Virtual Sensor for Soot Emissions in Heavy Duty Diesel Engines using alternative Fuels

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virtual sensor technology

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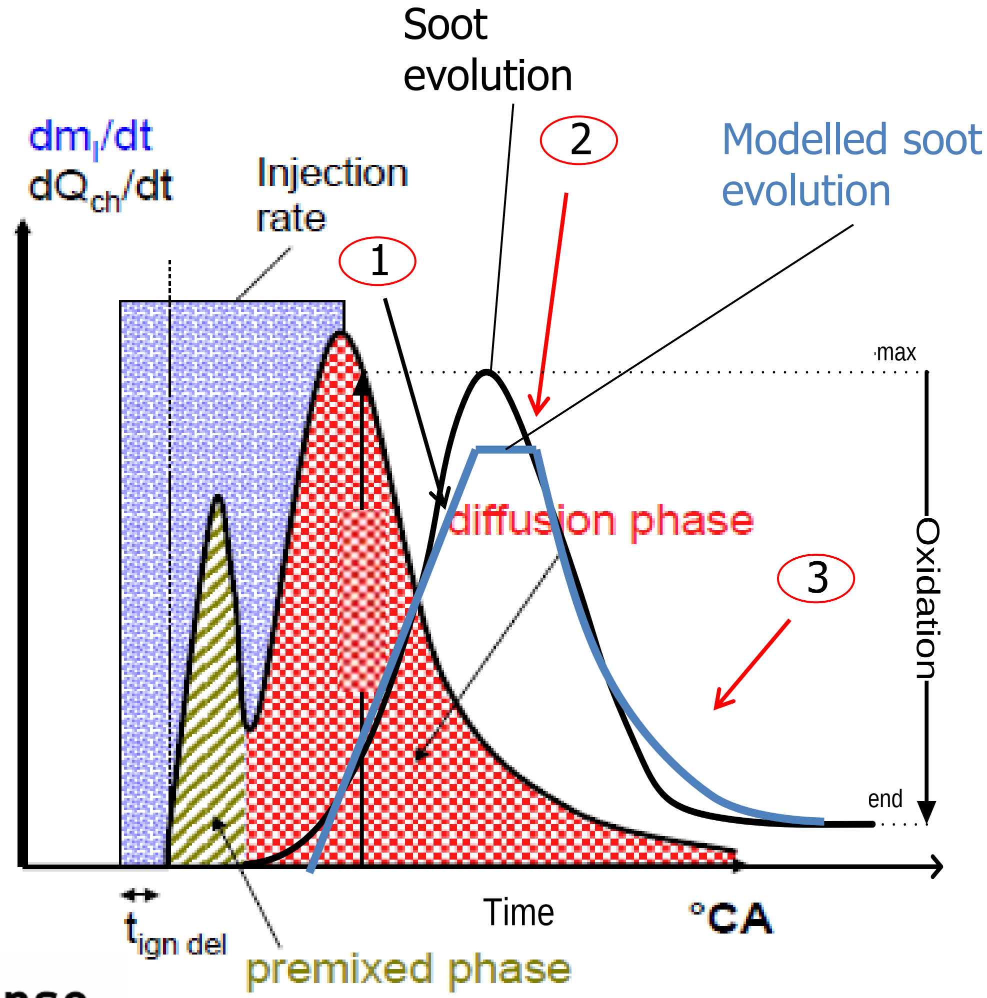
Outline

- Introduction / Motivation
- Modelling approach
  - Soot
  - Ignition & Combustion
- Alternative Fuels
- Results
- Summary and Conclusions

Introduction / Motivation

- Alternative energy carriers offer a beneficial CO2 footprint and show different combustion properties
- An engine setting optimization for alternative fuels offers the potential for a well-to-wheel CO2 reduction, which is as well addressed to the fuels CO2 footprint reduction (well-to-tank) as due to an increase in engine efficiency (tank-to-wheel)
- The high degree of freedom of operating settings provides the opportunity but also increase the complexity of an optimization and require models for combustion and emission

Phenomenolocigal Soot Model



Parts:

① •Soot formation
-f($dQ_{diff}/d\varphi$, p, T, fuel characteristics)

② •Balance: formation, oxidation

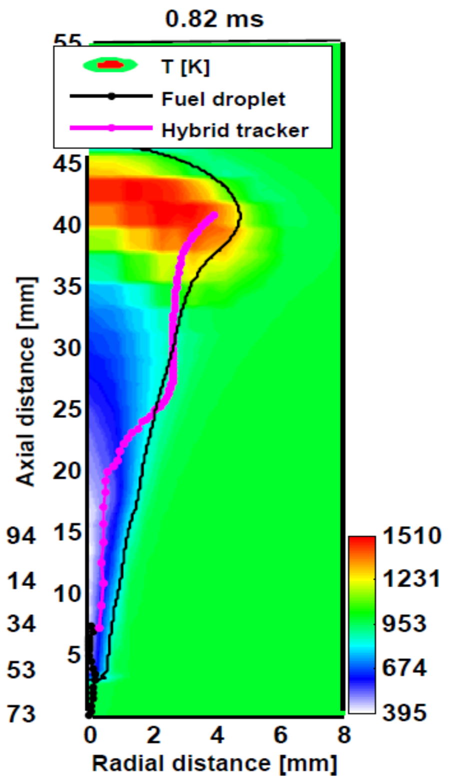
•Soot Oxidation
③ f(reactions kinetics (i.e T and global O_2), turbulence (i.e local O_2 / OH))

