INVESTIGATION OF THE FUEL PROPERTY INFLUENCE ON NUMBER OF EMITTED PARTICLES AND THEIR SIZE DISTRIBUTION IN A GASOLINE ENGINE WITH DIRECT INJECTION

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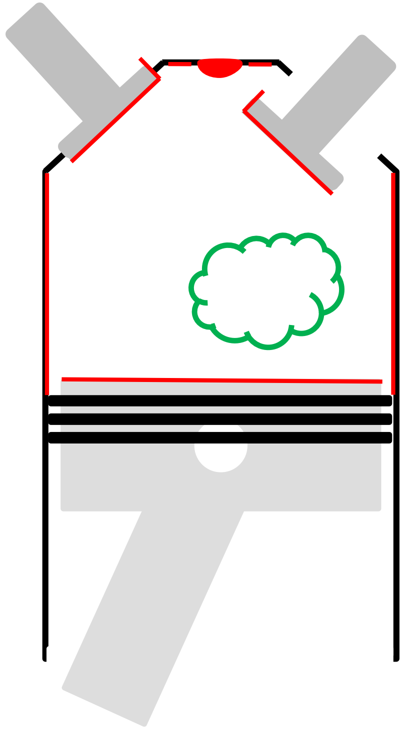
Motivation

- With the Euro 6c emission standard, the limit of emitted particles of gasoline engines with direct injection will be lowered **to 6 x 10^{11} particles per kilometer in 2017.**



What we know:

- Particle formation can be correlated with local rich mixture zones.
- These zones arise from in-homogeneities in the gas phase or from wall fuel films.

What we want to know:

- The **impact of fuel composition** on particle emissions.

  => section 1

- Which **sources of particles** inside of the combustion chamber are dominant?

  => section 2

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Presentation outline

- Motivation

- Section 1 - Influence of fuel composition on particle emissions
  - Experimental Setup
  - Measurement procedure
  - Investigated additives
  - Results
  - Conclusion

- Section 2 - Overview about the ongoing development of LIF for quantitative fuel film measurement

INFLUENCE OF FUEL COMPOSITION ON PARTICLE EMISSIONS

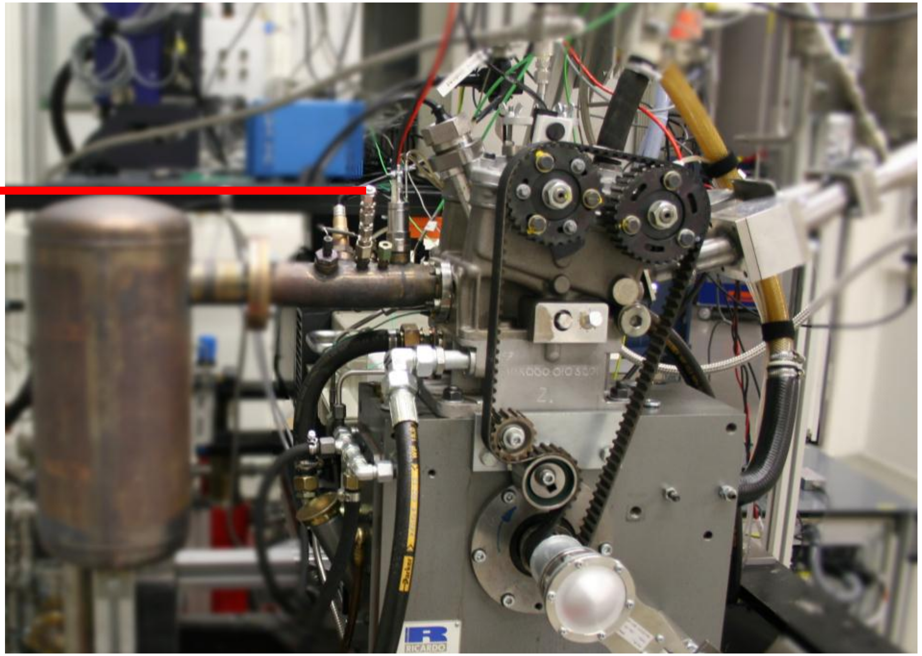
Influence of fuel composition on particle emissions
Experimental setup

TSI EEPS — **Dekati FPS 4000** — (engine)

Measures 10 particle size distributions per second.

Dilution Ratio ~ 30:1

=> Volatile particles can survive the dilution!



- Single cylinder engine (Daimler M271)
- Displacement: 449 cm³, ε=12.5
- GDI and PFI mode possible

EEPS = Engine Exhaust Particle Sizer
FPS = Fine Particle Sampler
PFI = Port Fuel Injection
GDI = Gasoline Direct Injection

Influence of fuel composition on particle emissions
Measurement procedure

1. For a better reproducibility the engine was conditioned before each measurement by burning methane (PFI) for 10 minutes.
2. Each additive was measured **3 times** for **10 minutes**.
3. The presented values are **arithmetic mean values (last 3 minutes).**

Operating Point:

- N = 2000 rpm, IMEP = 6 bar,
- Fuel pressure = 100 bar,
- Air fuel ratio λ = 1,
- MFB 50 = 8° a.t.d.c.,
- Start of Injection (SOI) = 270° b.t.d.c.

} Relevant operating point for certification circle.

PFI = Port Fuel Injection
IMEP = Indicated Mean Effective Pressure
MFB = Mass Fraction Burned
b.t.d.c = before top dead center

Influence of fuel composition on particle emissions

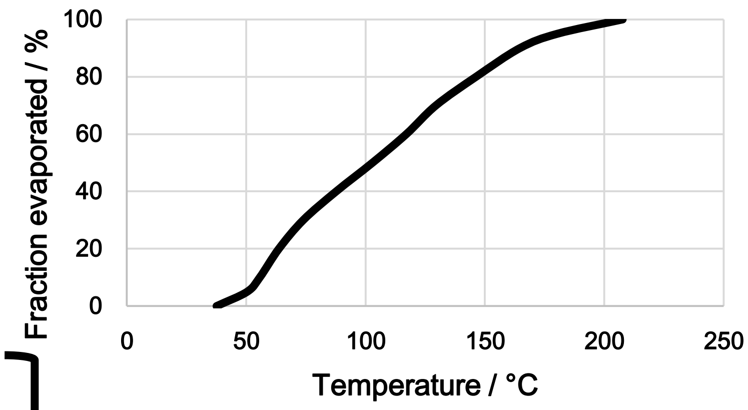
Investigated additives

Key parameters found in earlier investigations[1]

- Number of double bonds
- Boiling point

	boiling point	total formula
Decane	174 °C	$C_{10}H_{22}$
Decene	172 °C	$C_{10}H_{20}$
Indene	182 °C	C_9H_8
2,2,4-Trimethylpentane	99 °C	C_8H_{18}
2,4,4-Trimethylpentene	98 - 105 °C	C_8H_{16}
Toluene	111 °C	C_7H_8

Boiling curve of the reference fuel



Group 1: high boiling points

Group 2: middle boiling points

[1]Aikawa et al., Leach et al.

