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Characteristics of PM Emissions of an Automotive Diesel Engine Under Cold Start and Transient Operating Conditions

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Outline of Presentation

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- Background
- Objectives
- Experimental Setup
- Fuel Property
- Results and Discussion
- Conclusions

Background

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- Cold (warm) start and transients are frequent occurrences of vehicle driving
- Poor engine performance and high emissions are expected during the start and transient operation
- Research of transients (concerning PM) using advanced instrumentation is so far limited
- Bio-fuels are used widely in practical application

Objectives

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- **To improve understanding of the characteristics of combustion and emissions under cold start and transient conditions in a CR diesel engine**
- **To research the effect of using different bio-fuels blends (RME and HVO) on PM emissions during cold start and transient period**
- **To quantify the effect of engine coolant temperature on PM during the engine start**

Test Conditions

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Test mode	**Initial condition**	Final condition
Cold start	Ambient soaking for >9h to 20° C	2 min steady idling
Warm start	With engine coolant heat up to 90° C	2 min steady idling
Mode 1-3	750 RPM, 36 Nm	1500 RPM, 143 Nm
Mode 2-3	1500 RPM, 72 Nm	1500 RPM, 143 Nm
Mode 2-4	1500 RPM, 72Nm	2000 RPM, 167 Nm

$$n_{particles} = \int_0^{15} (22.7 \times 10^3 \times C_{PN} \frac{1}{MW_{exhaust}} \times (0.28 \times \dot{m}_{air} + 5 \times 10^{-5} \dot{m}_{fuel1} \times v))dt$$

- Engine tests were conducted in 5s, 8s and 12s transient period for each test mode
- Cumulative data for 12s transient test were calculated for 15s in order to cover all the transient recovery period

Engine and testing rig

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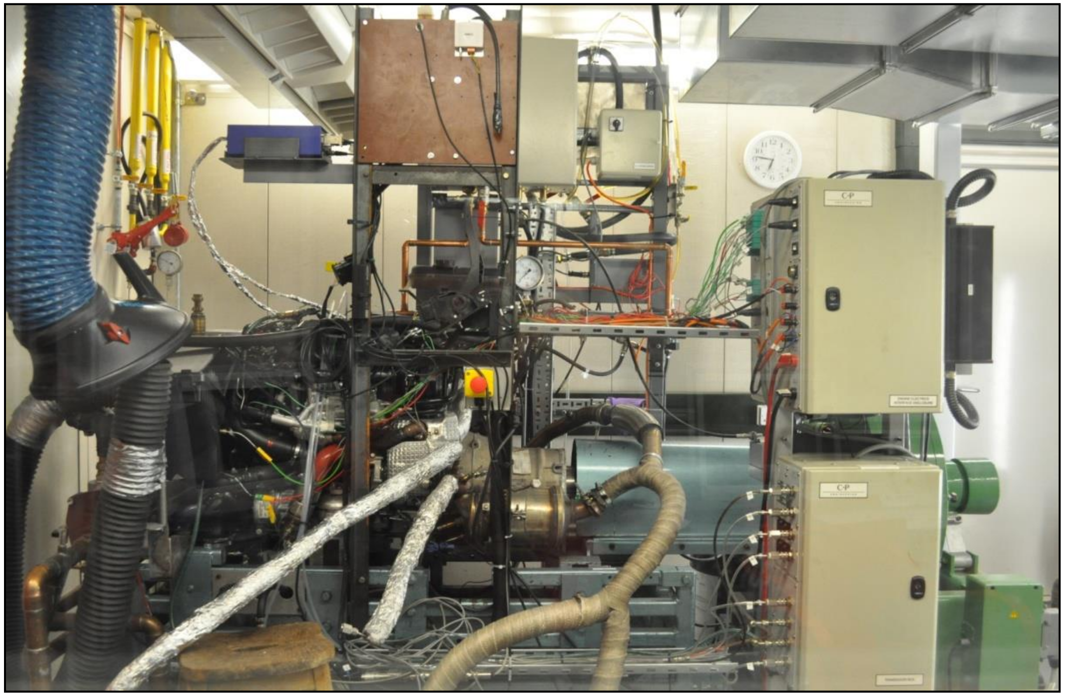

