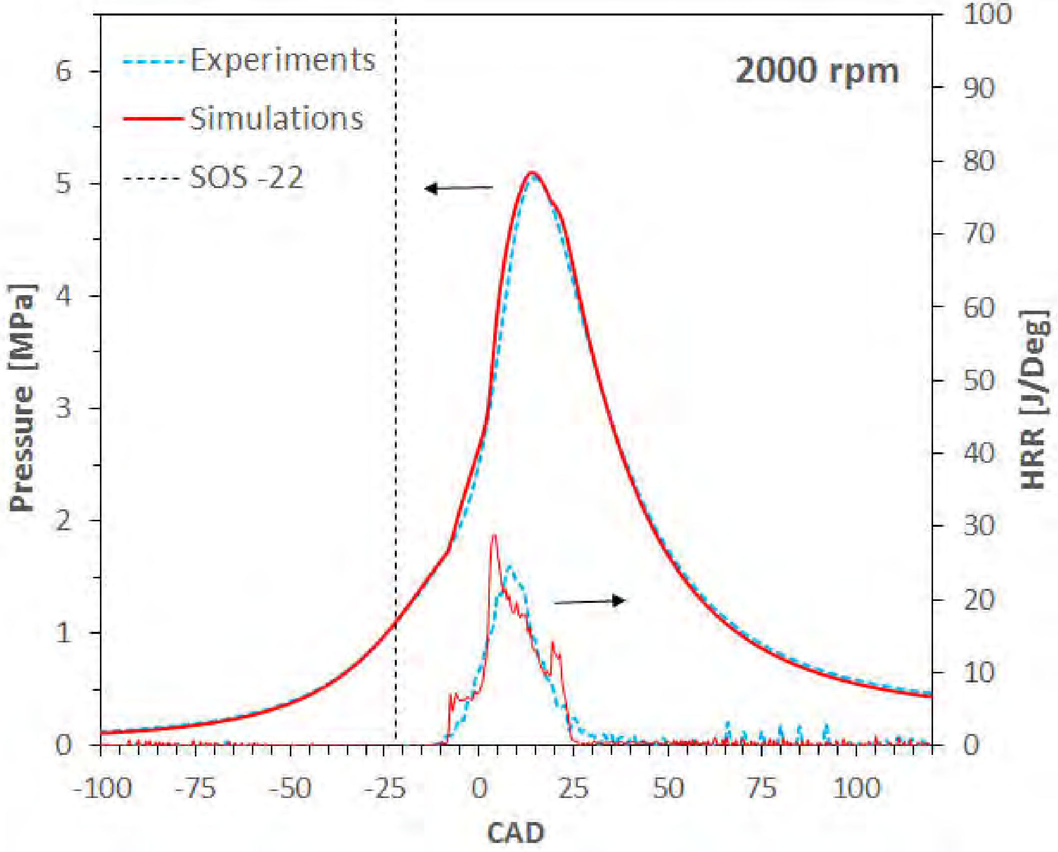
2 Combustione ossigenata della benzina

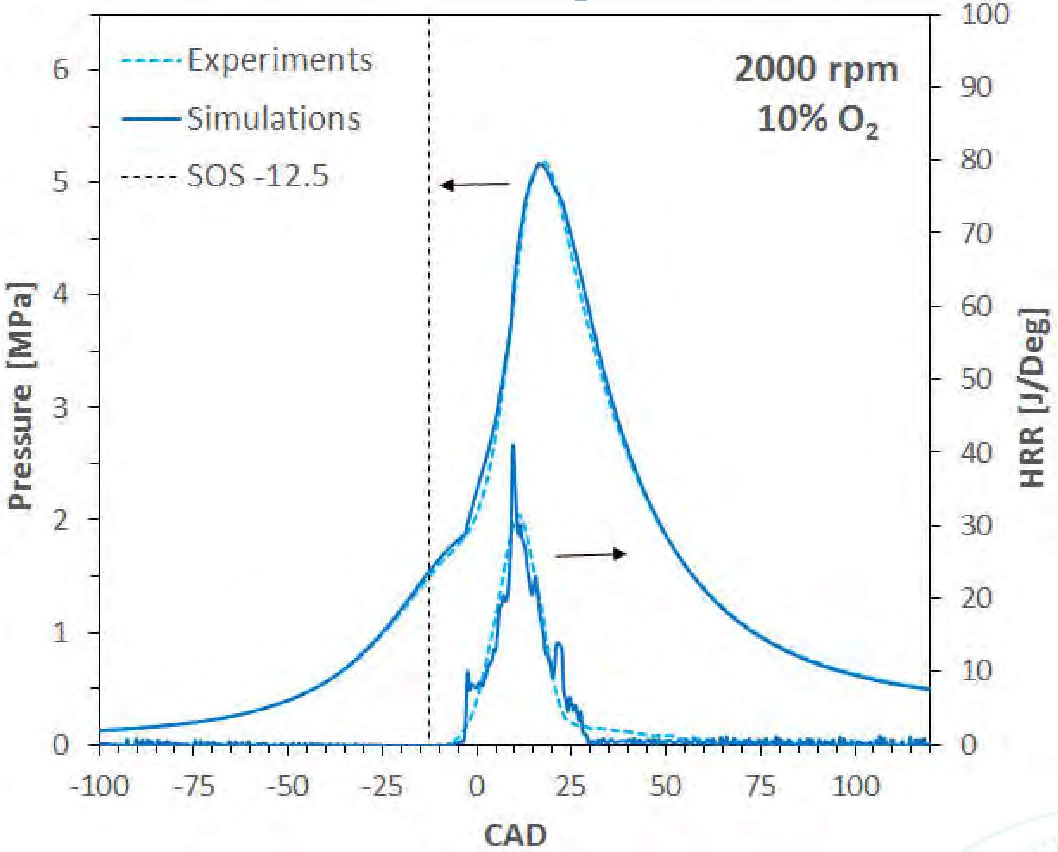
Soot Formation and Oxidation

2000 rpm

BASELINE



10% O_2



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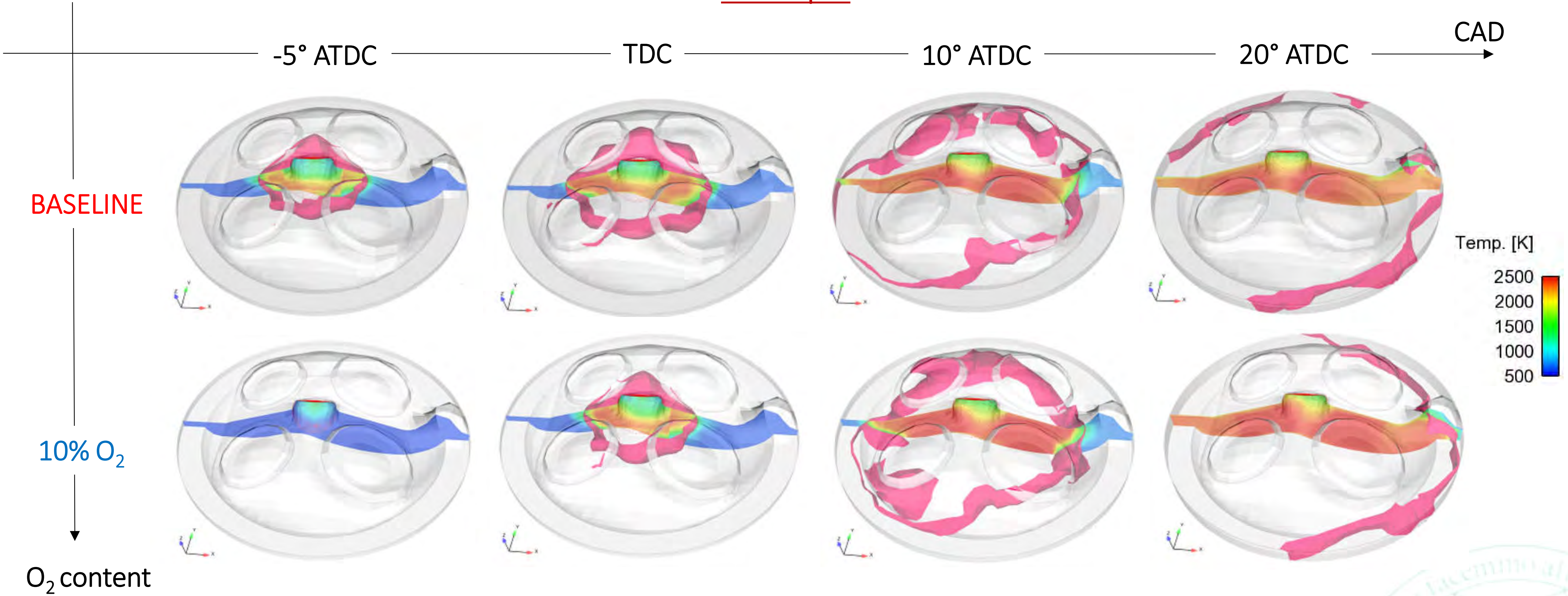
2 Combustione ossigenata della benzina