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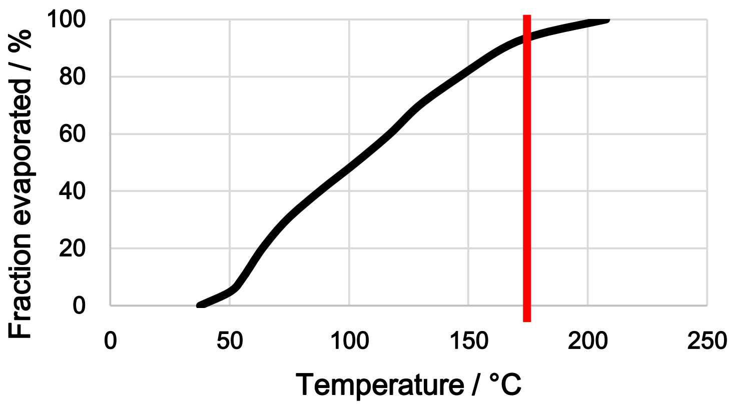

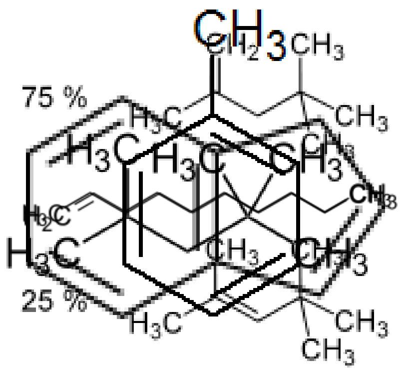

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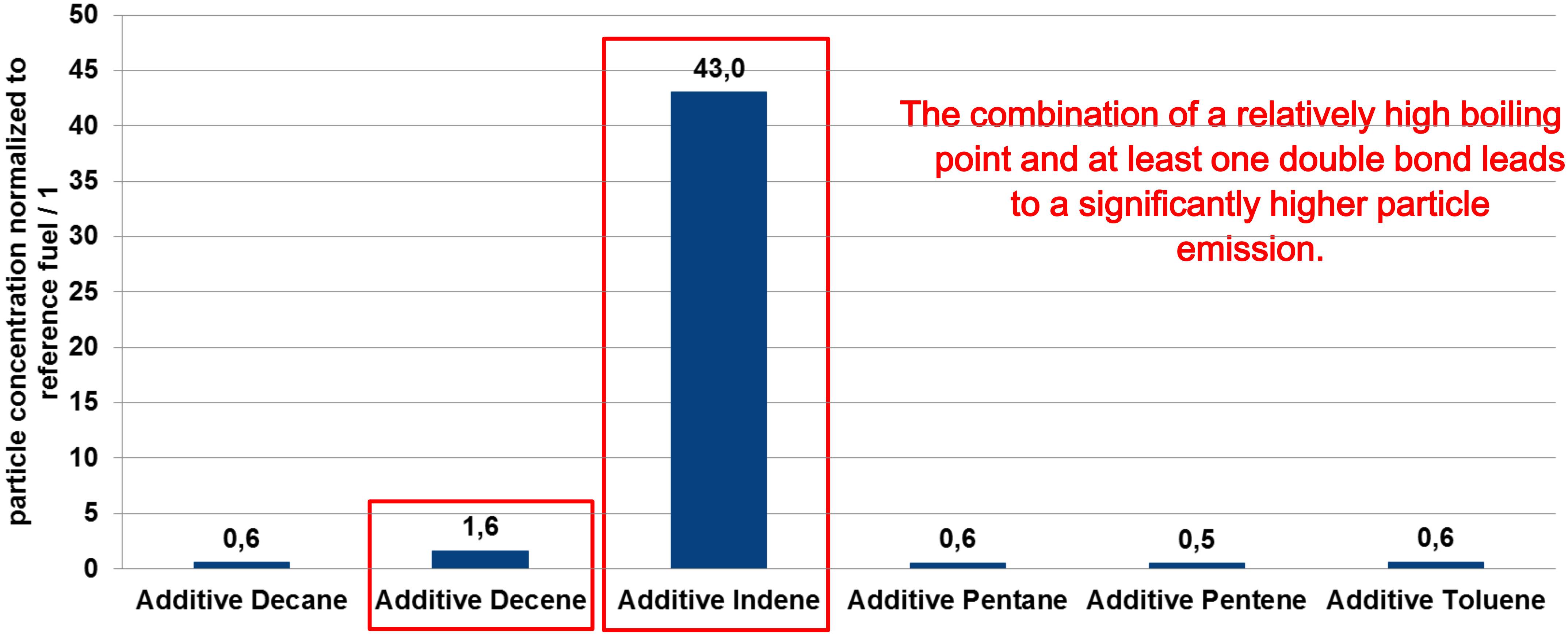
Influence of fuel composition on particle emissions
Results - particle concentration



The combination of a relatively high boiling point and at least one double bond leads to a significantly higher particle emission.

