Fuels Perspective on Stochastic Pre-Ignition

2020 CRC Stochastic Pre-Ignition Workshop
September 29, 2020

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TECHNOLOGY
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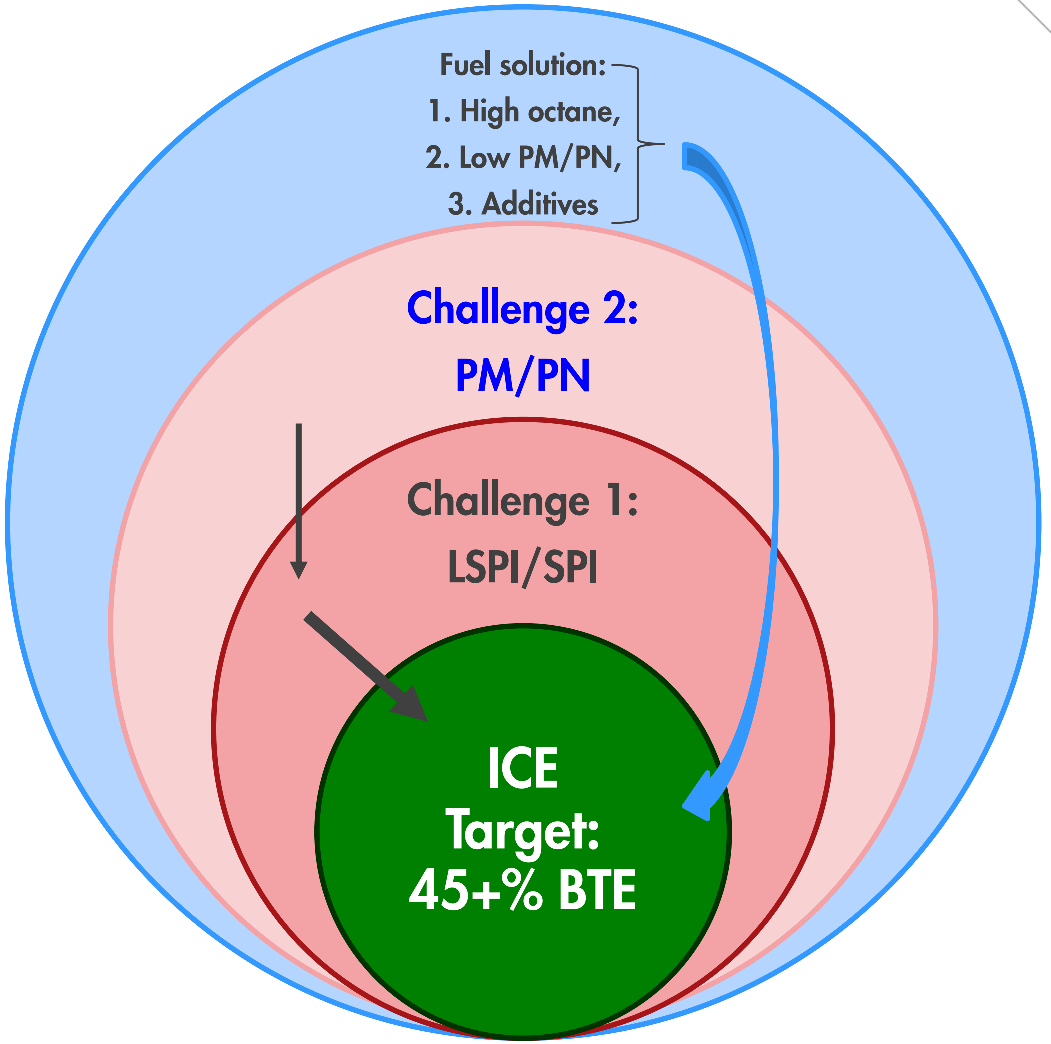
Outline

- Fuels Perspective on Stochastic Preignition
  - Why is stochastic pre-ignition (SPI) a problem?
    - Challenge to optimizing SI-ICEs on efficiency and emissions
  - Root causes
    - Lubricant
    - **Fuel**
      - **Fuel – PM/PN**
        - PM Index (PMI)
        - Injector deposits
  - Suggested solution
    - Low PMI (<1.80), high octane (RON 96+) fuel
    - Additives