Bore X Stroke	84.0 mm X 90.0 mm
Swept Volume	2993 cc
Max CP	180 bar
Max Power	199 KW @ 4000rpm, 475Nm
Max Torque	600 Nm @ 2000rpm
Max Speed	5000 rpm @ no Load
Injection Type	CRDI
Max Inj Press	2000 bar

- New Ford/JLR Lion 3.0L V6 diesel (Twin turbo, CR)
- Programmable Dyno and AVL combustion analyser
- Capable for full speed and full load operation:
  - ➢ Constant intake air temperature programmable between 18-25^{o}C $\pm$ 1 ^{o}C

Emission measurement equipment

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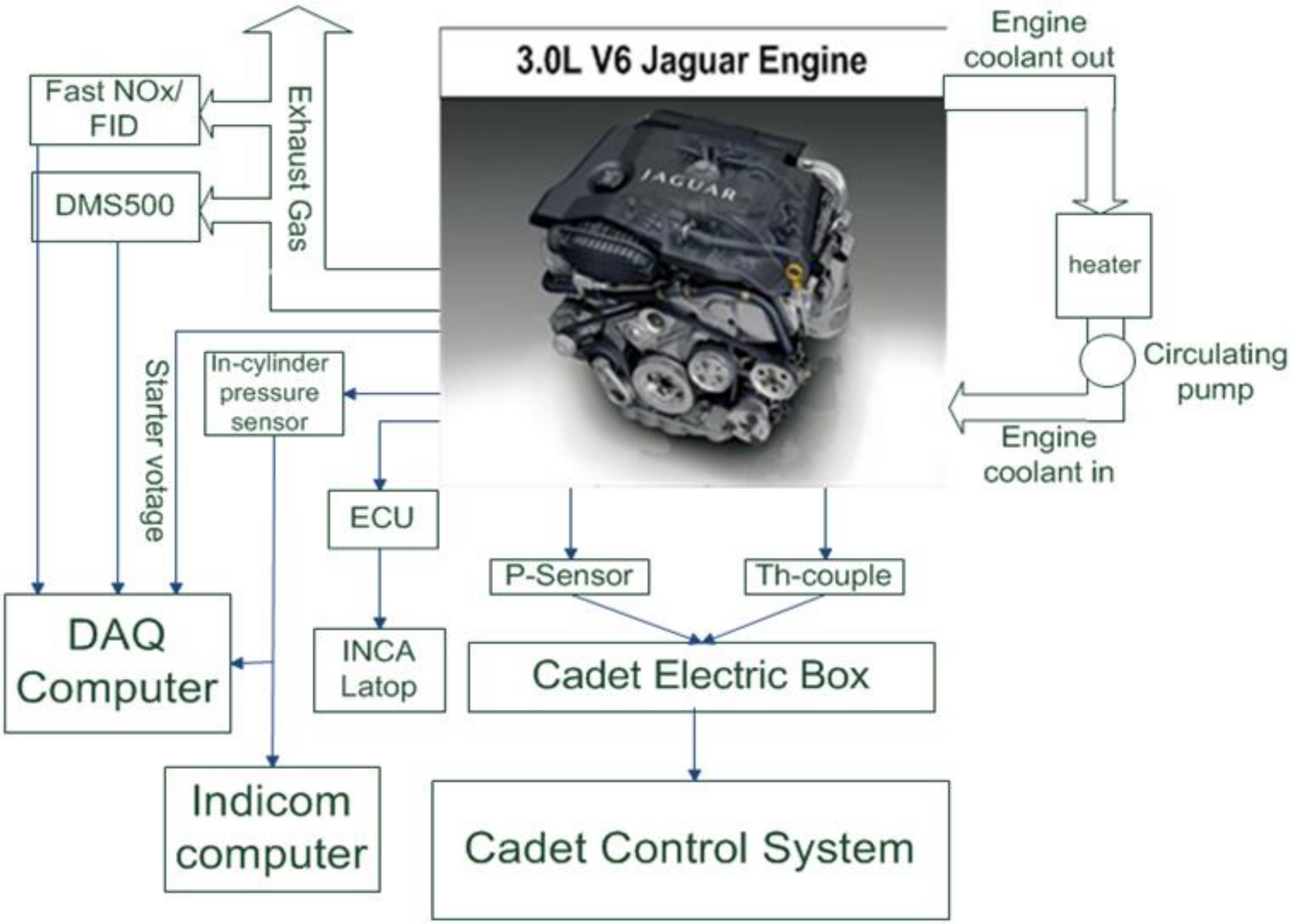
DMS500 Dilution ratio	Primary	Second
Cold/Warm start	4:1	500:1
Mode 1-3	4:1	180:1
Mode 2-3	4:1	180:1
Mode 2-4	4:1	120:1