Soot Formation and Oxidation

2000 rpm



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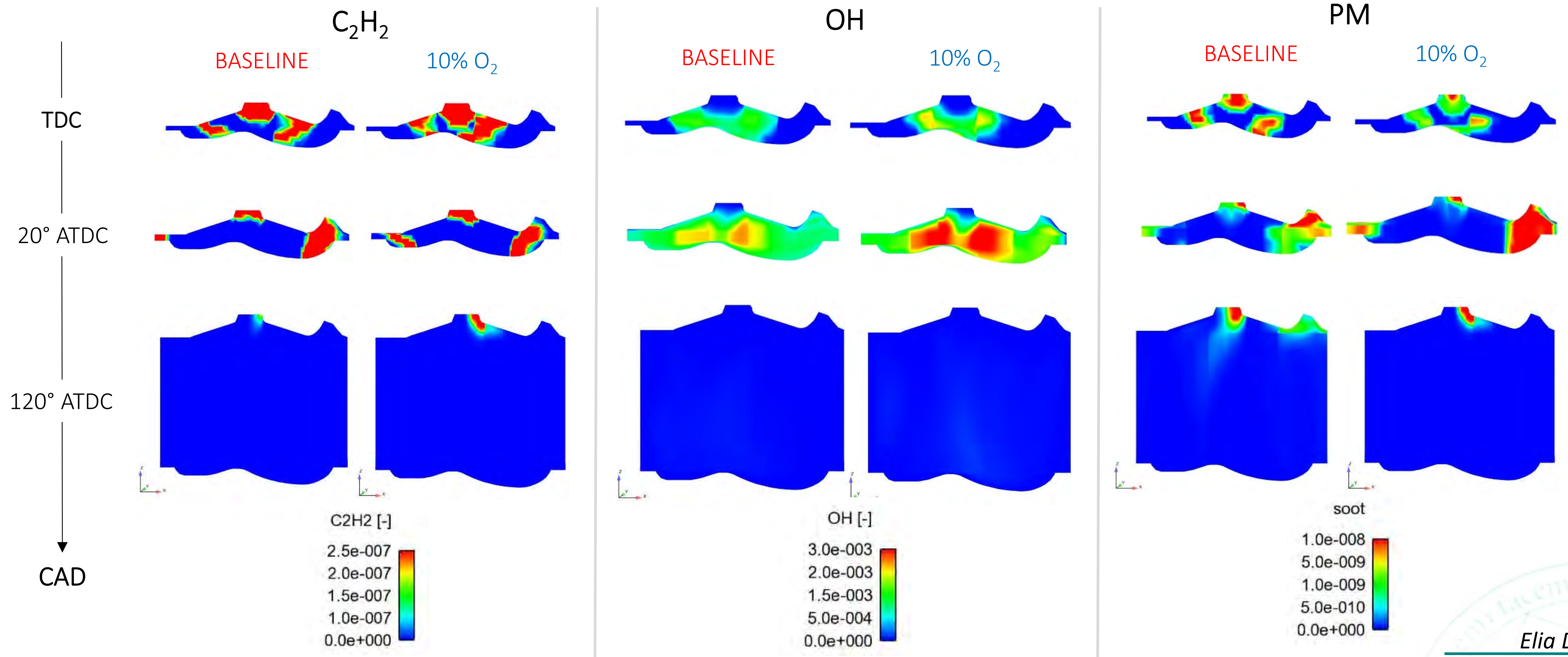
2 Combustione ossigenata della benzina

Soot Formation and Oxidation

2000 rpm



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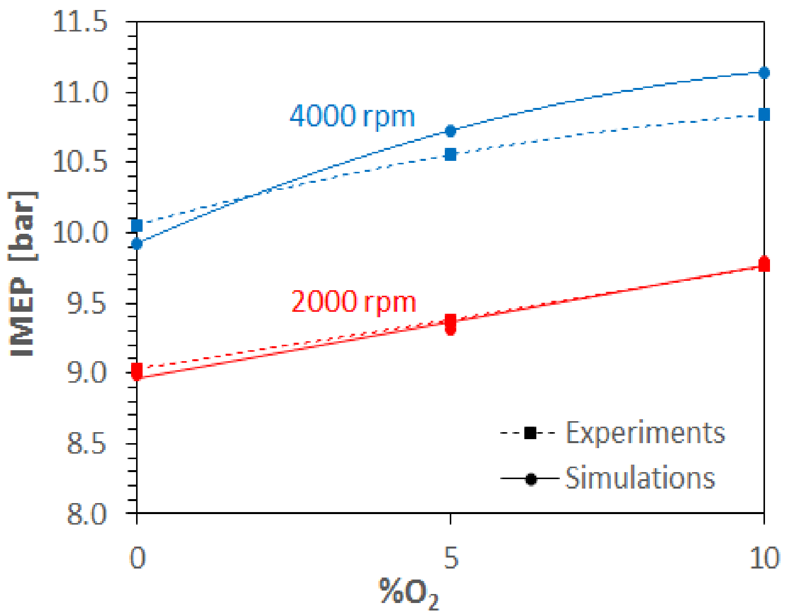
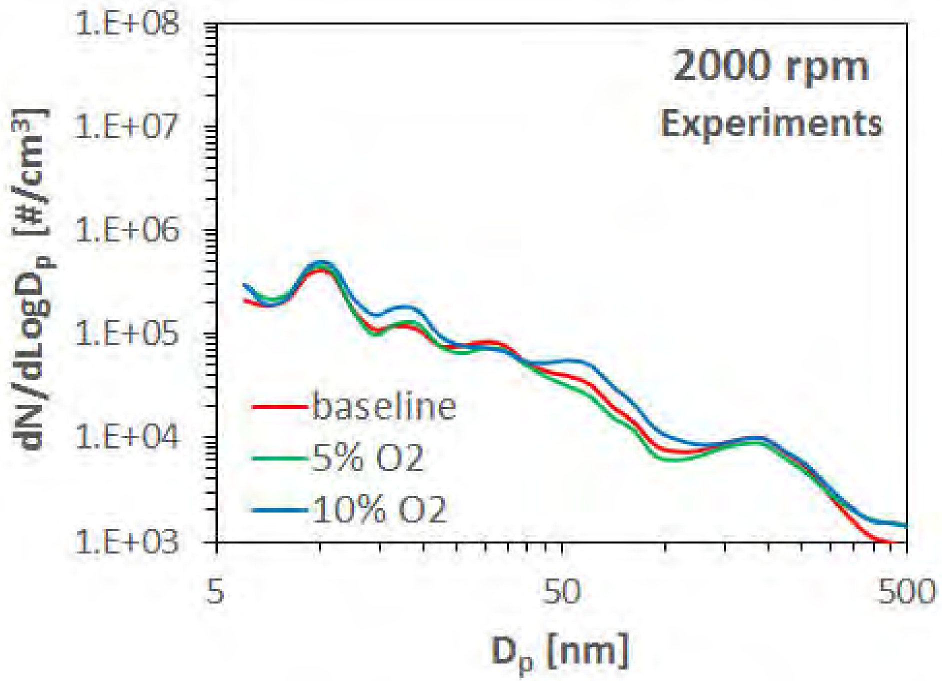
Combustione ossigenata della benzina