Result:
EC mass concentration

Challenges:
High ratio of exhaust vs max. in cylinder soot concentration causes high sensitivity of errors

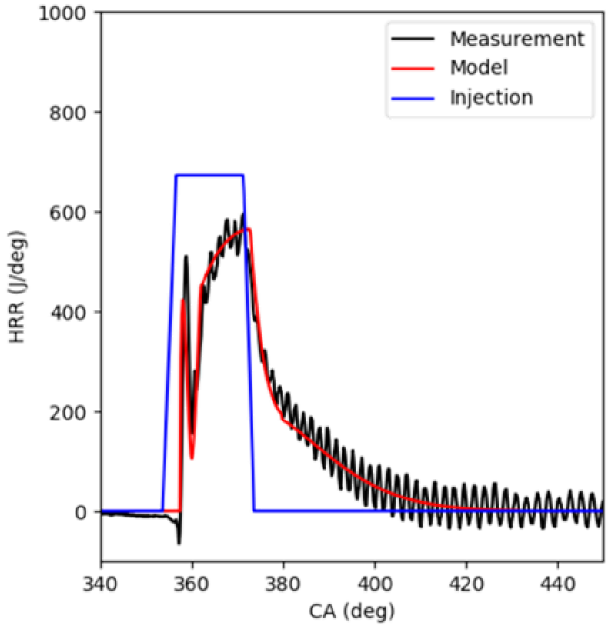
C. Barro, P. Obrecht and K. Boulouchos; *Development and validation of a virtual soot sensor: Part 1: steady-state engine operation*; International J of Engine Research 2014, Vol. 15(6) 719–730

Combustion Model / Soot Model Input Requirements



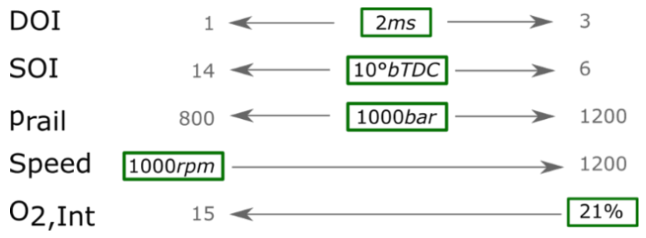
- Ignition delay model
  - Important to separate premixed and mixing controlled combustion portion
  - Accuracy difficult due to cross sensitivity of chemical (reaction kinetics, fuel characteristics) and physical (mixing, spray characteristics) processes

- Heat release Model
  - Separate model for premixed and mixing controlled combustion
  - Accurate mixing speed resp. characteristic mixing rate crucial for subsequent emission models

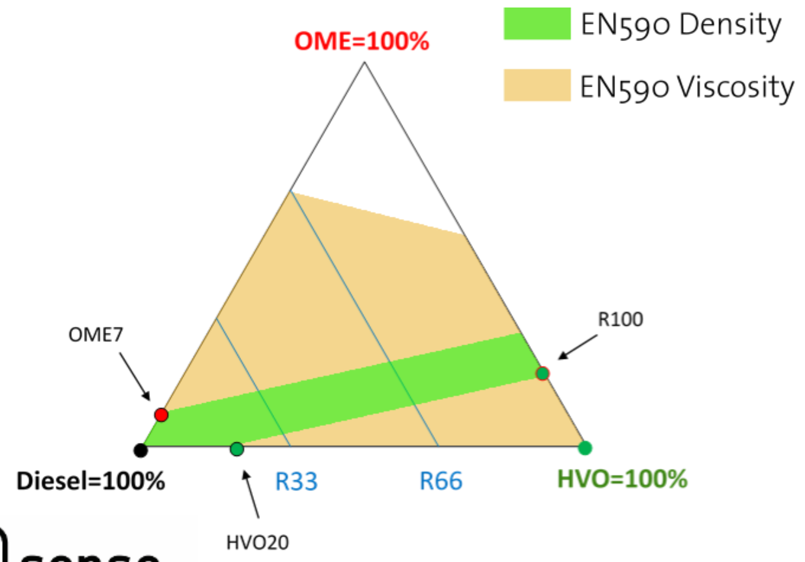


Engine Operation and Fuels Tested

- 4 liter heavy duty single cylinder supercharged common rail research diesel engine
- Engine operating conditions set to cover a wide spread of operating condition variation (in total 60 individual operating points for each fuel)
- Representatives of paraffinic fuels and a representative of oxygenated fuel has been selected
- Fuel blends with various blending ratios to understand non-linearities in fuel blends