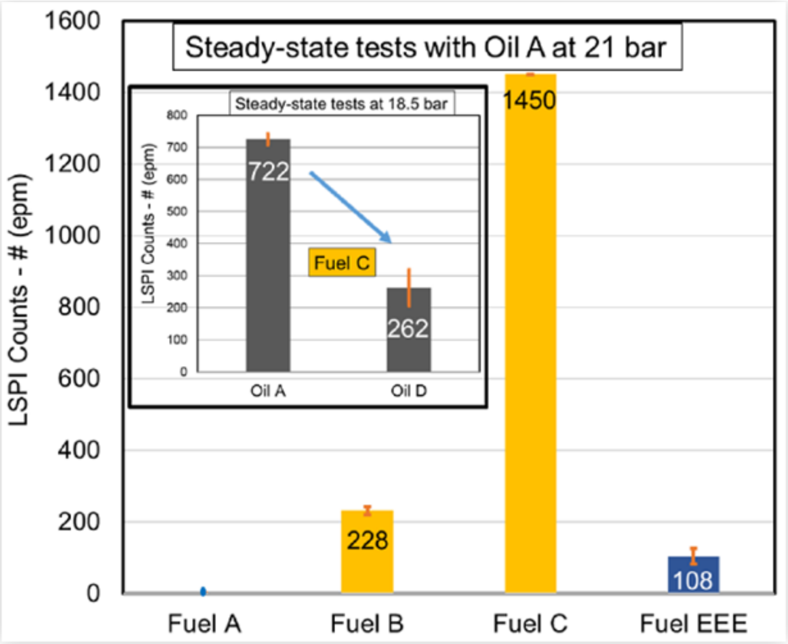
01

SPI LINK TO PM/PM

PM/PN Upward drift directly correlates to LSPI/SPI events

Aromatics heavy ends (C9/9+) have a chemical and physical effect on SPI

LSPI/PMPN Fuel	A	B	C
T90, °C	123.2	149.5	185.2
FBP, °C	170.2	194	208.7
Density, kg/m3	730.9	758.4	759.1
RON	97.6	97.7	97.6
MON	87.1	87.1	87.1
EtOH, vol%	10.7	10.2	10.2
Aro, vol%	9.6	30.8	30.9
Aro, C8 vol%	8	24.1	6.1
Aro, C9 vol%	0.3	1.2	4.4
Aro, C10+	0.8	5	19.9
Aro, C11+	2.3		1.5
Isoparaffins	51.9	41.8	39.4
Paraffins	73.3	53.3	53
Naphthenes	20.3	5.8	5.5
Olefins	4.9	5	4.8
ASVP, kPa	61.1	50.4	73.1
DVPE, kPa	55.2	44.9	66.8
PMI	0.49	1.36	2.83