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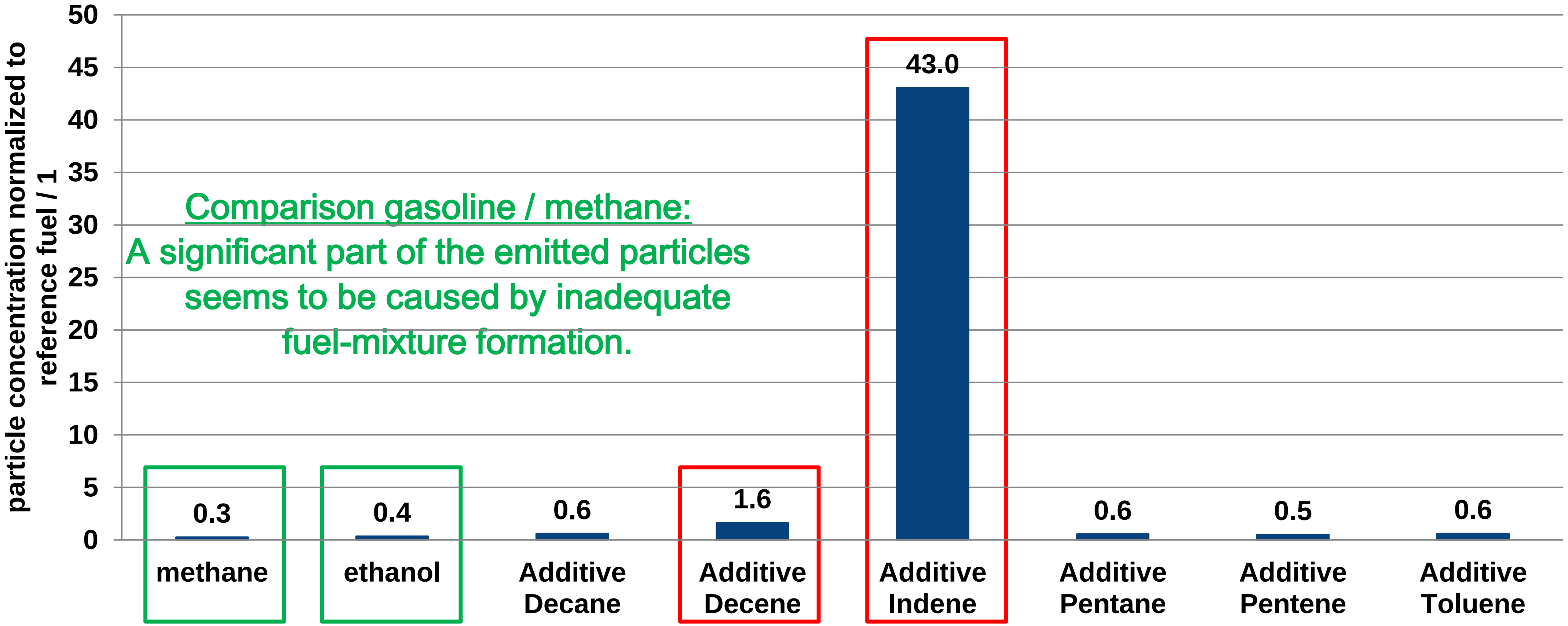
Influence of fuel composition on particle emissions
Results - particle concentration



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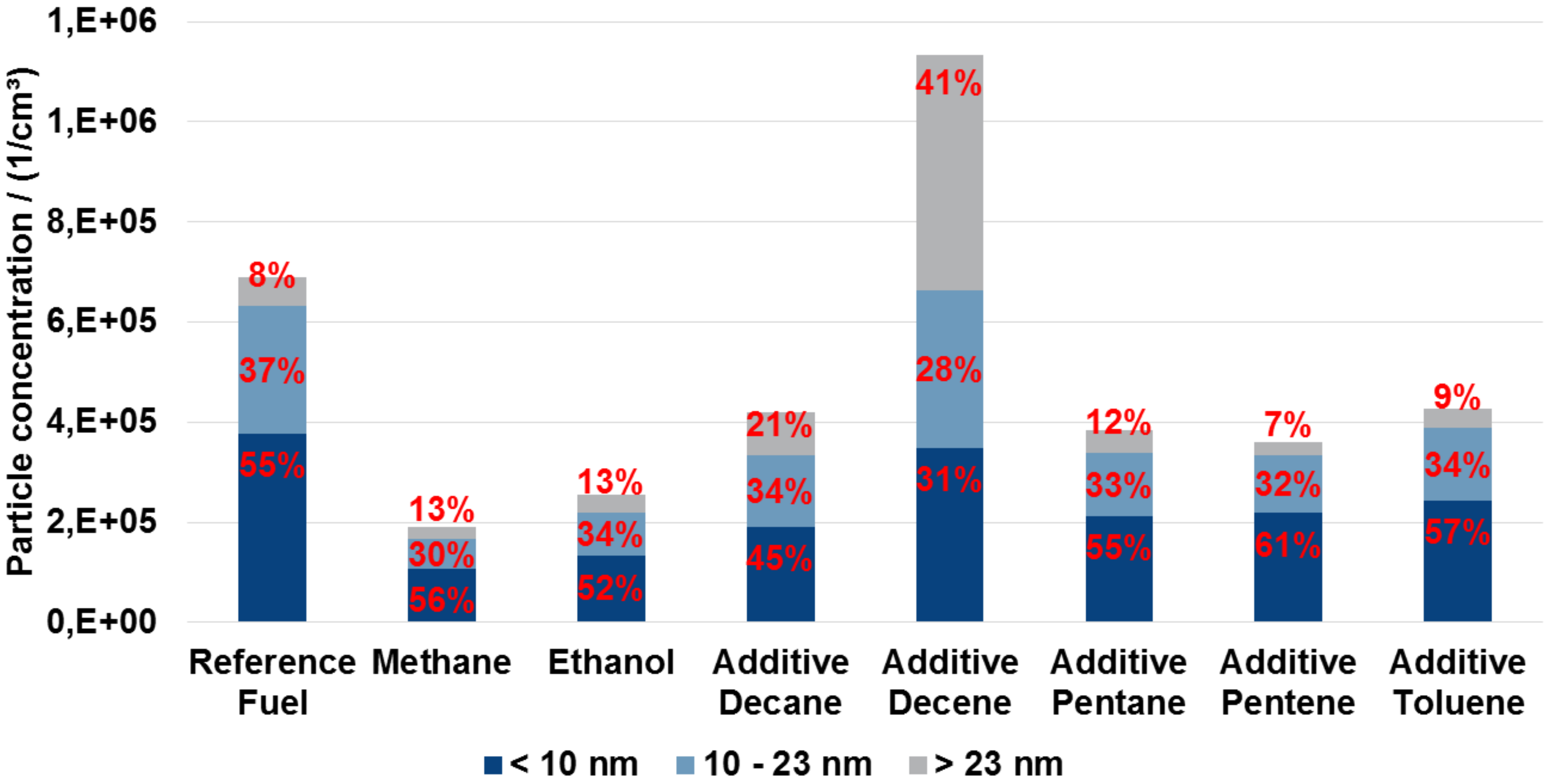
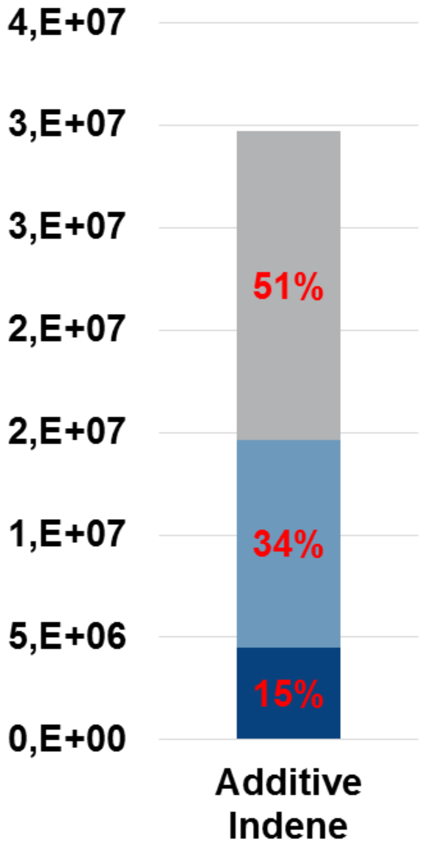
Influence of fuel composition on particle emissions
Results - particle size distribution