DOI	1	2ms	3
SOI	14	10°bTDC	6
Prail	800	1000bar	1200
Speed	1000rpm		1200
$O_{2,Int}$	15		21%

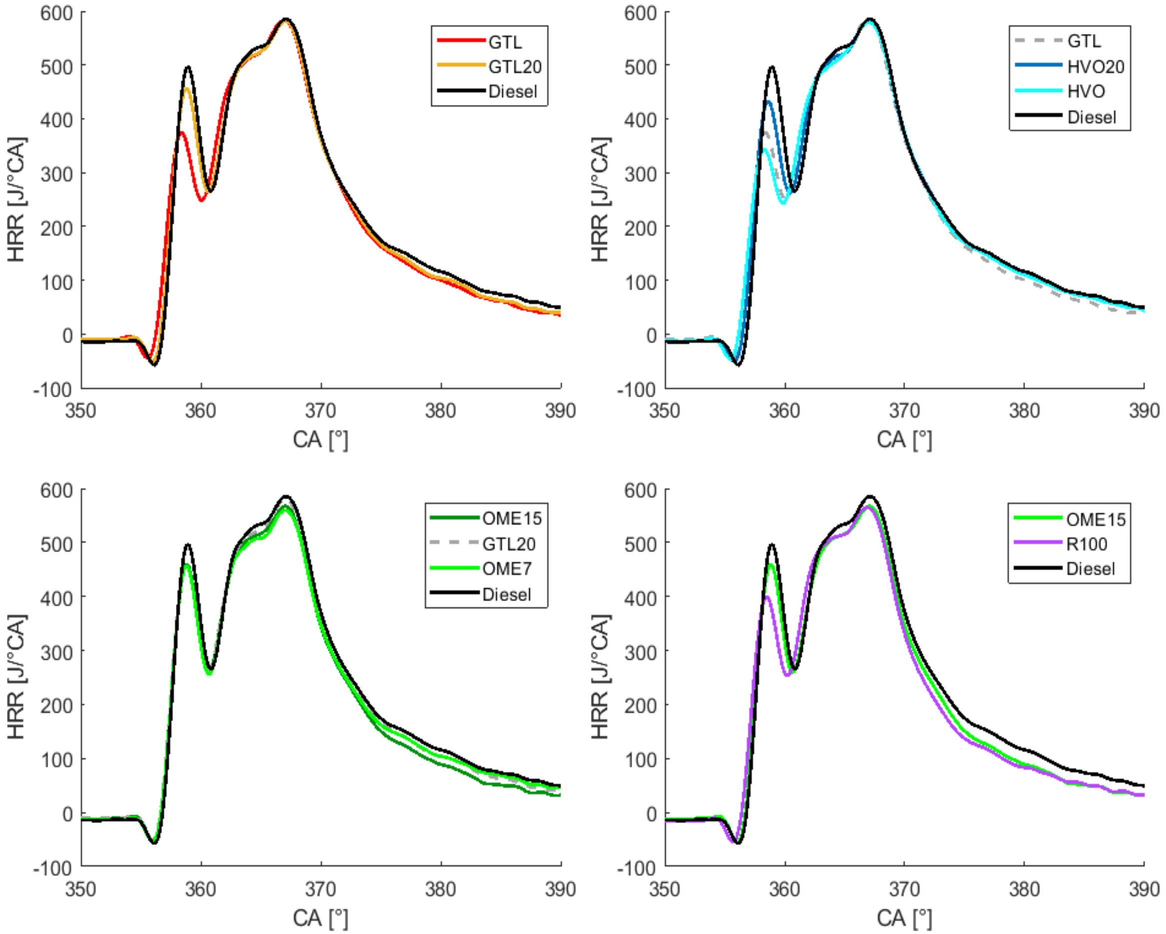


	Diesel	GTL20	GTL	OME15	OME7	HVO20	HVO	R100
Composition	100% Diesel	80% Diesel 20% GTL	100% GTL	85% Diesel 15% OME	93% Diesel 7% OME	80% Diesel 20% HVO	100% HVO	77% HVO 18% OME 5% Alcohol
LHV [MJ/kg]	43.5	43.57	43.8	39.89	41.89	43.6	43.8	38.61
Denstiy [kg/m^3]	827	817.3	778.3	859.9	842.3	817.6	780.2	820.9
CN [-]	56.1	61.1	82.4	<60	<57	61.2	82.8	75.1
Aromatics [wt%]	22.8	18.2	<0.1	19.4	21.2	8.3	<0.2	<0.2
Oxygen [wt%]	0	0	0	8.19	3.83	0	0	>8.19
Well-to-Tank CO2 red. [%]	0	n/a	n/a	9	4	18	90	~88

