Implications of spray angle detection on global equivalence ratio and emission predictions

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Overview

- The need for (diesel) IC engines
- Challenges
- How do we address these challenges?
- Spray angle detection methods
- Results
- Conclusions

The Guardian April 2017

The death of diesel: has the one-time wonder fuel become the new asbestos?

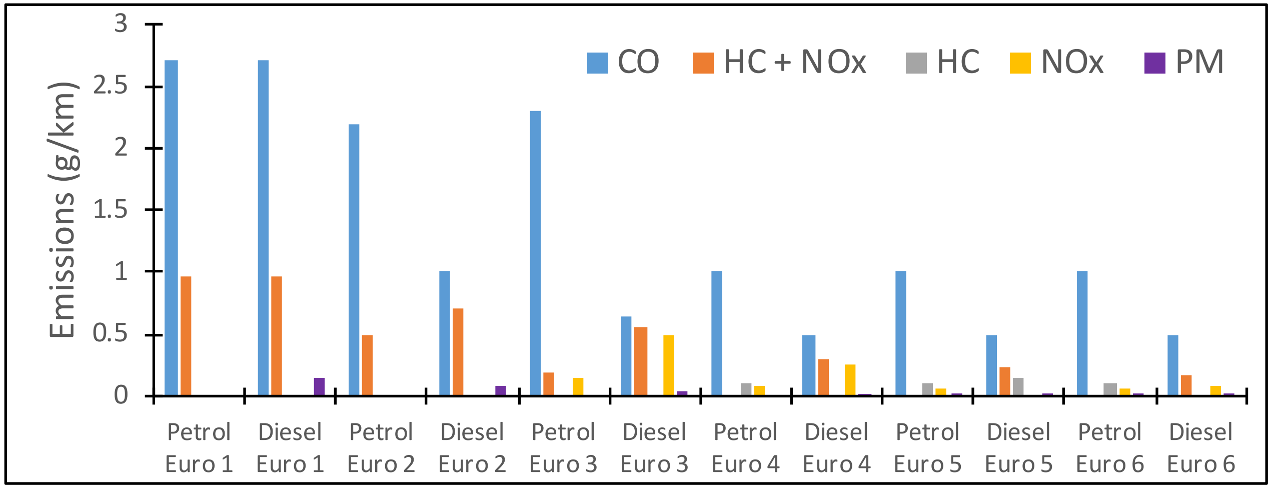
Are these claims true for today's diesel cars?

Let's see the current status…

THE TIMES June 2018

Diesel drivers to pay in world's largest low-pollution zone

The need for (diesel) IC engines



- Euro 6 emission standards are very similar for gasoline and diesel (see table below in g/km) [2]

Pollutant	Gasoline	Diesel
CO	1	0.5
HC	0.1	
HC+NOx		0.17
NOx	0.06	0.08
PM	0.005	0.005

- **Newer generations of diesel vehicles are forced to have similar emissions to new petrol vehicles**

[1.] Data obtained from ‘AA’ summary of emissions regulation

[2.] The International Council on Clean Transportation , A technical summary of euro 6/VI vehicle emission standards, 2016

The need for (diesel) IC engines

- Transport is mostly powered by IC engines and demand is increasing (~28 million barrels of oil equivalent daily of Diesel/Gasoil alone) [3]
- Diesel engines are fuel efficient and have low CO_2 emissions
- Better thermal efficiency due to higher compression ratios
- Longer service life than counterparts
- No alternative to replace Heavy Duty Vehicles (HDV) on road, marine, locomotive, industrial and power generation applications
- Electric alternatives are (for now) limited to small passenger vehicles due to battery size, cost and production limitations
- IC infrastructure already in place

[3.] International Energy Agency. Oil market report, 14 December 2017. https://www.iea.org/media/omrreports/fullissues/2017-12-14.pdf

Challenges for diesel engines

- Strict regulation control beyond EURO 6 (and VI) : NOx, soot and UBHC → driving towards Euro VII ? [4]
- Depletion of fossil fuels to meet increasing energy demands
- After-treatment costs are high: need to address challenge from in-cylinder combustion fundamentals

How can we address these challenges?

- One way is by addressing the combustion process itself via 2nd/3rd generation biofuels blends or by implementing new advanced combustion strategies
- This can be advanced by modelling studies, experimental work or a combination of both

4. 'Post-Euro VI Emission Regulation', ACEA Presentation at Emission Standards for the Future (European Commission), October 2018

Understanding of the spray parameters allows for the control of the combustion process and development of new combustion strategies

↓

Spray models are vital for realistic prediction of combustion and emissions

↓

Spray data must be consistent between different studies

Importance of the Spray Angle Evaluation For Emissions Interpretation

Provides a direct insight into ambient gas entrained in the spray → Determining the extent of fuel-air mixing → Ultimately influencing the interpretation of emissions

Correct assessment is important to:

- Reflect the true physics of the spray
- Allow for comparison between studies at different conditions
- Allow for consistent and realistic spray angle use for modelling works
- Raise awareness on how these differences can influence the interpretation of mixing

Spray Angle

Spray Angle Detection Methods

Method i): Fitting the tangent lines to the spray edge to measure the angle as a function of spray penetration

- Angle determined from lines fitted to spray boundary stemming from the spray origin reaching up to a certain % of the spray penetration

- 60% of the penetration length used in this study

Method ii): Fitting the tangent lines to the spray edge as a function of injector geometry (or at a fixed distance)

- Angle determined from lines fitted to spray boundary stemming from the spray origin reaching up to two sets of points defined as a fixed distance from the spray origin

Method iii): Triangle-based method based on the spray area

- Angle determined from a triangle with an area equivalent to the spray area at a certain % of the penetration length

- 50% of the spray penetration used as the triangle height

Method iv): Fitting tangents lines to the spray coincident at an origin which can move freely with the spray

- Angle determined from lines fitted to two sets of points of the spray but WITHOUT the coincident point of the line fixed at the spray's origin

Method v): Locally measuring and averaging angles as a function of the spatial location along the spray

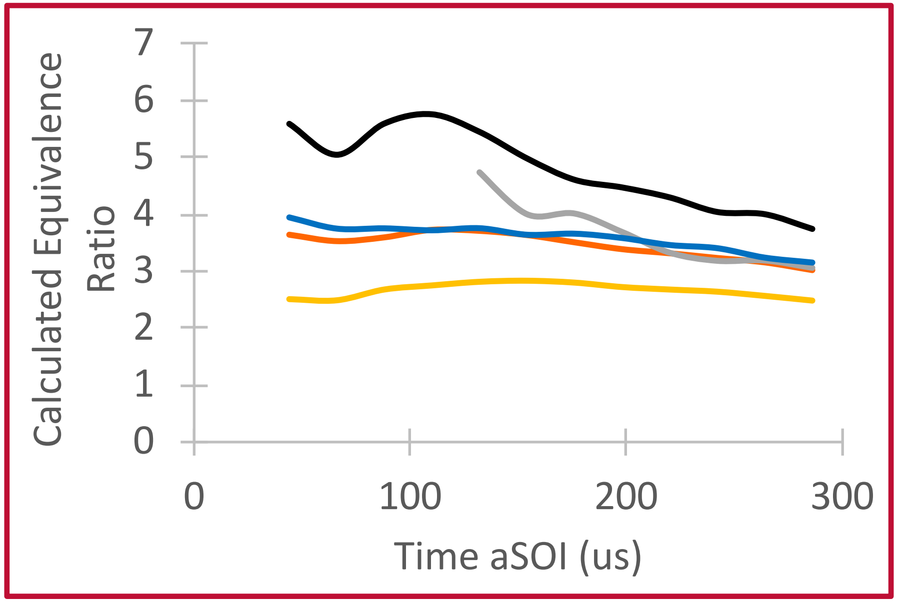
- The angle is detected at several user-defined locations for every time instant and averaged to obtain one angle value

Equivalence Ratio *

(from Start of Injection (SOI) to 300µs aSOI)

*** This was calculated using the relations in reference 4 with the previous spray angles as inputs**

Method i) Method ii) Method iii) Method iv) Method v)



- Different equivalence ratios are obtained depending on which method was used to detect the angle
- Differences in equivalence ratio can be as large as 50% at the very early SOI
- These differences decrease to 30% later on

[4] Naber. J, Siebers, D., ' Effects of Gas Density and Vaporization on Penetration and Dispersion of Diesel Sprays', SAE International, 1996

$$^{*}\bar{\phi}(x) = \frac{2(A/F)_{st}}{\sqrt{1 + 16(x/x^{+})^{2}} - 1}$$

&

$$x^{+} = \sqrt{\frac{\rho_f}{\rho_a}} \frac{\sqrt{C_a} d_0}{a \tan(\theta/2)}$$

Implications on the Interpretation of Emissions

- Equivalence ratio gives us an idea of air entrained in the spray
- Higher values of global equivalence ratio is associated with less air entrainment and the potential for more soot emissions
- Likewise, higher values of global equivalence ratios can be associated with less oxygen availability and the potential for more CO emissions
- If the equivalence ratio is skewed towards fuel-leaner values, our interpretation of NOx can also become skewed

Awareness of possible differences at least gives the option to assess how relevant these differences are for different applications

Conclusions

- The angle evolution trend with time is the same for most methods
- Differences do exist in angle output and are larger at the early SOI
- Different angle values produce different equivalence ratio when simple models are used to compute it
- Differences in angle values are magnified when interpreting the equivalence ratio
- Interpretation of the equivalence ratio will impact preliminary interpretation on emission like soot, CO and NOx
- Awareness of this becomes important at preliminary experimental stages and when comparing data in the literature

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Thank you for your attention

Any Questions?