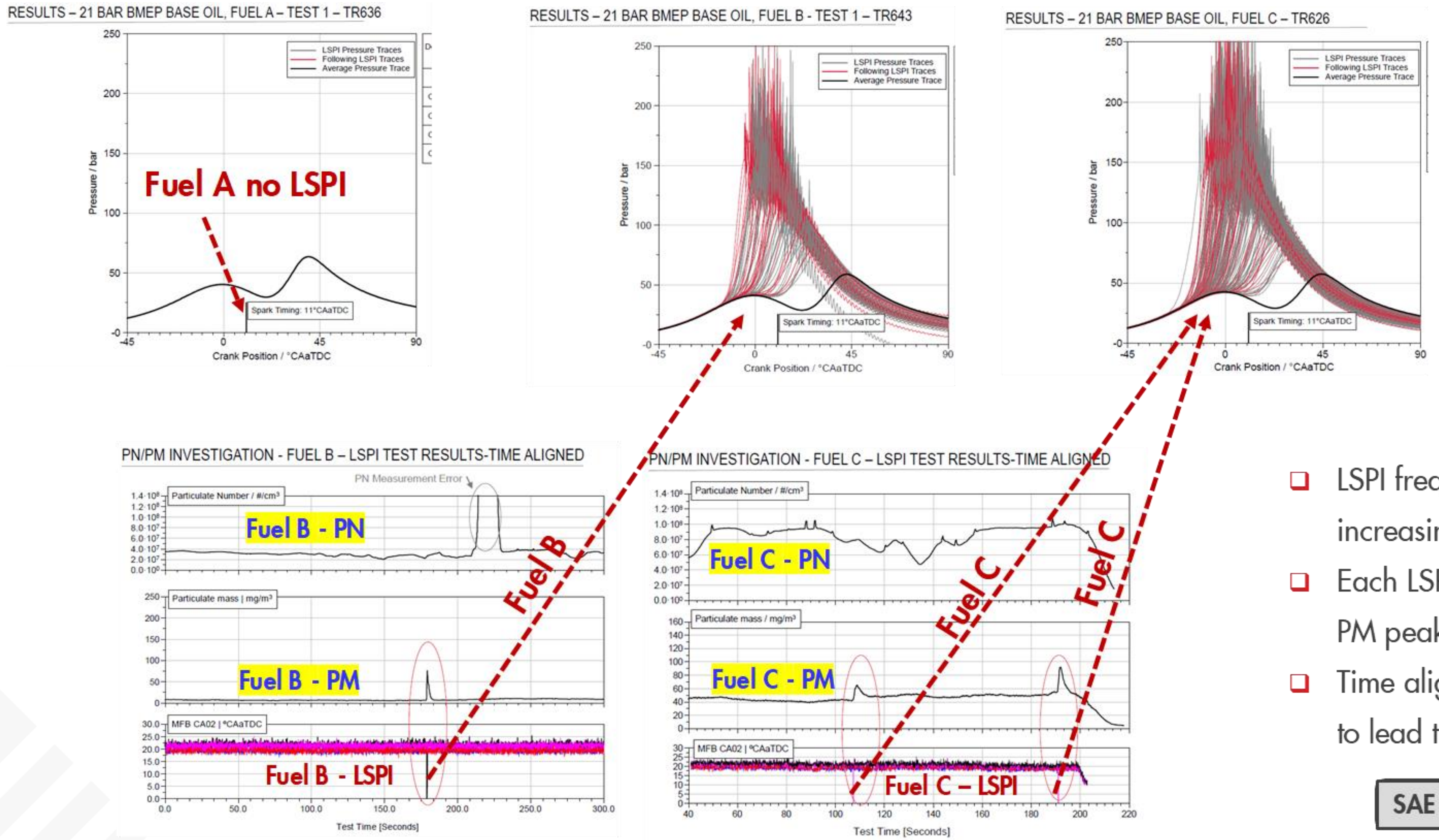
- Test fuels demonstrated extreme differences in LSPI count at 1500 rpm/21 bar BMEP with the baseline oil
- Fuel A yielded zero events, while Fuel C resulted in an extremely high LSPI count
- Fuel LSPI count can increase or decrease with Oil formulation
- Fuel C unlikely to be found in marketplace

1) Kar, A. et al. "Assessing the impact of lubricant and fuel composition on LSPI and emissions in a turbocharged gasoline direct injection engine." SAE 2020-01-0610.

2) Tanaka, D. et al. "Effects of Fuel Properties Associated with In-Cylinder Behavior on Particulate Number from a Direct Injection Gasoline Engine." SAE 2017-01-1002.

3) Wiese, W. et al. "Effects of Fuel Composition, Additives and Injection Parameters on Particulate Formation of Gasoline DI Engines." 39th International Vienna Motor Symposium (26-27 April 2018)