Combustion characteristics: Heat Release Rate

HRR:

- Overall only apparently minor differences
- Changes in Cetane number lead to significantly decreased premixed portion in all cases with high paraffinic fuel content (HVO, GTL, R100)
- Late phase combustion is particularly faster for the oxygenated fuels (OME, R100)



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Combustion characteristics: Characteristic Mixing Rate

$1/\tau_{mix}$:

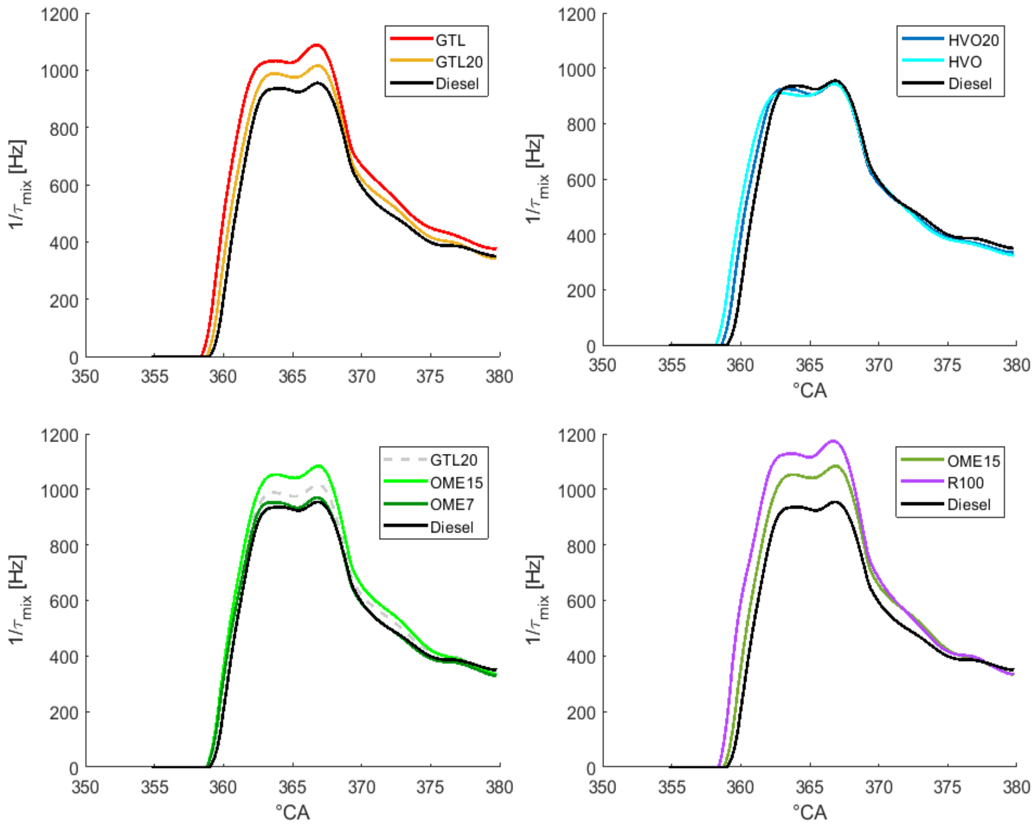
- $1/\tau_{mix}$ characterizes the diffusion combustion.

$$\frac{1}{\tau_{mix}(t)} = \frac{HRR_{diff}(t)}{Q_{inj} - \int_{SOC}^{t} HRR(t)\,dt}$$

combustion rate
available fuel

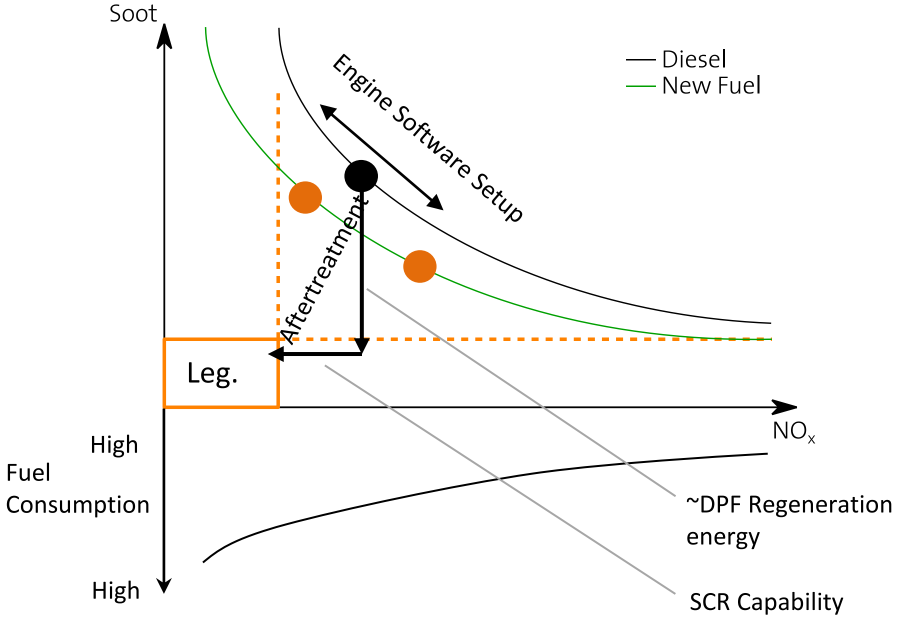
$$\tau_{mix} = \tau_{evap} + \tau_{diff} + \tau_{ign}$$