Soot Formation and Oxidation





Amirante R, Distaso E, Tamburrano P., Reitz R.D.
Numerical Investigation of Load Effects on Particulate Emissions in Gasoline Spark-Ignition Engines.
Symposium for Combustion Control 2017; June 28*th*-29*th*, 2017, Aachen, Germany

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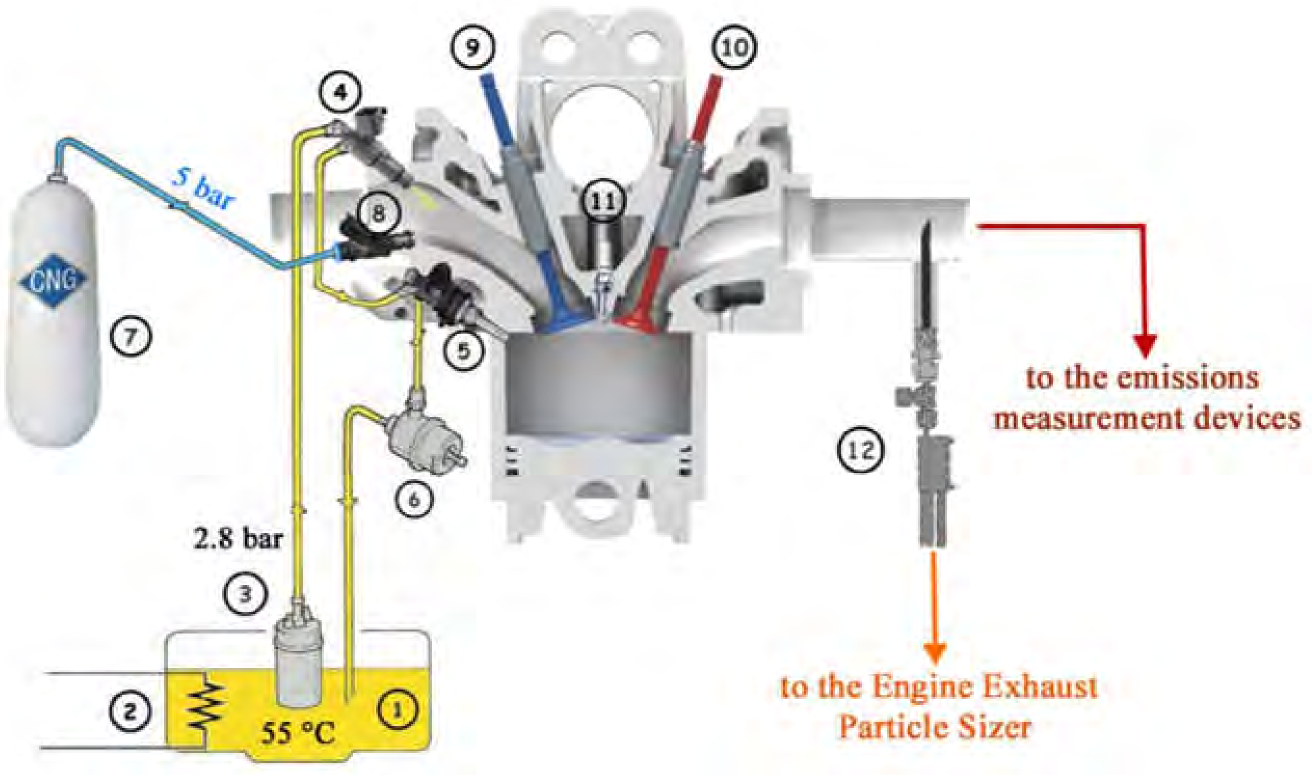
2 Ruolo dell’olio lubrificante

Campagne sperimantali

- “Oil-free” optical engine at 2000 rpm and full load
- Multi-grade, low viscosity, full-synthetic lubricant 0W-30
- Oil-to-fuel mass = 1, 3, 5, 7%



Optical engine specifications

Name	Units	Value
Cylinder volume	cm^3	250
Bore	mm	72
Stroke	mm	60
Compression ratio	None	10.5
Max power	kW	7.9 at 5000 rpm
Max torque	Nm	14.7 at 5500 rpm

	PFI tests	DI tests
CNG tests	CNG → injector 8 oil → injector 4	CNG → injector 8 oil → injector 5
Gasoline tests	Gasoline + oil → injector 4	Gasoline + oil → injector 5

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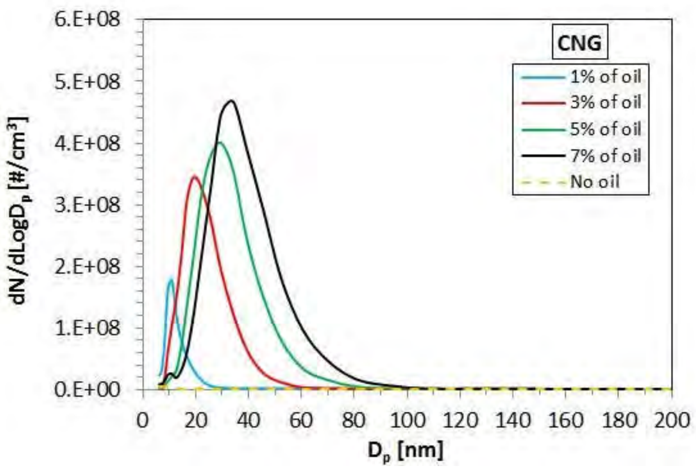
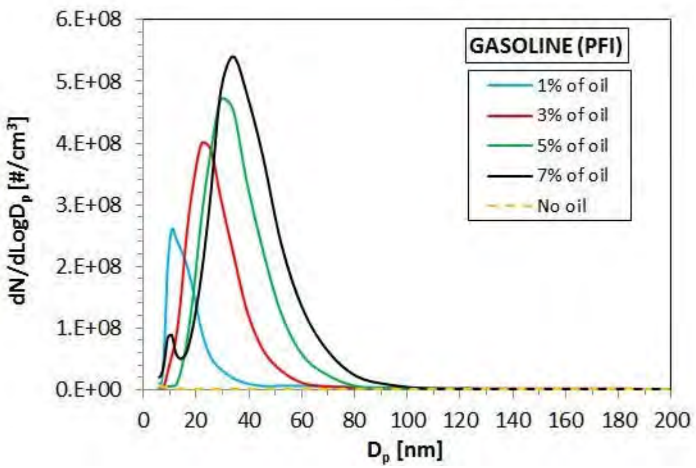
2 Ruolo dell'olio lubrificante