Test Equipments	DMS500	Fast FID	Fast NOx
Time Response	200 ms	As low as 0.9 ms	As low as 2 ms
Acquisition Frequency	10 Hz		
Measurement Range	5 nm to 1000 nm	0-1000 ppm to 0-200,000 ppm	0-100 ppm to 0-5,000 ppm

Experimental system



Fuel Properties

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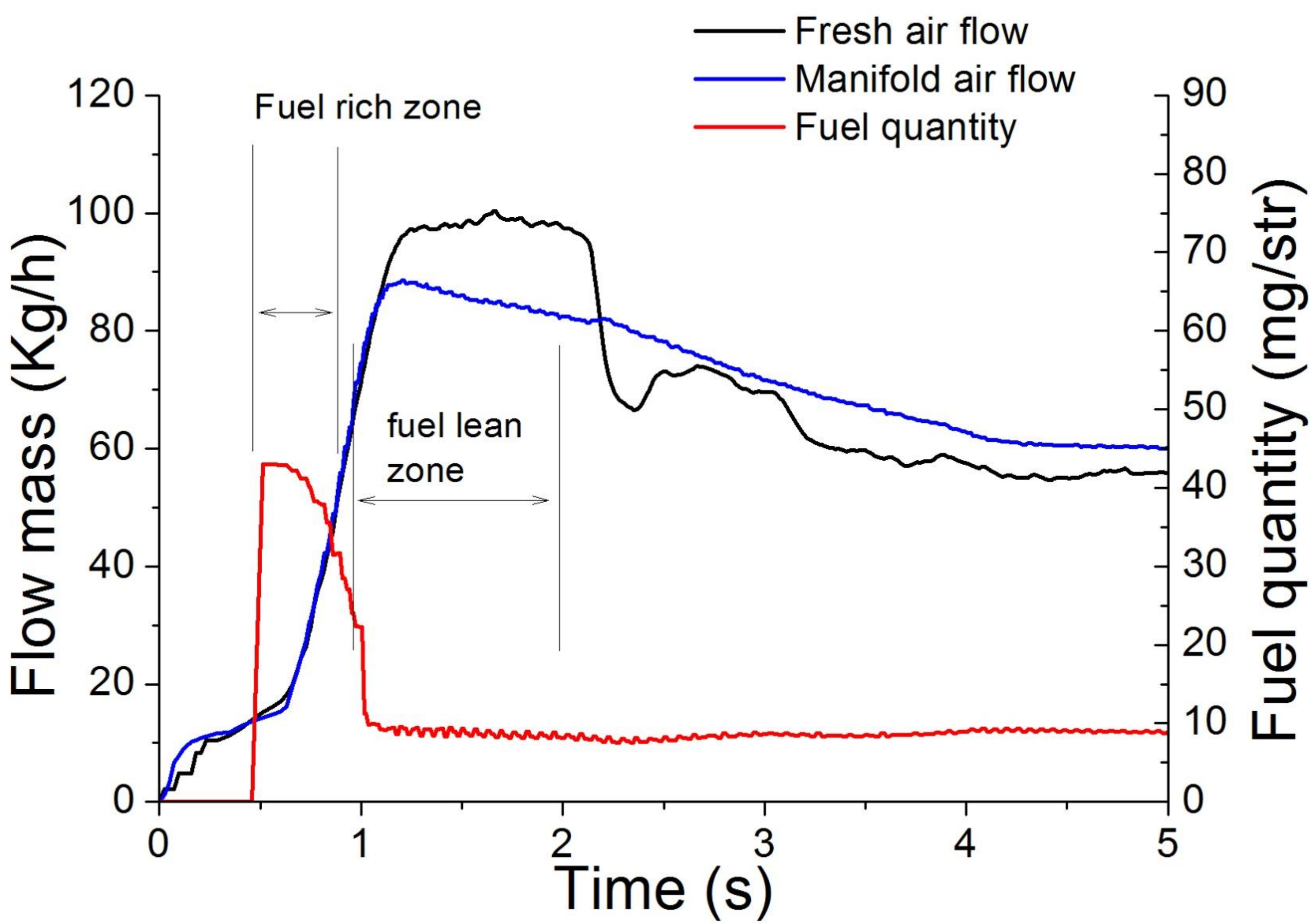
Fuel Properties	Unit	Mineral diesel	RME30	RME60	RME100	HVO60
Cetane number		56.7	57.8	60.3	61.2	64.3
density	Kg/m3	832.7	847.9	863.3	883.3	798.7
net heat of combustion	MJ/kg	42.72	40.76	38.98	36.41	43.66
Viscosity @ 40° C	10-3Pa.s	3.6	4.3	5.27	6.77	3.43
Oxygen Content	%	0	4.6	7.8	10.8	0