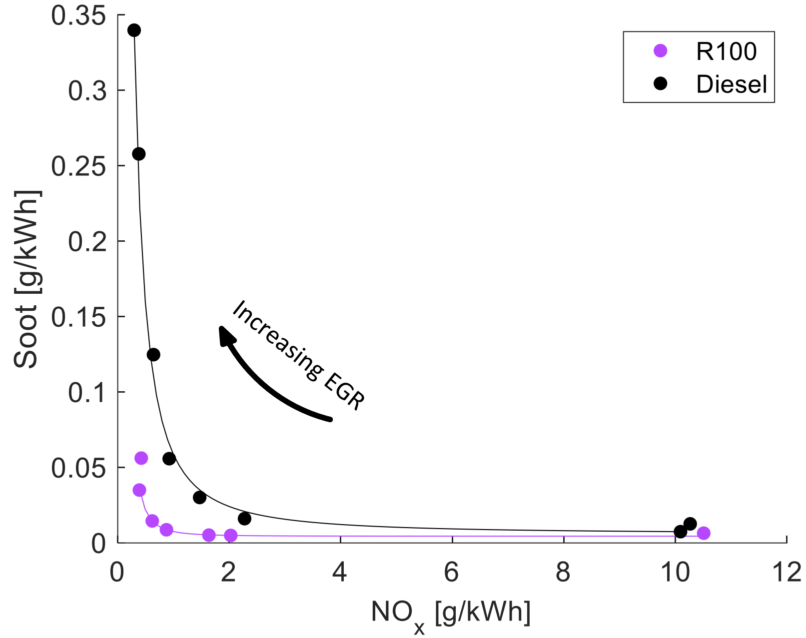
- τ_{mix} is a good proxi for the residence time in the hot combustion zone and therefore important for emission formation

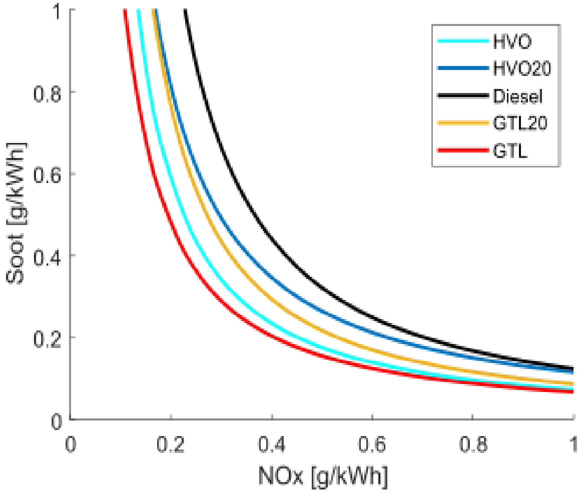


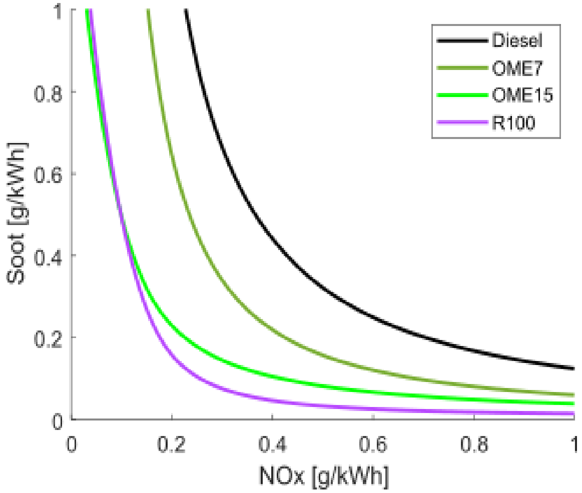
Emission Characteristics

- Paraffinic and oxygenates reduce soot emissions strongly. NOx emissions do not show a unequivocal trend
- The difference in trade-off line is the CO2 reduction potential, which needs to be realized by optimum engine settings
- Soot/PM, NOx and its trade-off behaviour is different for each fuel