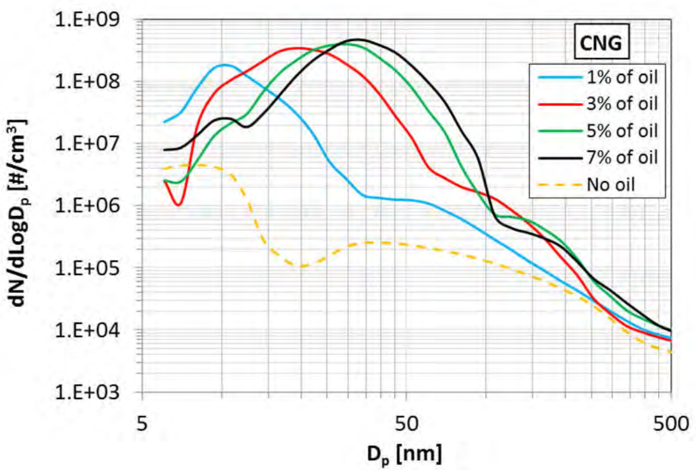
Campagne sperimantali

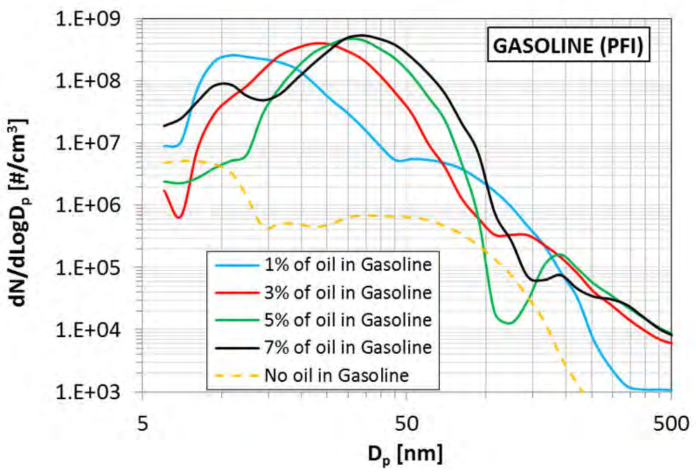
CNG

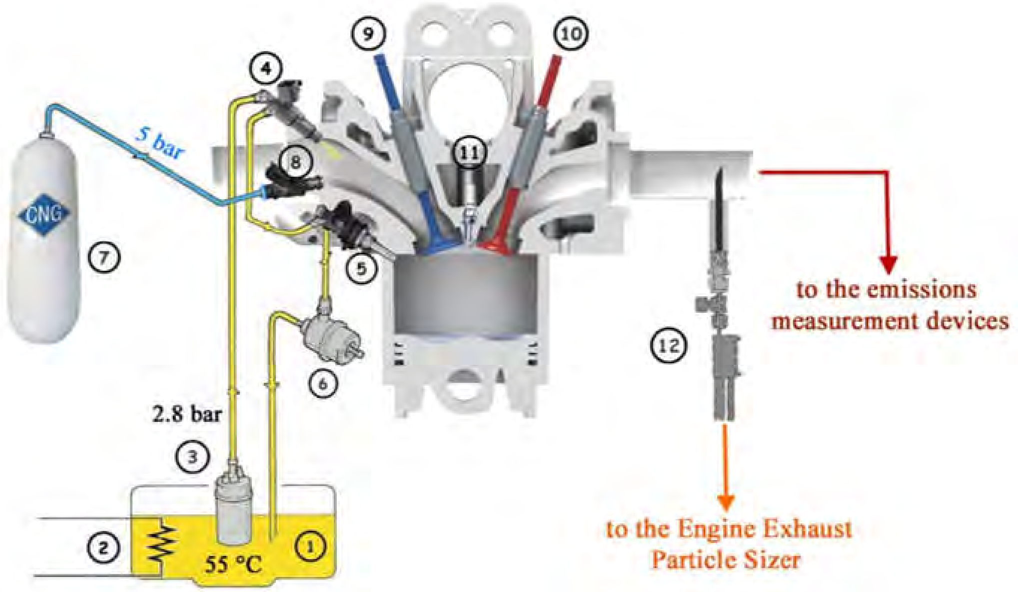
Gasoline (PFI)











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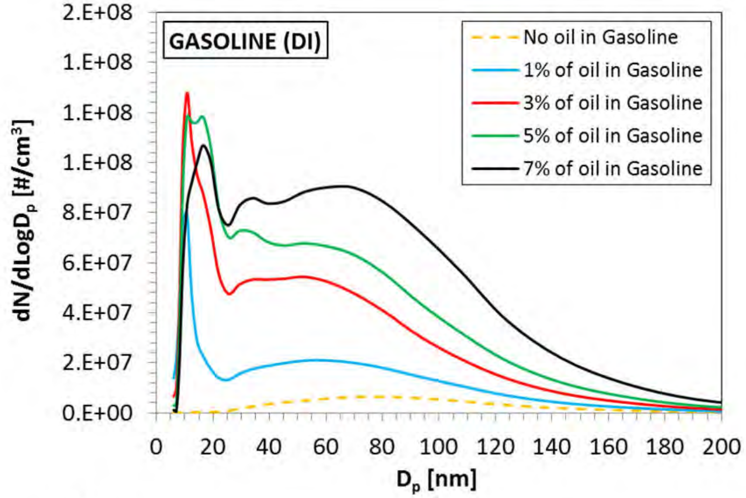
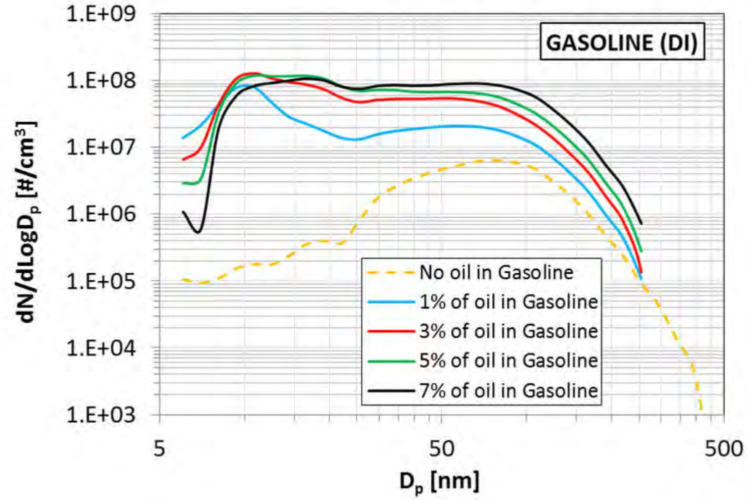
2 Ruolo dell’olio lubrificante

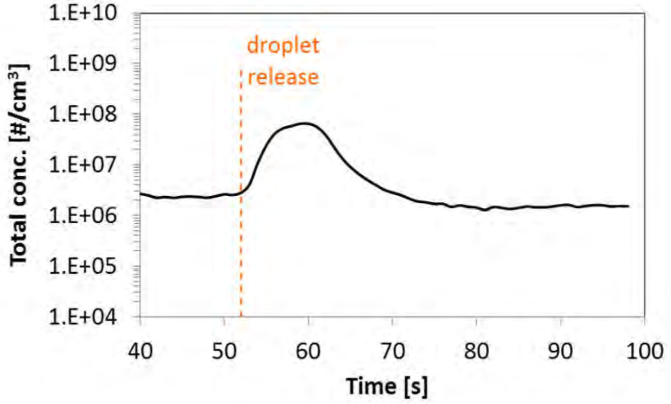
Campagne sperimantali

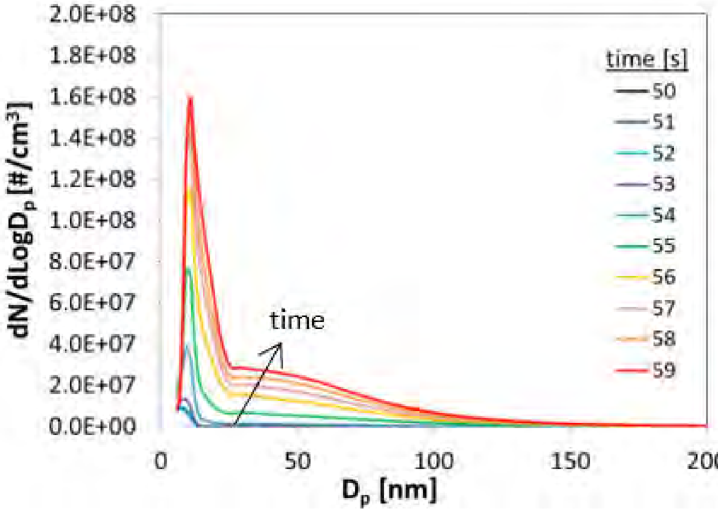
Gasoline (DI)