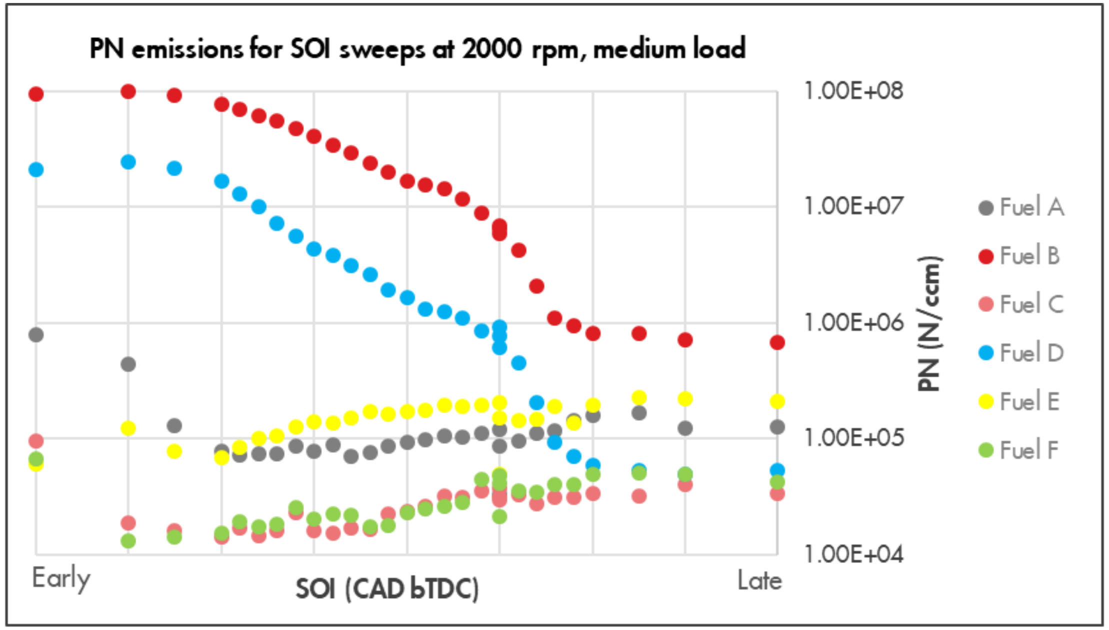
Relationship between PMPN and LSPI

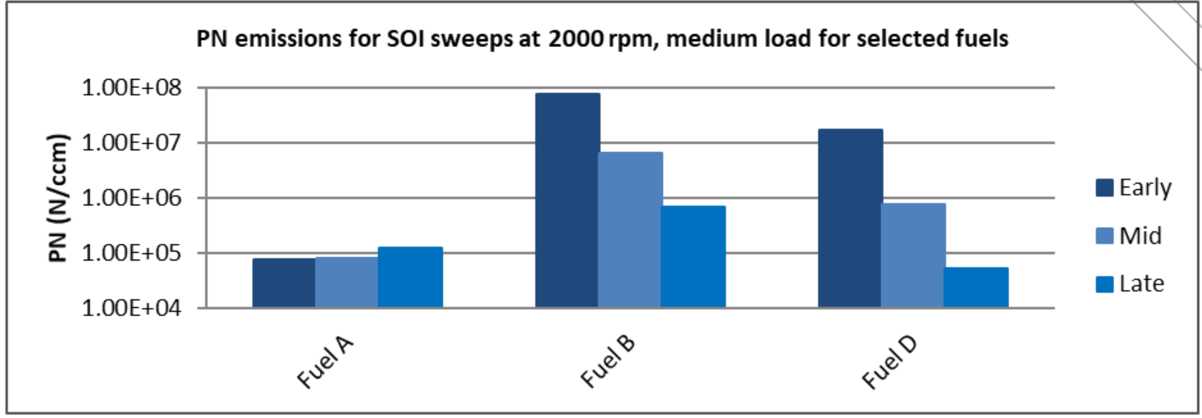


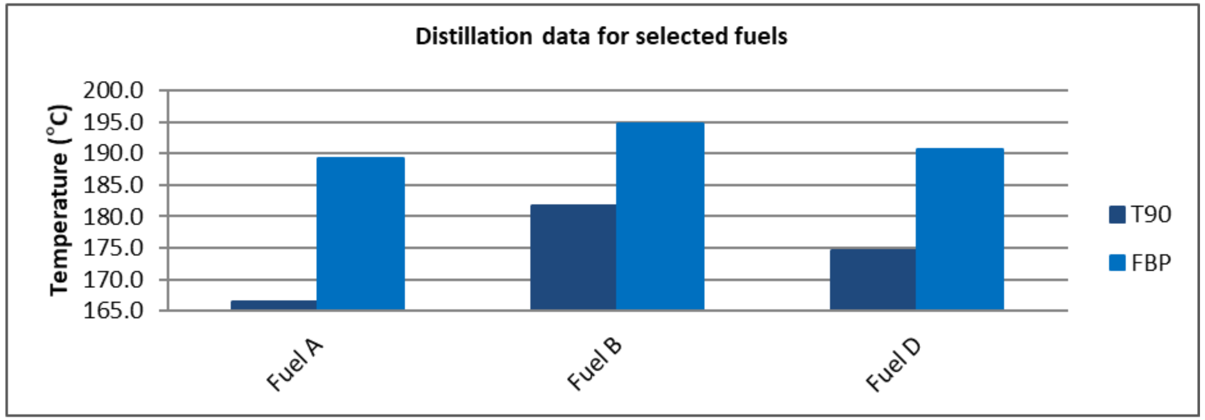
- LSPI frequency increase with increasing PM/PN
- Each LSPI event associated with a PM peak spike
- Time alignment shows the LSPI event to lead the PM peak spike

SAE 2020-01-0610

Start of Ignition vs Fuels Impact on PMPN: (wall wetting)