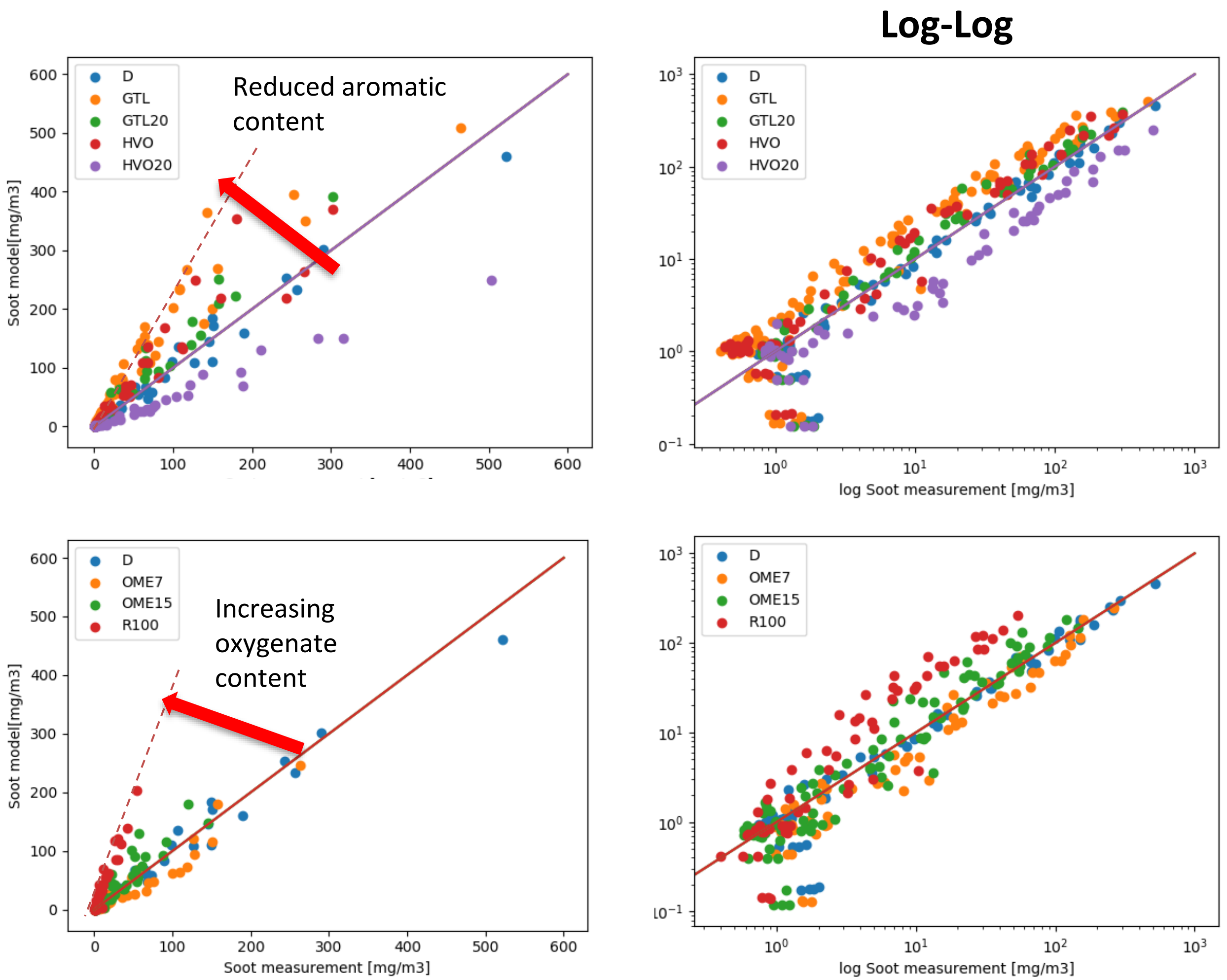




Results: Soot with Diesel Parameters

- All cases have the same engine model, but individual settings for HRR model; soot model constants are taken for diesel
- Results show the pure effect of fuel composition on soot emissions
  - Lower aromatic content reduces emissions
  - Higher oxygenated portion reduces emissions