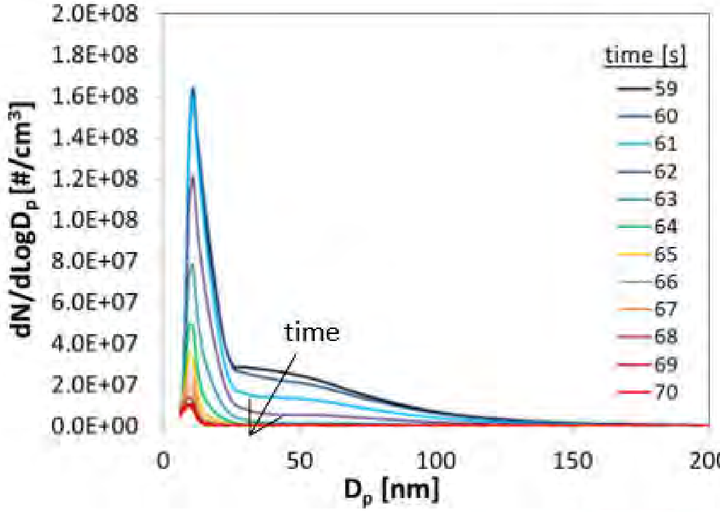




Emulation of oil droplet release with CNG-PFI







Amirante R, Distaso E, Di Iorio S, Napolitano M, Sementa P, Tamburrano P, Vaglieco B.M., Reitz R.D. **Effects of Lubricant Oil on Particulate Emissions from Port Fuel and Direct Injection Spark-Ignition Engines**. Int J Engine Res 2017;18:606-6202. doi:10.1177/1468087417706602

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3 Idee sul monitoraggio e il controllo della combustione

- **Miscele gassose real-time**
- **Misura a basso costo della pressione in camera**

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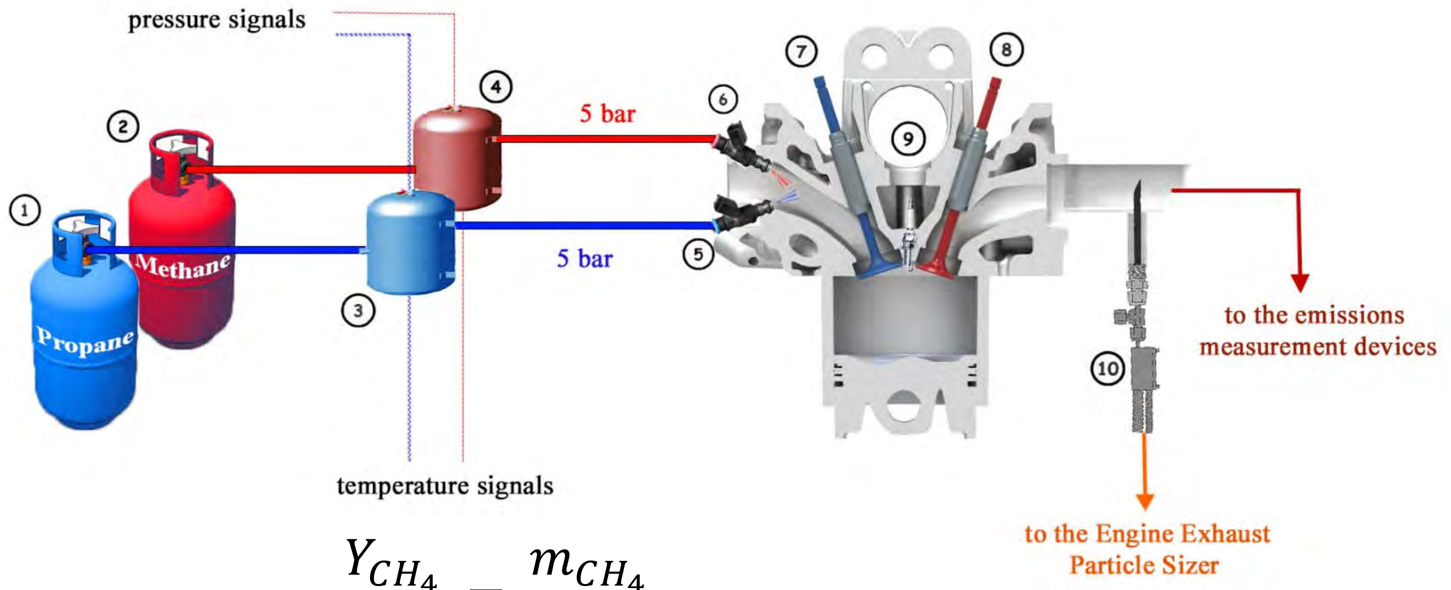
3 Miscele gassose real-time

Idee sul monitoraggio e il controllo della combustione



$$\chi_{CH_4}, \chi_{C_3H_8} \quad \rightarrow \quad \frac{Y_{CH_4}}{Y_{C_3H_8}} \equiv \frac{m_{CH_4}}{m_{C_3H_8}}$$

$$\boxed{\frac{\Delta t_{CH_4}}{\Delta t_{C_3H_8}} = C\,\frac{\chi_{CH_4}}{\chi_{C_3H_8}}\,\frac{p^o_{C_3H_8}}{p^o_{CH_4}}\,\sqrt{\frac{T^o_{CH_4}}{T^o_{C_3H_8}}}}$$

$$\dot{m}_i = A_{inj}\frac{p_i^0}{\sqrt{R_i T_i^0}}\sqrt{\gamma_i}\sqrt{\left(\frac{2}{\gamma_i + 1}\right)^{\frac{\gamma_i+1}{\gamma_i-1}}}$$

$$C = \frac{MW_{CH_4}}{MW_{C_3H_8}}\frac{\sqrt{\frac{\gamma_{C_3H_8}}{R_{C_3H_8}}\left(\frac{2}{\gamma_{C_3H_8}+1}\right)^{\frac{\gamma_{C_3H_8}+1}{\gamma_{C_3H_8}-1}}}}{\sqrt{\frac{\gamma_{CH_4}}{R_{CH_4}}\left(\frac{2}{\gamma_{CH_4}+1}\right)^{\frac{\gamma_{CH_4}+1}{\gamma_{CH_4}-1}}}}$$