Proportion of each size range

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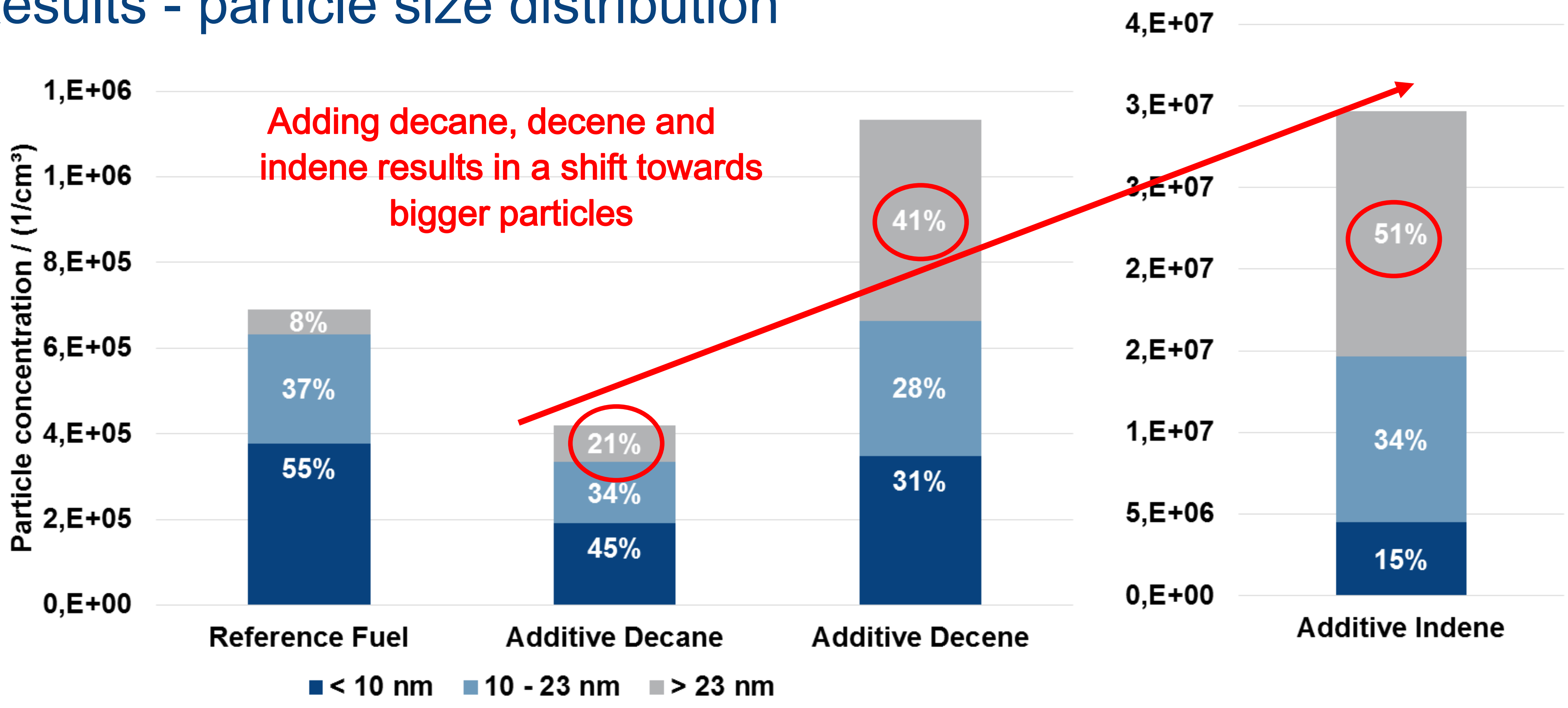
Influence of fuel composition on particle emissions
Results - particle size distribution



Influence of fuel composition on particle emissions
Conclusions

- The presented results confirm the effect of fuel composition on the emitted particle concentration and show additionally **an impact on the particle size distribution**.

- **Especially additives with a high boiling point** show **an impact on the number** of emitted particles **and their size distribution.**

- By using methane the number of emitted particle can be reduced to 30 %. This means that a **significant part of the emitted particles seems to be caused by inadequate fuel-mixture formation**.