Log-Log



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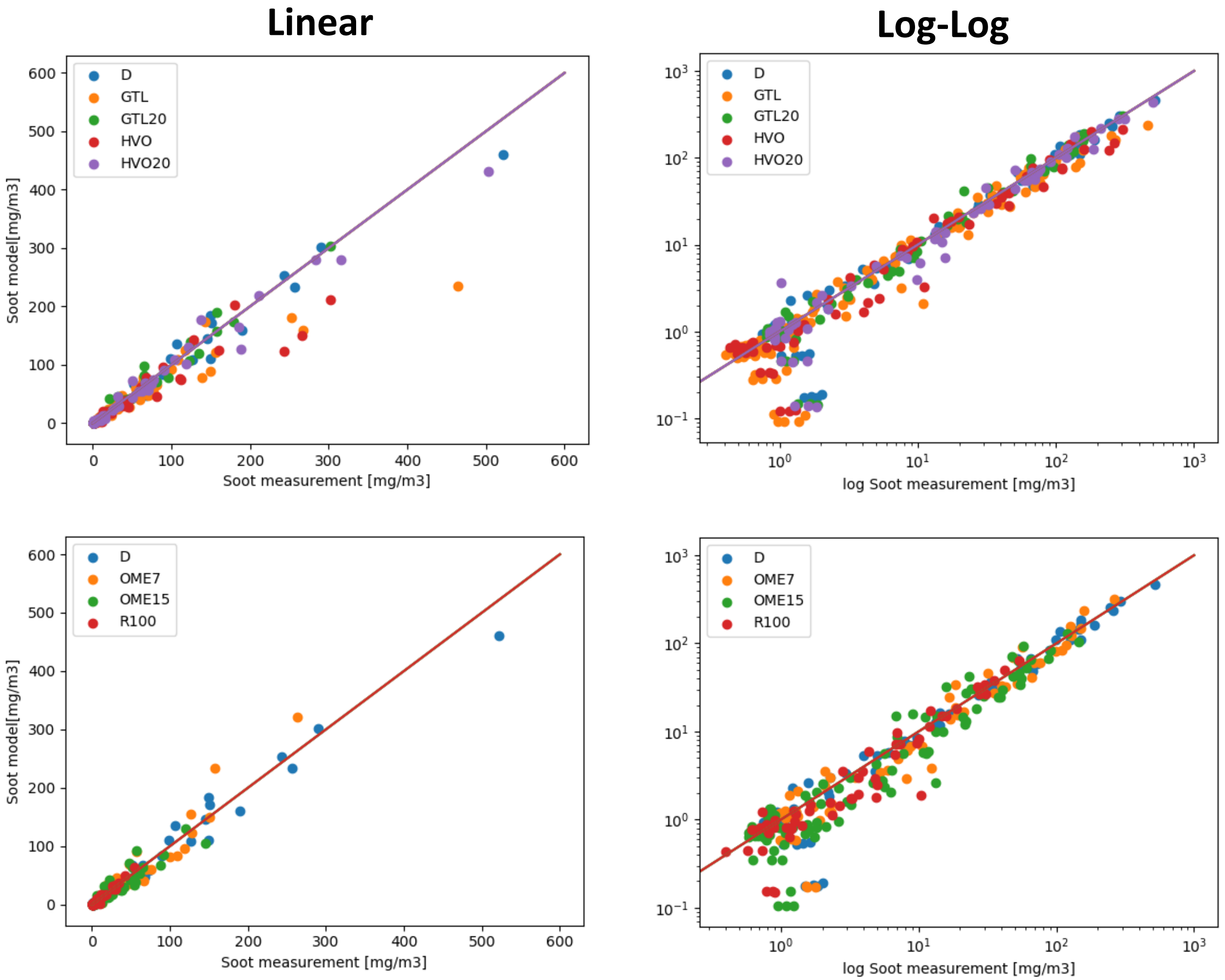
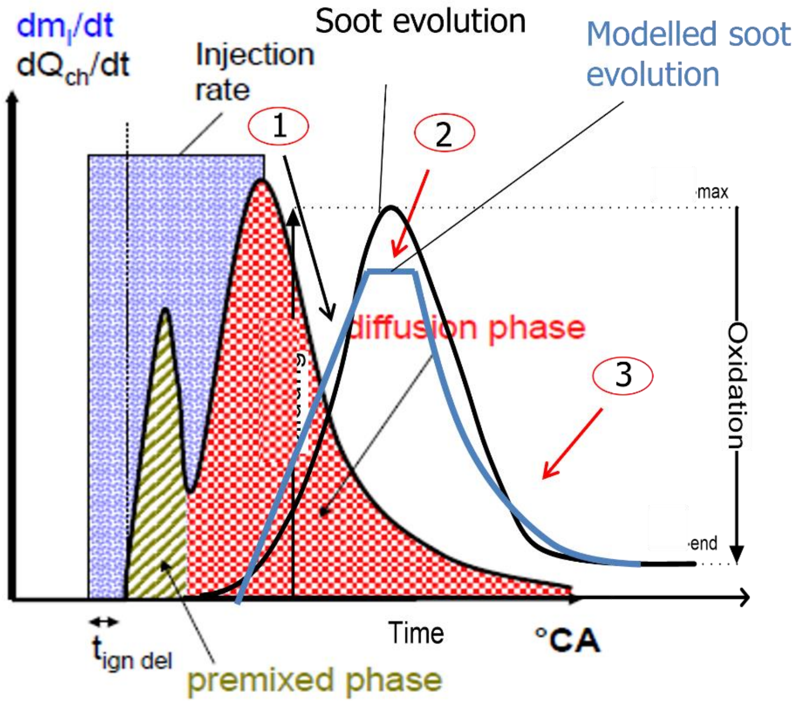
Results: Soot with Tuned Parameters