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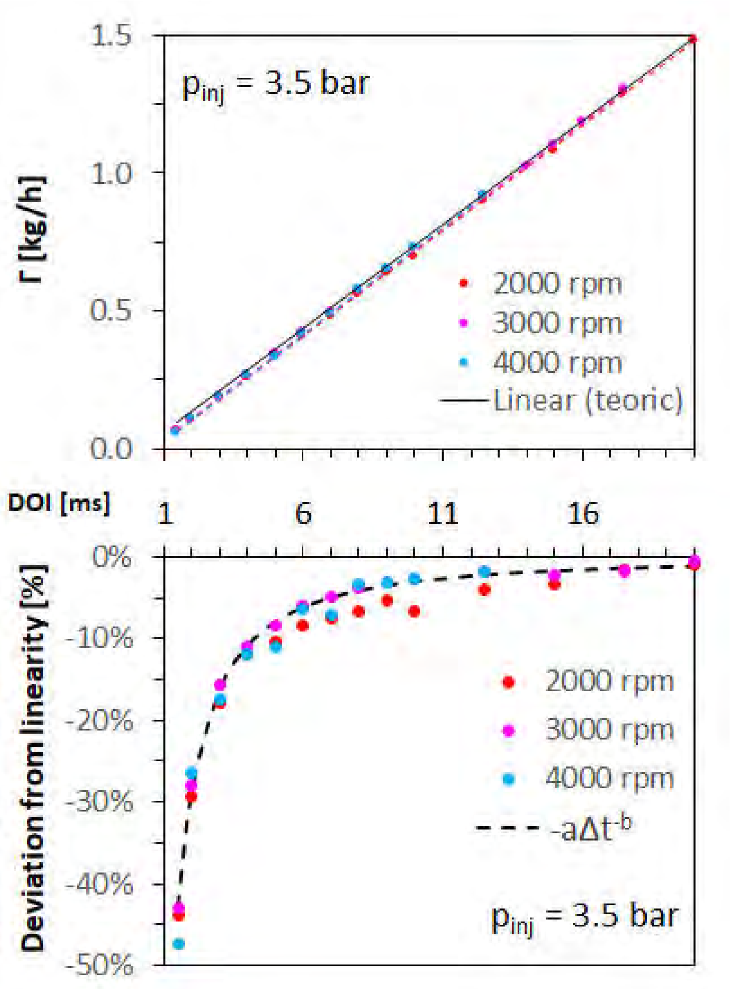
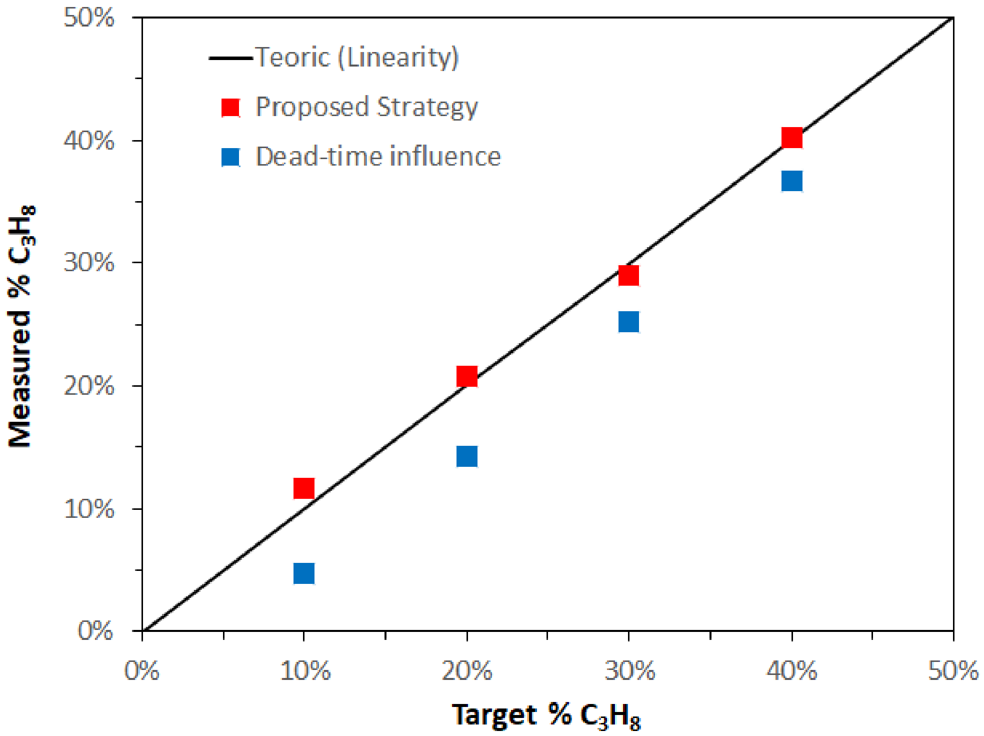
3 Miscele gassose real-time

Idee sul monitoraggio e il controllo della combustione



$$\dot{m}_i = A_{inj}\frac{p_i^0}{\sqrt{R_i T_i^0}}\sqrt{\gamma_i}\sqrt{\left(\frac{2}{\gamma_i+1}\right)^{\frac{\gamma_i+1}{\gamma_i-1}}}\frac{f_{inj}}{f_{inj}^{ref}}\left(1-a\Delta t_i^{-b}\right)$$

$$\Gamma = \frac{f_{inj}^{ref}}{f_{inj}}\dot{m}_{meas}$$



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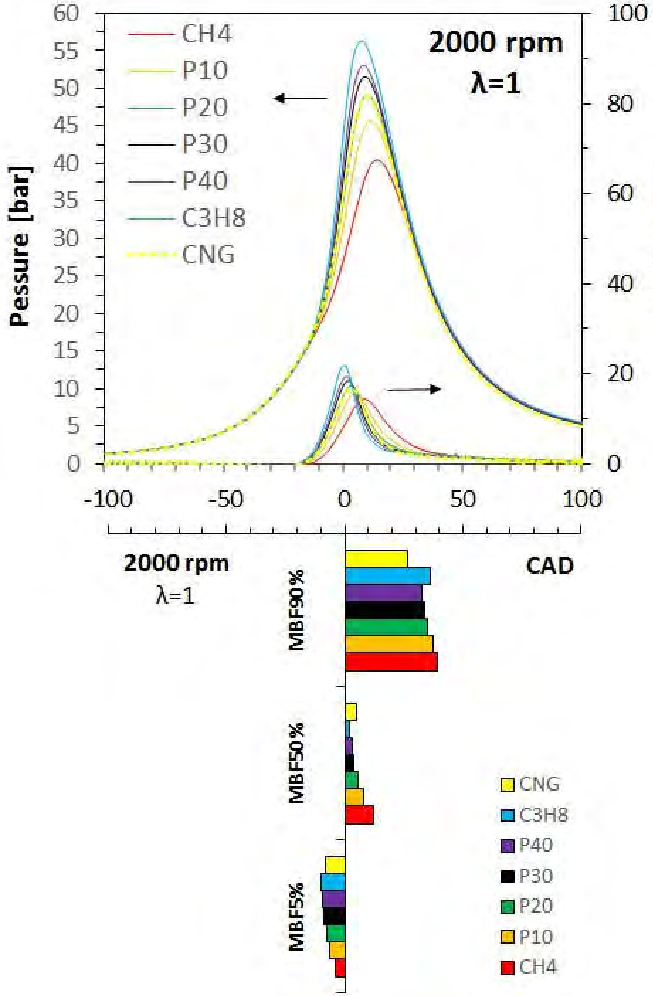
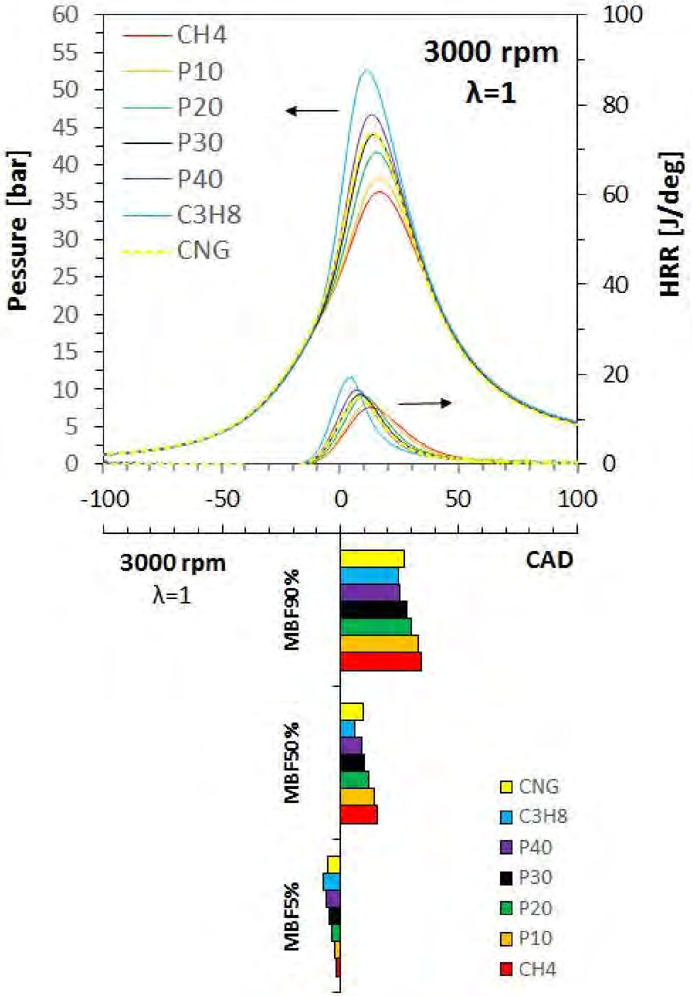
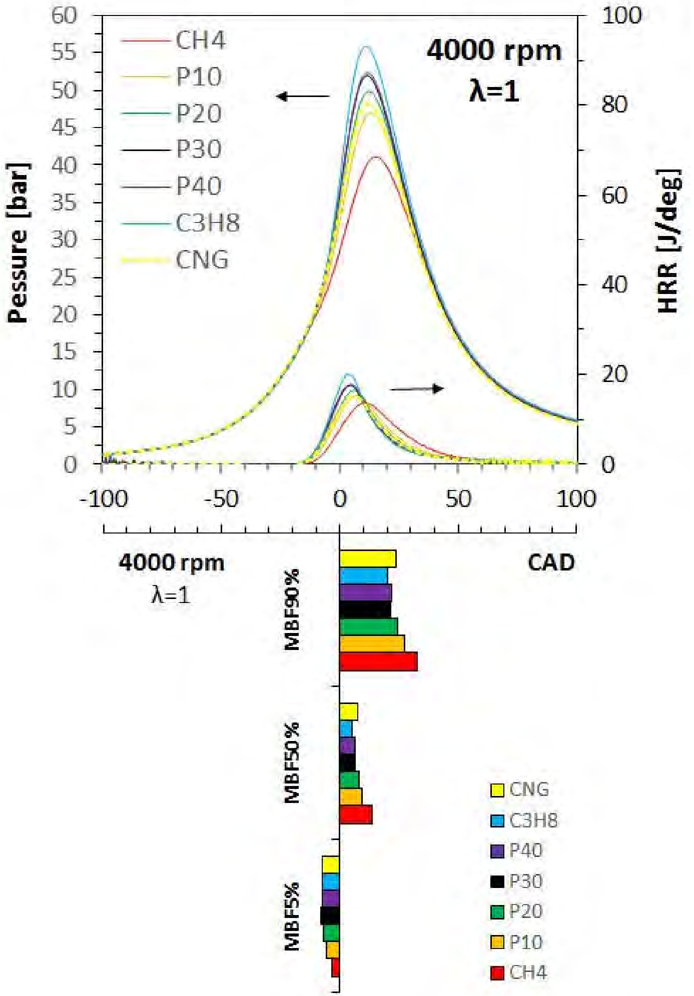
3 Miscele gassose real-time