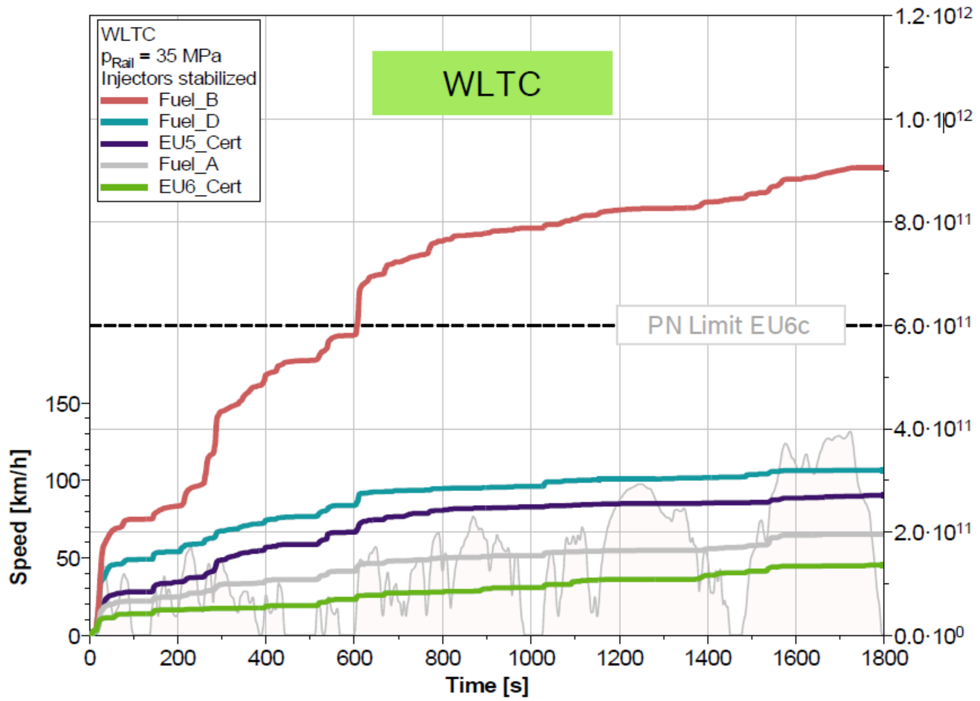


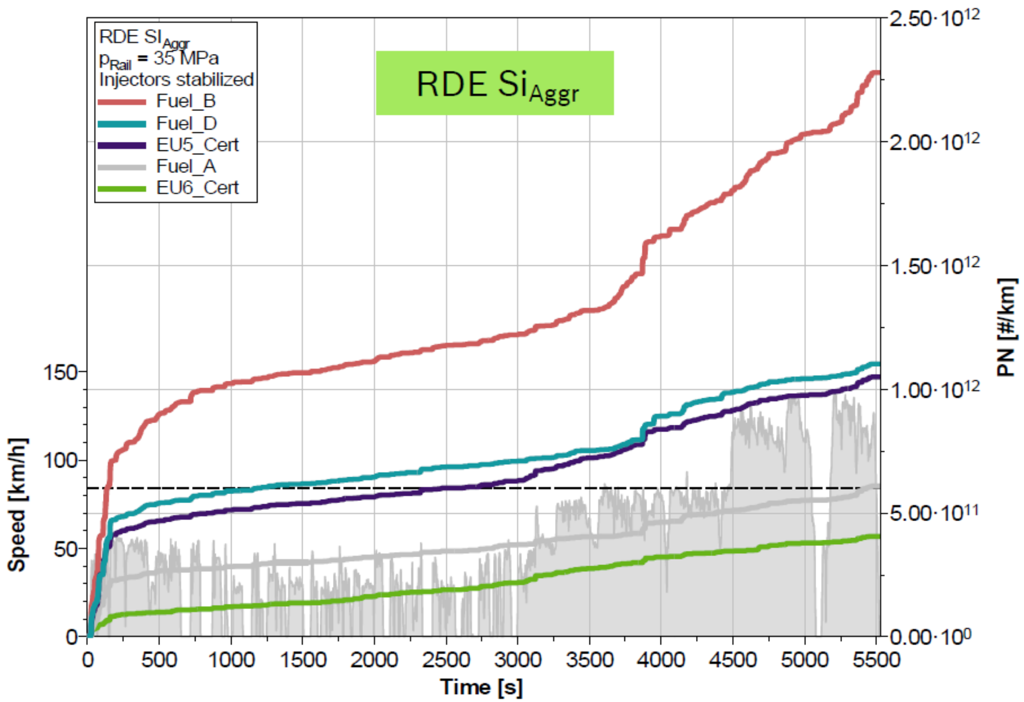
Base fuel impact during stationary start of injection (SOI) sweeps

- Heavy aromatics (C9+) and heavy paraffin fuels due to low volatility lead to high PN emissions due to combustion chamber wall films at early SOIs.

Wiese, W. et al. "Effects of Fuel Composition, Additives and Injection Parameters on Particulate Formation of Gasoline DI Engines." 39th International Vienna Motor Symposium (26-27 April 2018)

Test Cycles vs Fuels Impact on PMPN: (vehicle testing)





For selected base fuels the PN emissions were measured for the WLTC/RDE test cycles

- Heavy aromatics (C9+) on the endurance runs on the bench engine contribute to PN-drift for the highway part of the test cycles.
- Heavy aromatics (C9+) and heavy paraffin fuels due to low fuel volatility lead to higher cold start PN emissions, which correlates to SOI sweep results on the bench engine. Fuels behave similar in both drive cycles, but RDE limit is more challenging.

Wiese, W. et al. "Effects of Fuel Composition, Additives and Injection Parameters on Particulate Formation of Gasoline DI Engines." 39th International Vienna Motor Symposium (26-27 April 2018)