- Soot production and oxidation multiplier parameters fitted to each fuel’s measurements
  - Variation of soot emission characteristics with different fuels allowed the determination of individual effects of composition on soot formation and oxidation
  - Production term decreases linearly with increasing non-paraffinic content
  - Oxidation term increases quadratically with increasing oxygenate content



Soot Model Parameters



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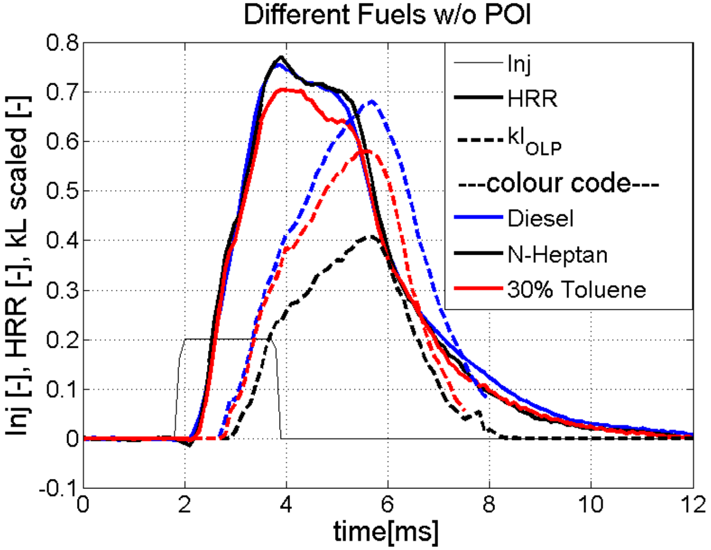
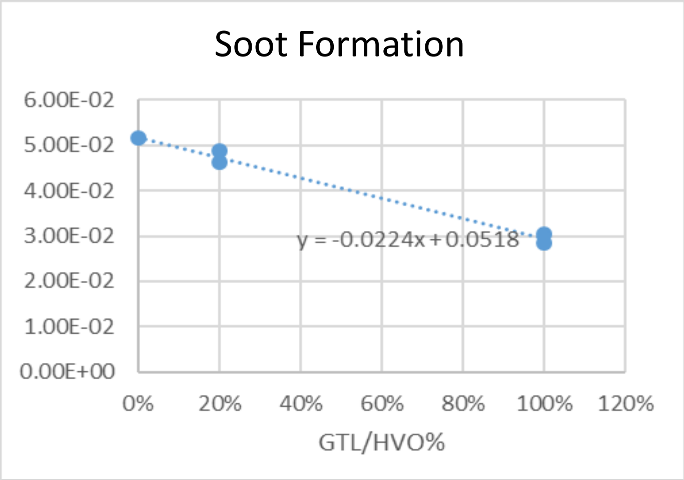
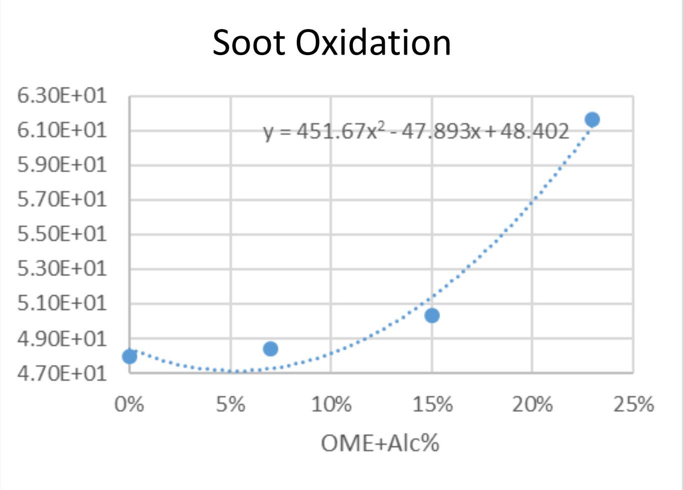


Barro et al. SAE 2014-01-2839





Summary & Conclusions

- Modelled prediction of HRR, NOx and soot very accurate for a wide range of conditions and different fuels:
    - Variable load (λ), fuel pressure, SOI, EGR, rpm
    - Fuels: combinations of Diesel (0-100%), GTL/HVO (0-100%) and OME (0-20%)
    - Only few parameters required to be adapted to change from one fuel to another
    - Relation between model parameter and fuel composition explored
    - Parameter adaptation inline with fuel composition (i.e. aromatic content / oxygen content)

- Final result is a fully tuned model for combustion, NOx and soot emissions for variable fuel composition, capable of being used for:
    - Off-line tuning of engine parameters
    - Determination of improvement of efficiency using different fuels with adaptive parameter settings
    - Possibility for onboard optimization for different fuel compositions
    - Models can be used as virtual sensors and only require inputs, typically available on the ECU

- Details of full engine optimization can be found on:

https://www.aramis.admin.ch/Default?DocumentID=67587&Load=true

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