Idee sul monitoraggio e il controllo della combustione







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3 Miscele gassose real-time

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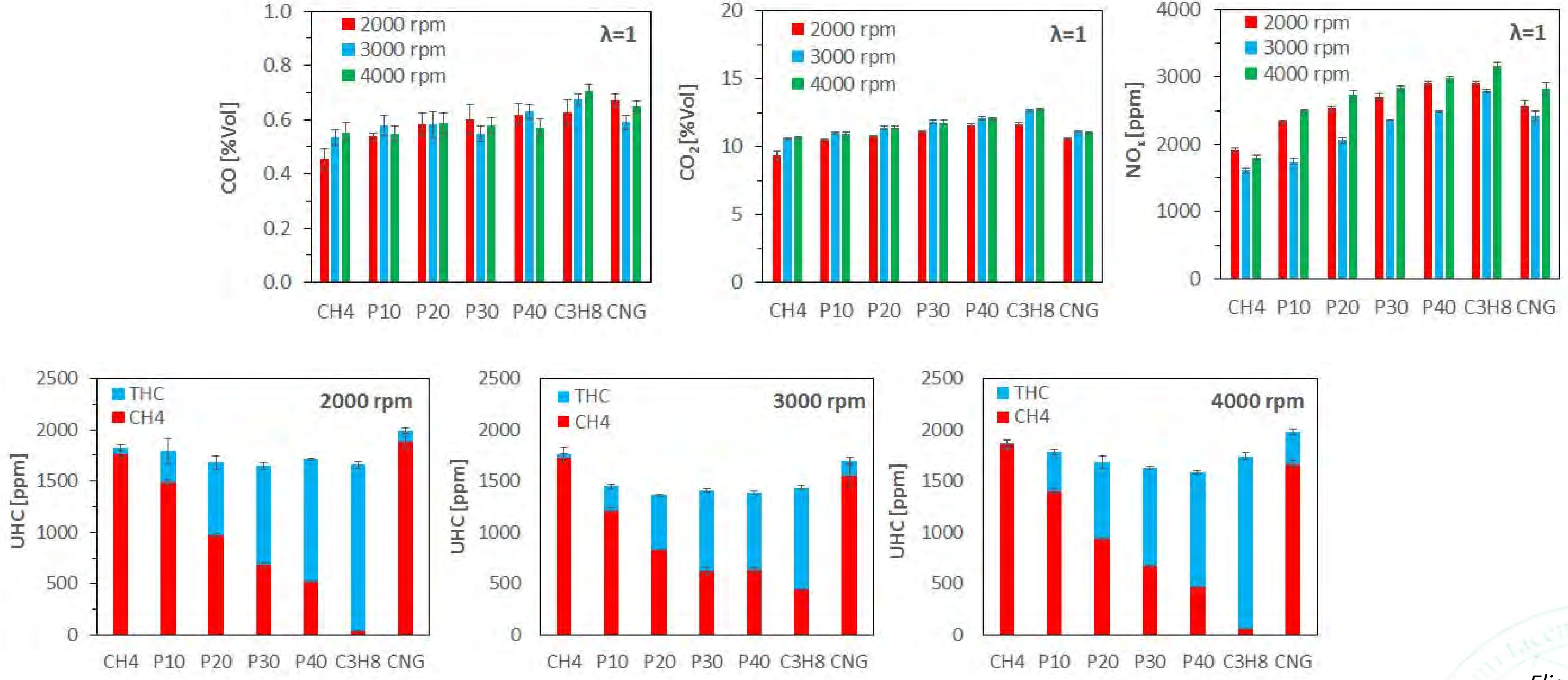