- An **optical measurement technique has to be developed** to understand the cause and effect relationship.

LASER INDUCED FLUORESCENCE (LIF) FOR QUANTITATIVE FUEL FILM MEASUREMENT

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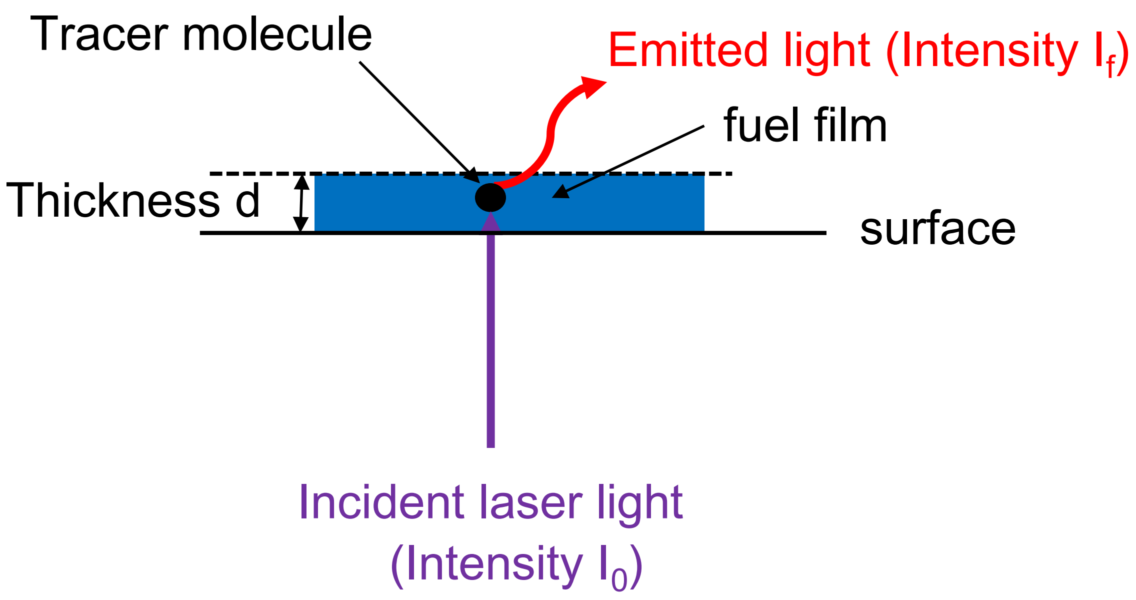
LIF for quantitative fuel film measurement

Principle



$$I_f = \phi(\lambda, T, n_i) \cdot I_0(\lambda) \cdot \left(1 - e^{-\epsilon^* \cdot c \cdot d}\right)$$

$$I_f \approx \phi(\lambda, T, n_i) \cdot I_0(\lambda) \cdot \epsilon^* \cdot c \cdot d$$

Calibration with a known thickness:

$$\frac{d_{exp}(x,y)}{d_{ref}(x,y)} = \frac{I_{f,exp}(x,y)}{I_{f,ref}(x,y)}$$

I_f: Intensity Fluorescence
I_0: Intensity incident light
c: concentration of fluorescent tracer
d: thickness
ϵ^*: extinction coefficient
ϕ: Fluorescence-Quantum-Yield

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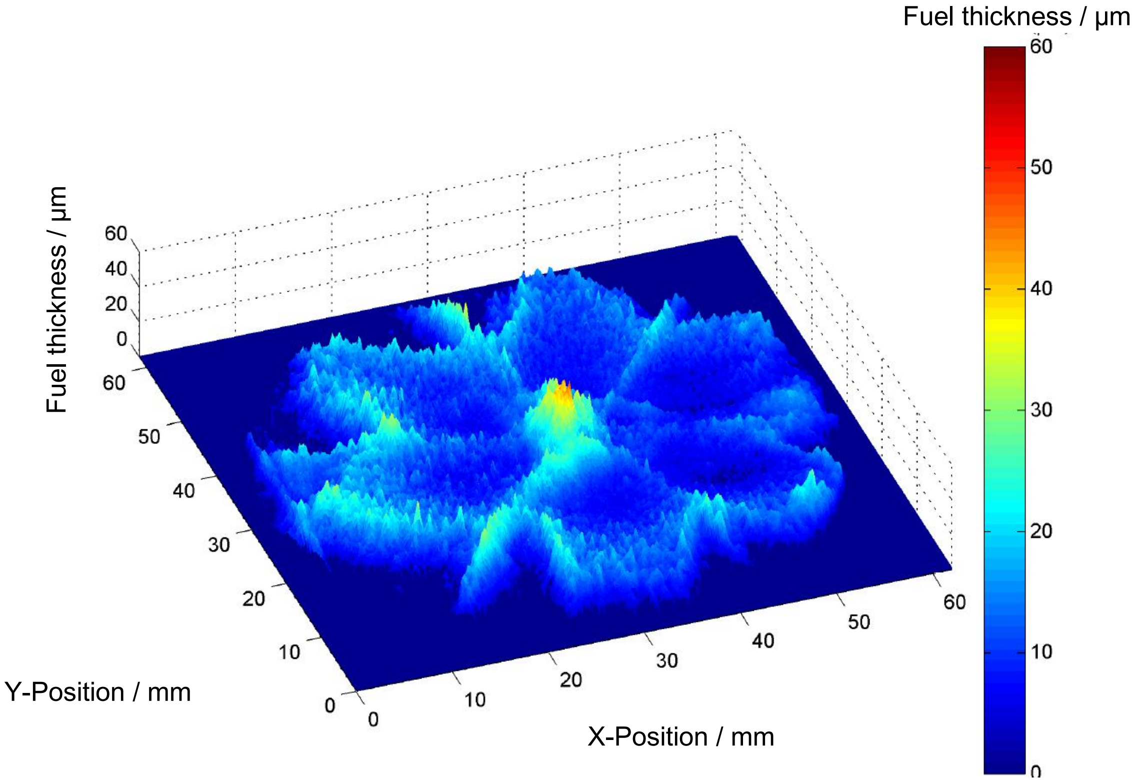
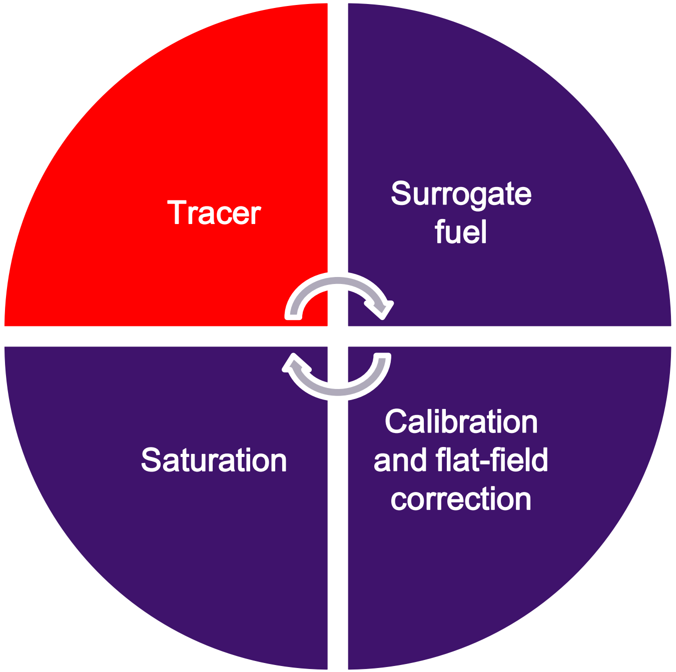
LIF for quantitative fuel film measurement
Overview