02

SOLUTIONS

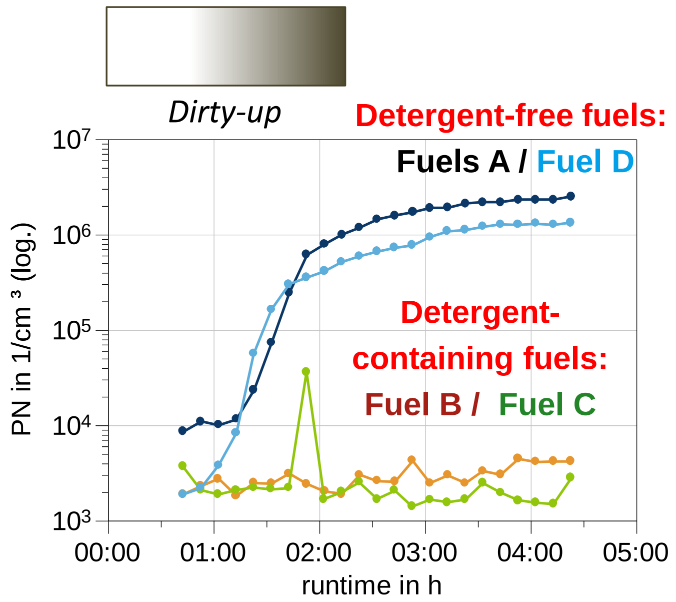
2) Injector cleaning additives

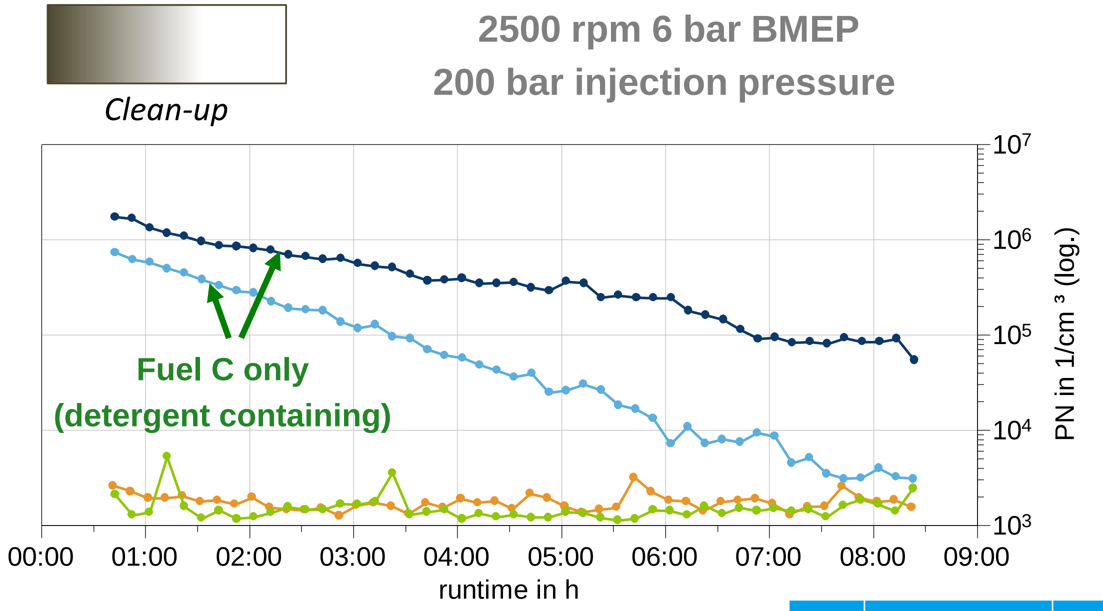
Conifer, C. et al. “Injector Fouling and its Impact on Engine Emissions and Spray Characteristics in Gasoline Direct Injection Engines.” SAE Technical Paper Series 2017-01-0808

1) Low PM/PN fuel (PMI <1.80)

Wiese, W. et al. “Effects of Fuel Composition, Additives and Injection Parameters on Particulate Formation of Gasoline DI Engines.” 39th International Vienna Motor Symposium (26-27 April 2018)

The link between injector tip cleanliness and engine-out PN





Fuel	Detergent Content	Aromatics (vol.%)	T90 (°C)
A	0	40	134.3
B	Medium	40	134.3
C	High	40	134.3
D	0	20	173.9

Without detergent:

- ➢ Increase in particulate emissions over 4 hours

With detergent:

- ➢ No increase in particulate emission over 4 hours test cycle
- ➢ Detergents can actively decrease particulate emissions over 8 hour ‘clean-up’ cycle

SAE 2017-01-0808

Conclusions

- ICE Target
  - 45+% BTE
  - **High octane (RON 96+) / Low PMI fuel**
- Challenge1: LSPI/SPI
  - Occurs across all speeds and high load
  - Both lubricant and fuel sensitive
- Challenge 2: PM/PN
  - **Injector coking biggest source**
  - **Low PM/PN fuels (PM Index < 1.80) depress LSPI**
  - **PM Index PM Index found to be a superior predictor of PM/PN than both the PN Index and the Moriya Index**
  - There is a PM spike associated with every SPI event
  - C9+ heavy aromatics increase PM/PN chemically and physically
  - Lowering fuel T90 and FBP decreases PM/PN by wall wetting
  - Increasing fuel VP decreases PM/PN
  - **Significant nucleation mode peak at about 10 nm**
  - TWC should be expected to remove volatiles (~10 nm peak); **need experimental data!**

$$PM\ index = \sum_{i=1}^{n} \left[\frac{DBE_i + 1}{VP_i} \right] W_{ti}$$