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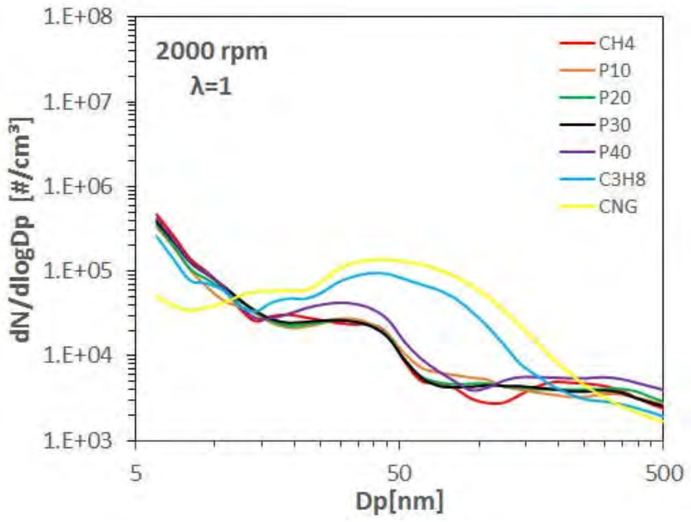
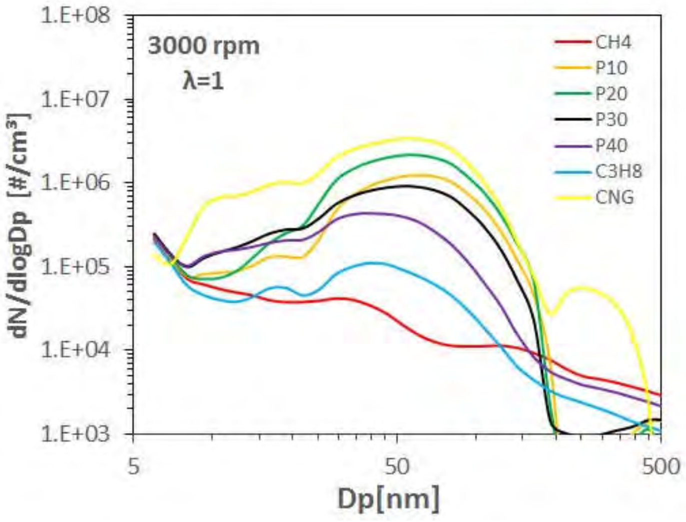
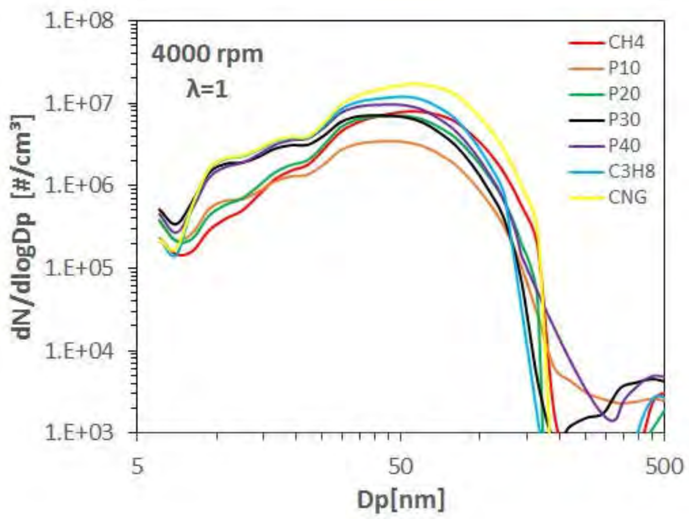
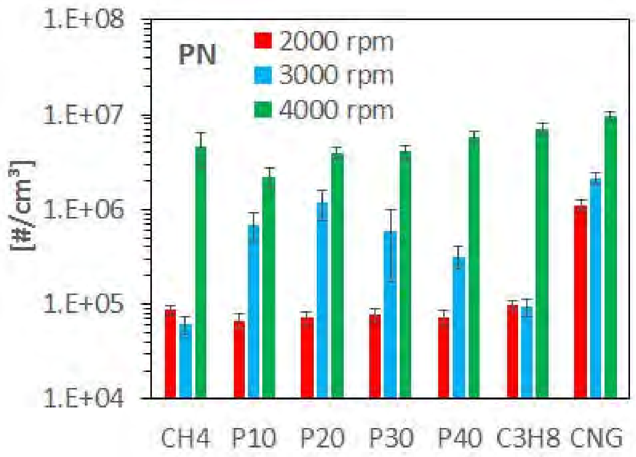
Idee sul monitoraggio e il controllo della combustione







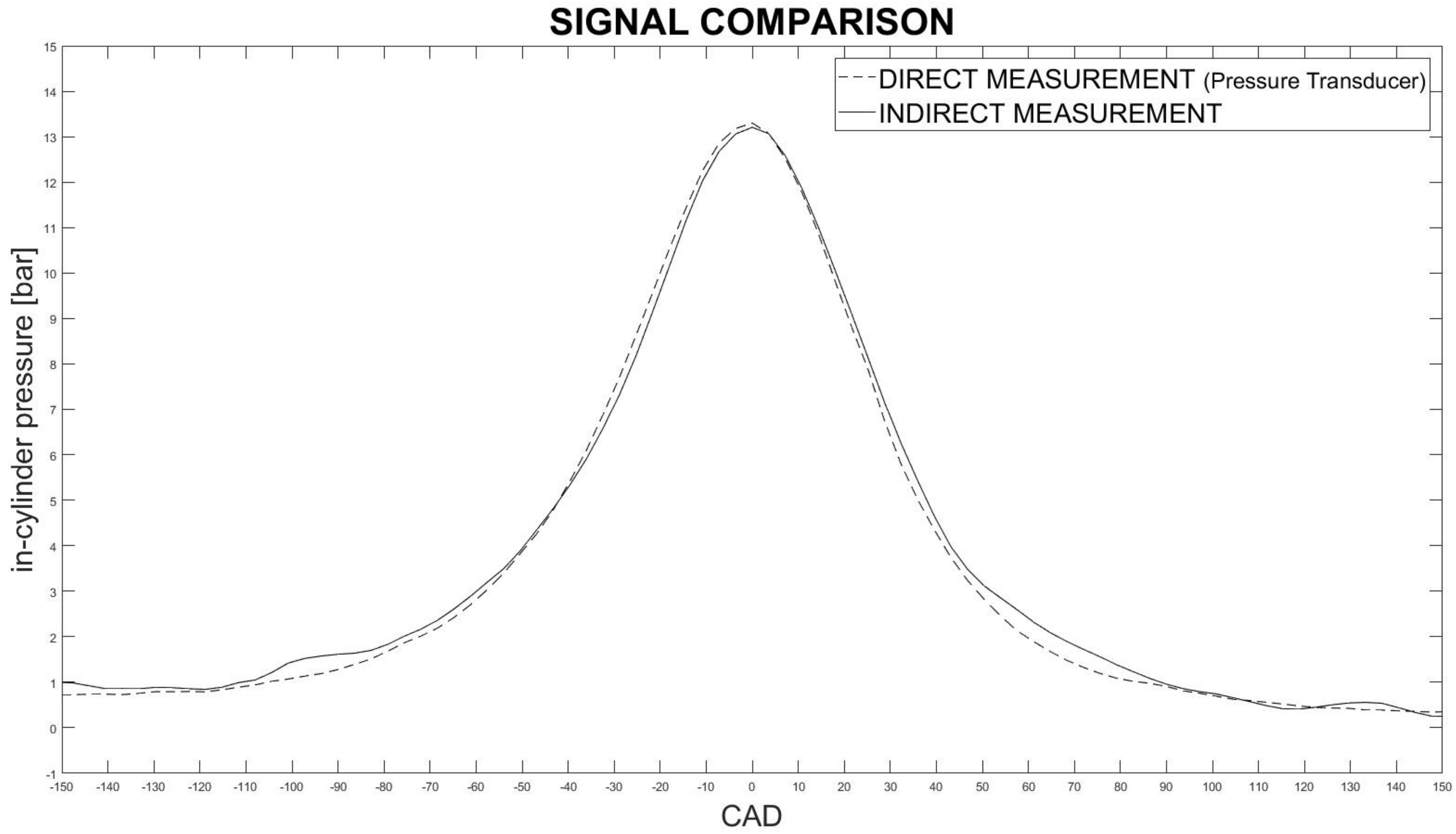


Amirante R, Distaso E, Di Iorio S, Sementa P, Tamburrano P, Vaglieco B.M., Reitz R.D. **Effects of Natural Gas Composition on Performance and Regulated, Greenhouse Gas and Particulate Emissions in Spark-Ignition Engines**. Energy Convers Manag 2017;143:338–47. doi:10.1016/j.enconman.2017.04.016

Amirante, R., Distaso, E., Di Iorio, S., Pettinicchio, D., Sementa, P., Tamburrano, P., Vaglieco, B.M**.** **Experimental Investigations on the Sources of Particulate Emission within a Natural Gas Spark-Ignition Engine**. SAE Technical Paper 2017-24-0141. doi:10.4271/2017-24-0141

3 Misura a basso costo della pressione in camera

Idee sul monitoraggio e il controllo della combustione



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Grazie per l’attenzione

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