Fuel thickness distribution on the piston surface:



Schropp2013

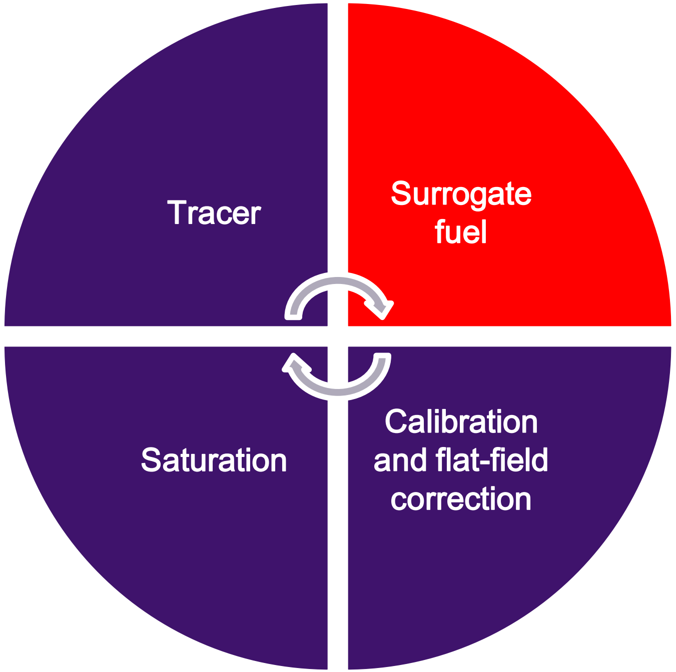
LIF for quantitative fuel film measurement
Overview



- A fluorescent component is needed:
  - Aromatics (e.g. Toluene, Trimethylbenzene),
  - Ketones (e.g. Acetone, 3-Pentanone).

- The fluorescence of the tracer should not be sensitive
  - to high pressure,
  - temperature or
  - an oxygen containing environment (quenching).

LIF for quantitative fuel film measurement
Overview



- For quantitative fuel thickness information a non-fluorescent surrogate fuel:
  - The surrogate fuel should **evaporate exactly like the reference fuel** and
  - the selected **tracer** should show an **excellent co-evaporation in respect to the surrogate fuel.**

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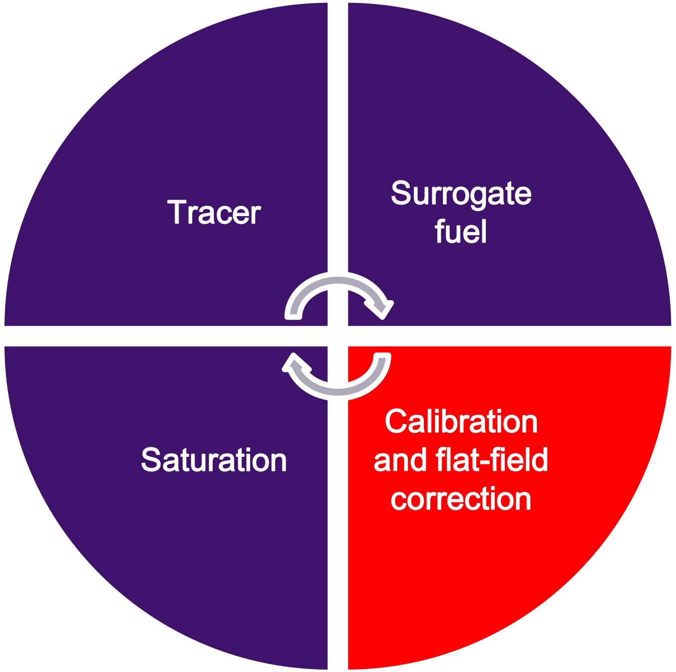
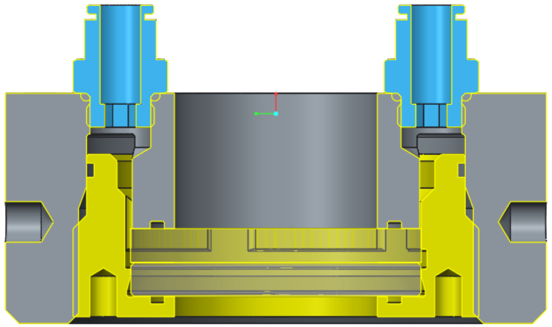
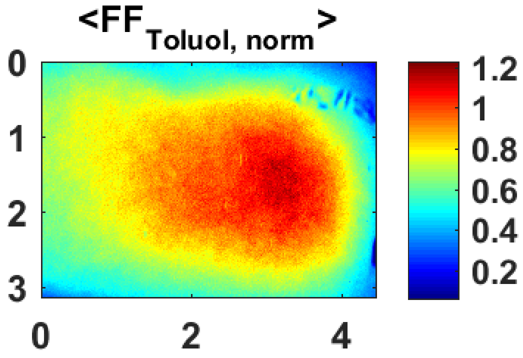
LIF for quantitative fuel film measurement
Overview



- Development of **a calibration tool to set different film thicknesses** (5 – 200 µm) **at different temperatures** (up to 200 °C).
- **Flat-Field correction** to consider the local exciting laser radiation:
  - Foil used for overhead projectors was found to be a suitable material.