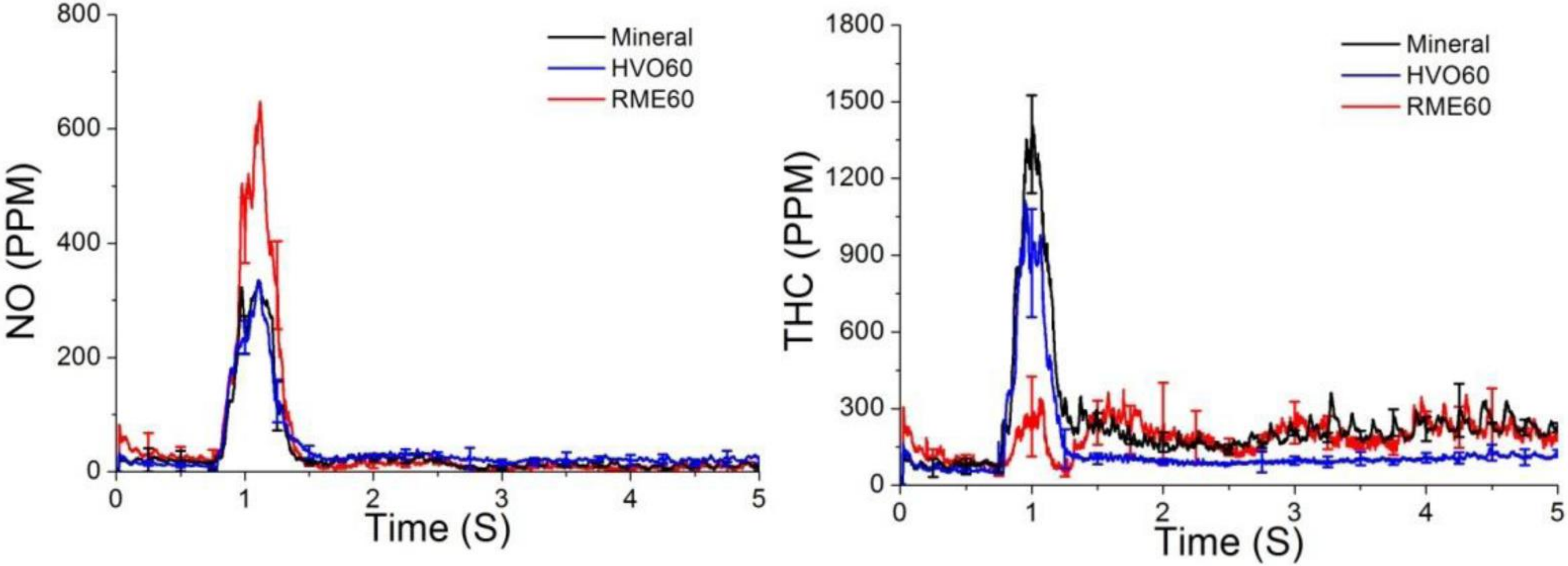
Fuels Data Provided by Shell Company

Cold and warm start

Cold start with mineral diesel

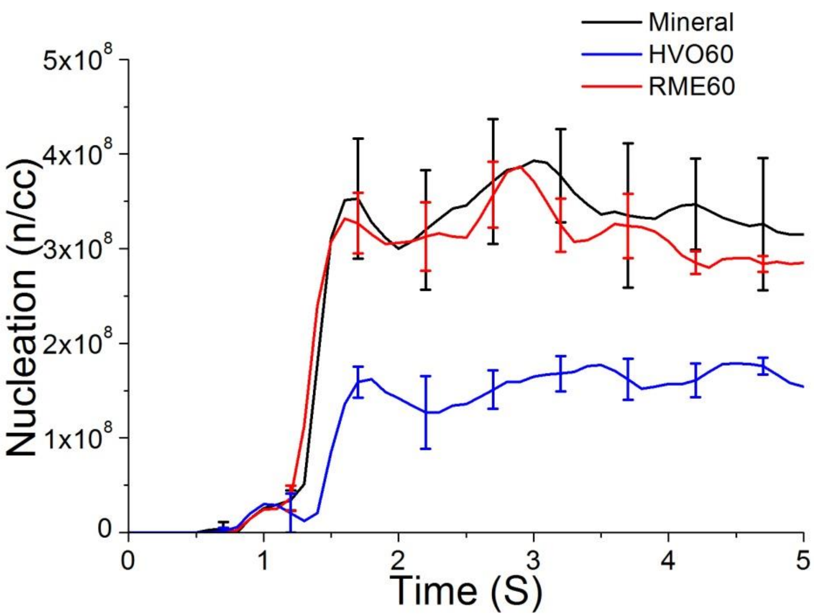


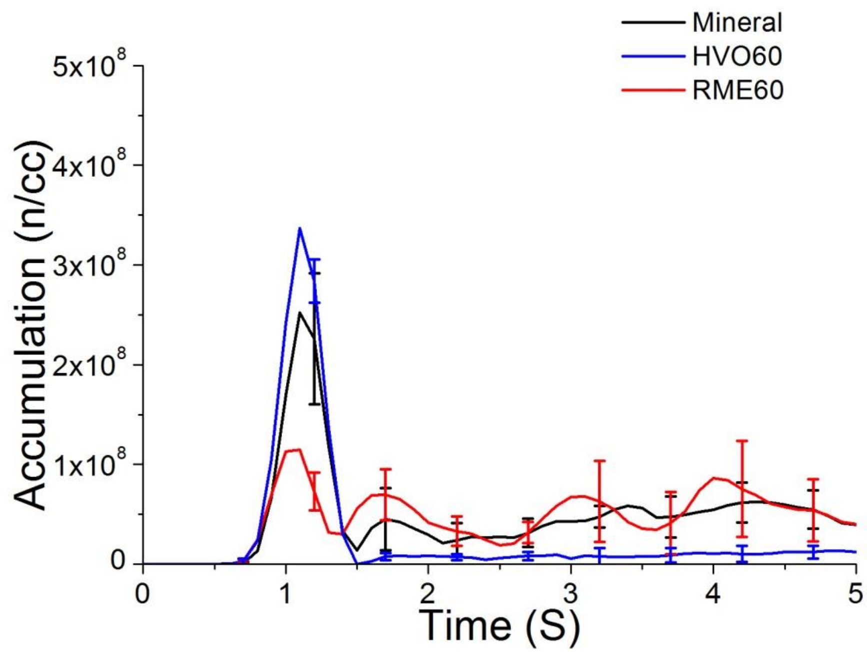
Cold start with mineral diesel



- NO and HC emissions peaked at around 1s
- RME produced the maximum NO and lowest HC peaks

PM emissions of cold start with different fuels





- ***Acceleration period (0.7-1.3s):***
  - Nucleation: RME60=Mineral diesel=HVO60;
  - ***Accumulation:*** RME60<Mineral diesel<HVO60.

- ***Idling period (after 1.3s):***
  - ***Nucleation***: RME60<Mineral diesel<HVO60;
  - ***Accumulation***: HVO60<Mineral diesel=RME60.