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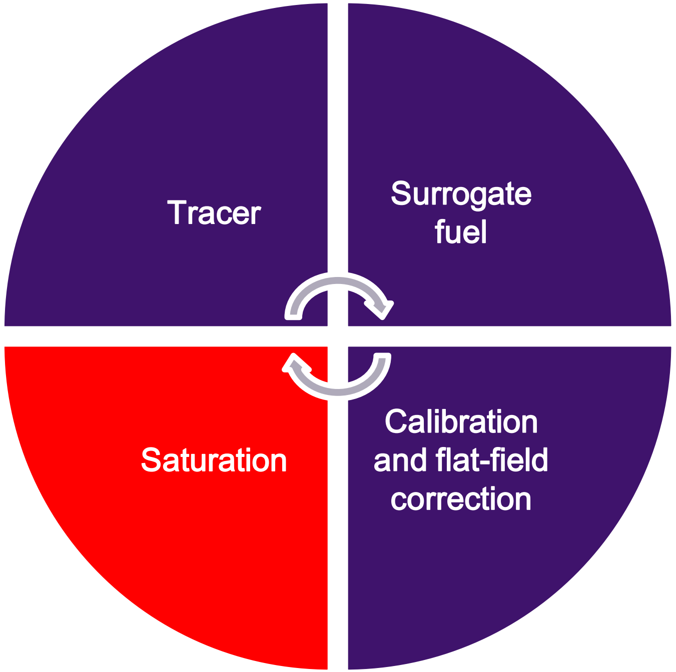
LIF for quantitative fuel film measurement
Overview



- **The concentration of the tracer should be as low as possible.**
  - If the concentration of the tracer is chosen too high, the film thickness is underestimated because all the laser light is absorbed and does not reach the whole measuring volume.

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LIF for quantitative fuel film measurement
Summary

- Various interactive parameters have to be considered in order to derive quantitative information.
- By following LIF shows the potential to give a pixel wise **information about film thickness.**
- The information gained by **LIF** can help us to understand **the causes of particle formation** inside of the combustion chamber and to **identify the main sources.**

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THANK YOU FOR YOUR ATTENTION

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SAE Int. J. Fuels Lubr., SAE International, 2010, 3, 610-622

Leach, F.; Stone, R. & Richardson, D.
The Influence of Fuel Properties on Particulate Number Emissions from a Direct Injection Spark Ignition Engine, SAE Technical Paper, SAE International, 2013

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Optische Methoden zur Bewertung des Kolbenwandfilms in Benzinmotoren mit Direkteinspritzung, Master Thesis, *Institut für Kolbenmaschinen, Karlsruher Institut für Technologie,* **2013**

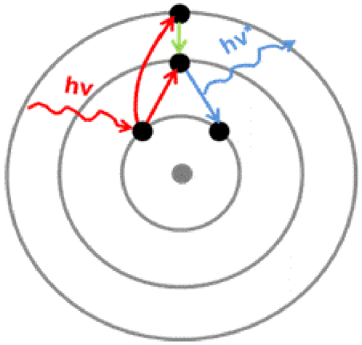
BACKUP

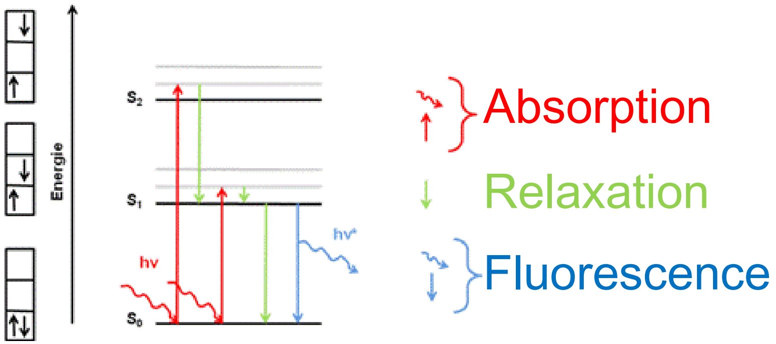
Laser Induced Fluorescence (LIF)
Physical principle

- Fluorescence = brief, spontaneous emission of light

$$I_f = \phi(\lambda, T, n_i) \cdot I_0(\lambda) \cdot \left(1 - e^{-\epsilon^* \cdot c \cdot d}\right)$$

$$I_f \approx \phi(\lambda, T, n_i) \cdot I_0(\lambda) \cdot \epsilon^* \cdot c \cdot d$$





I_f: Intensity Fluorescence
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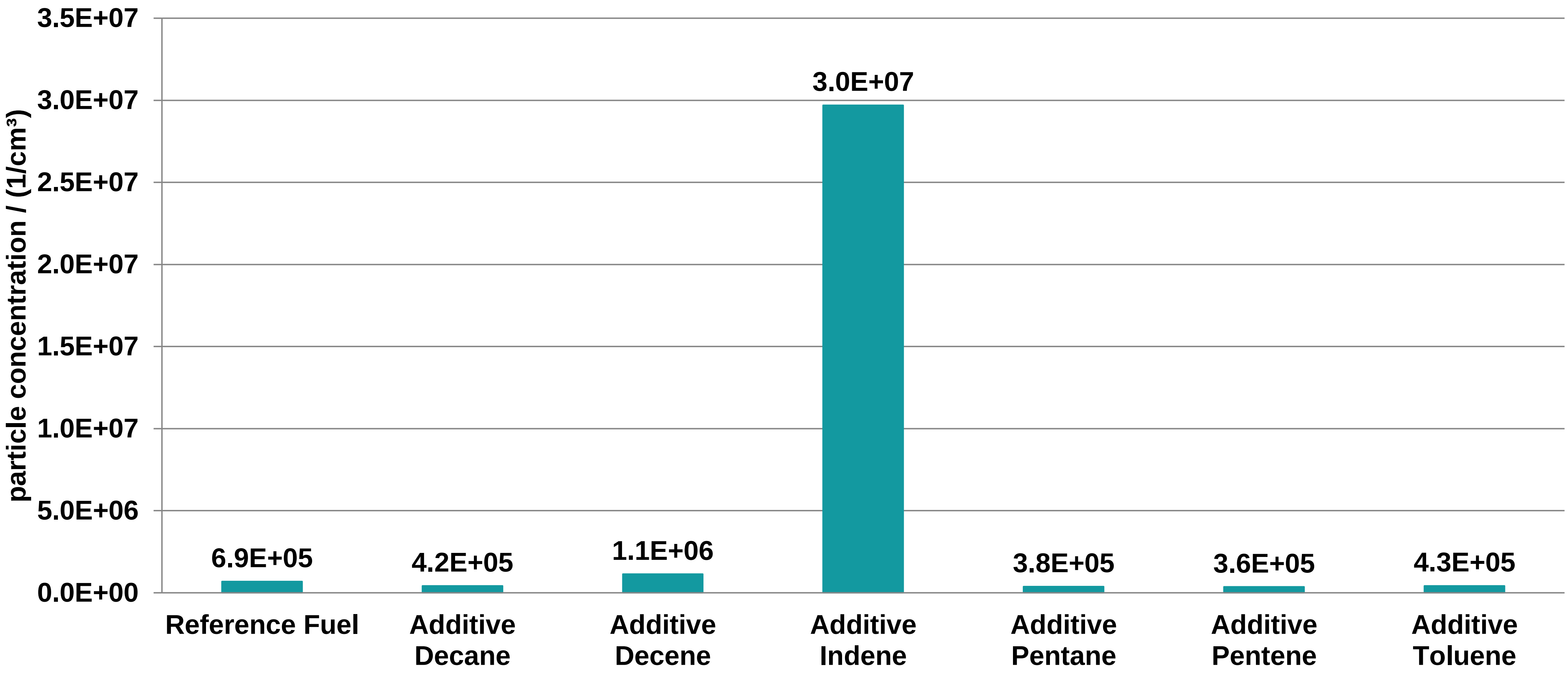
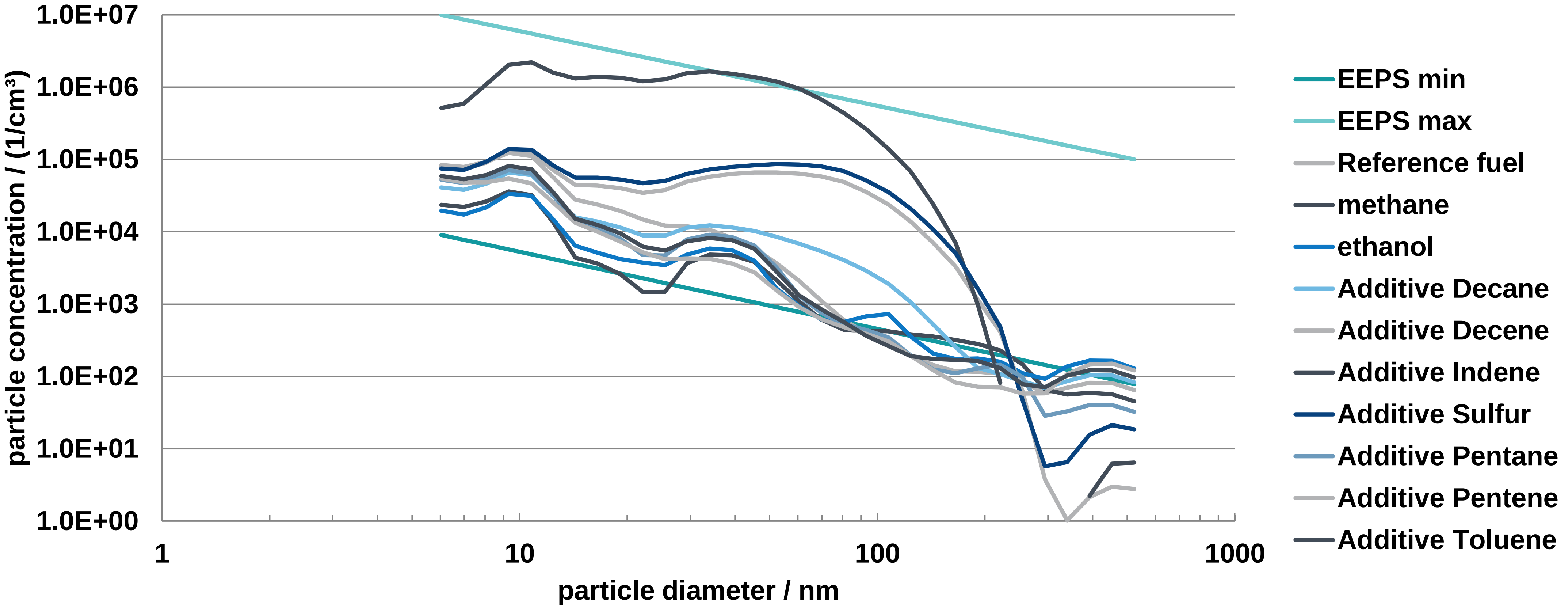
Backup


particle concentration / (1/cm³)
3.5E+07
3.0E+07
2.5E+07
2.0E+07
1.5E+07
1.0E+07
5.0E+06
0.0E+00
6.9E+05
4.2E+05
1.1E+06
3.0E+07
3.8E+05
3.6E+05
4.3E+05
Reference Fuel
Additive Decane
Additive Decene
Additive Indene
Additive Pentane
Additive Pentene
Additive Toluene

Backup


1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
particle concentration / (1/cm³)
1
10
100
1000
particle diameter / nm
EEPS min
EEPS max
Reference fuel
methane
ethanol
Additive Decane
Additive Decene
Additive Indene
Additive Sulfur
Additive Pentane
Additive Pentene
Additive Toluene