Particulate distributions from time 0.8s-1.3s

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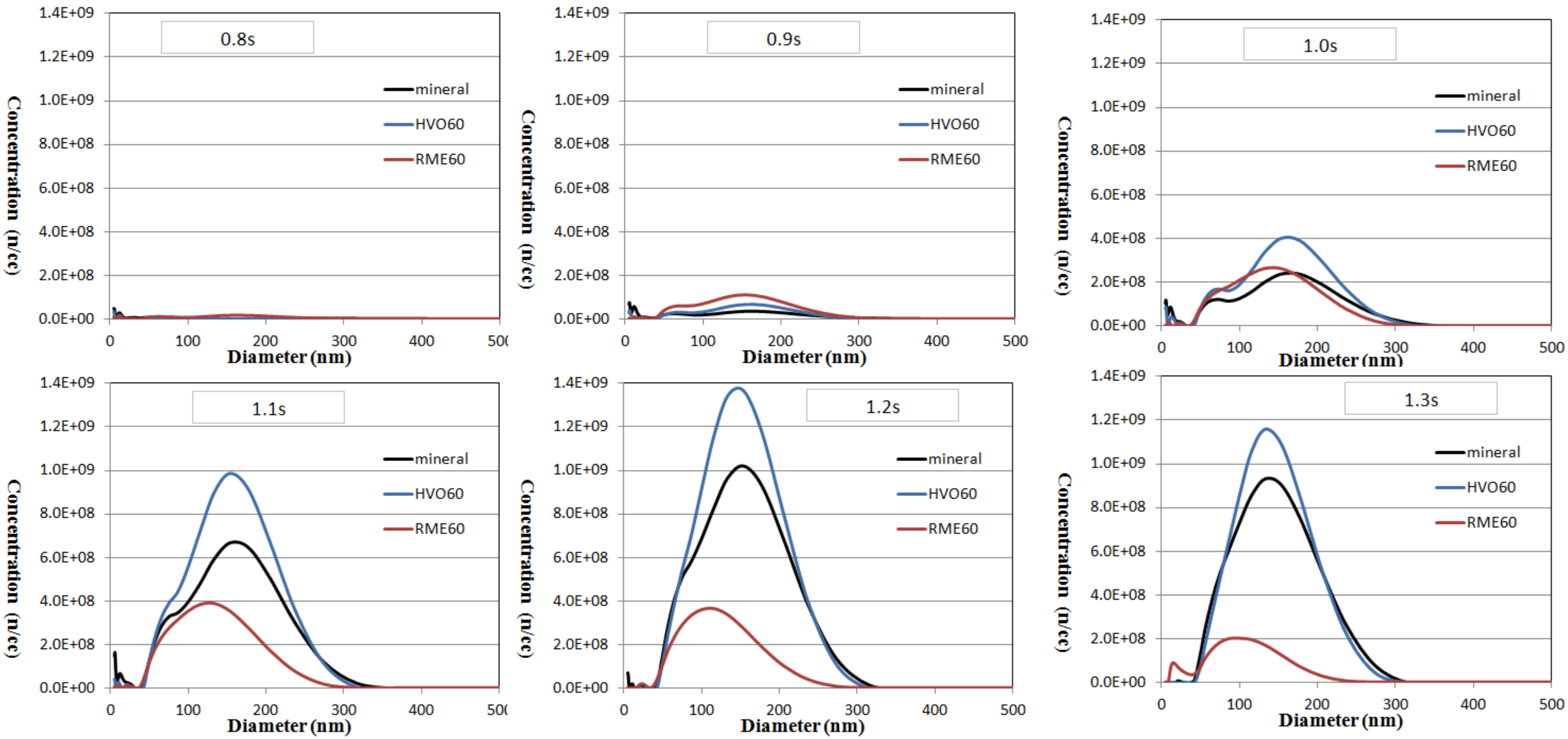

- Particulates roughly divide to two phase: accumulation particulate (diameter between 50nm-300nm), nucleation particulate (diameter less than 40nm)
- With high injected fuel quantity and low air flow inlet initially, the emission of large particulates increased, the emission of small particulates decreased.
- Combustion of RME60 produce lowest particulate emission.

Particle distribution from time 1.4s-1.8s

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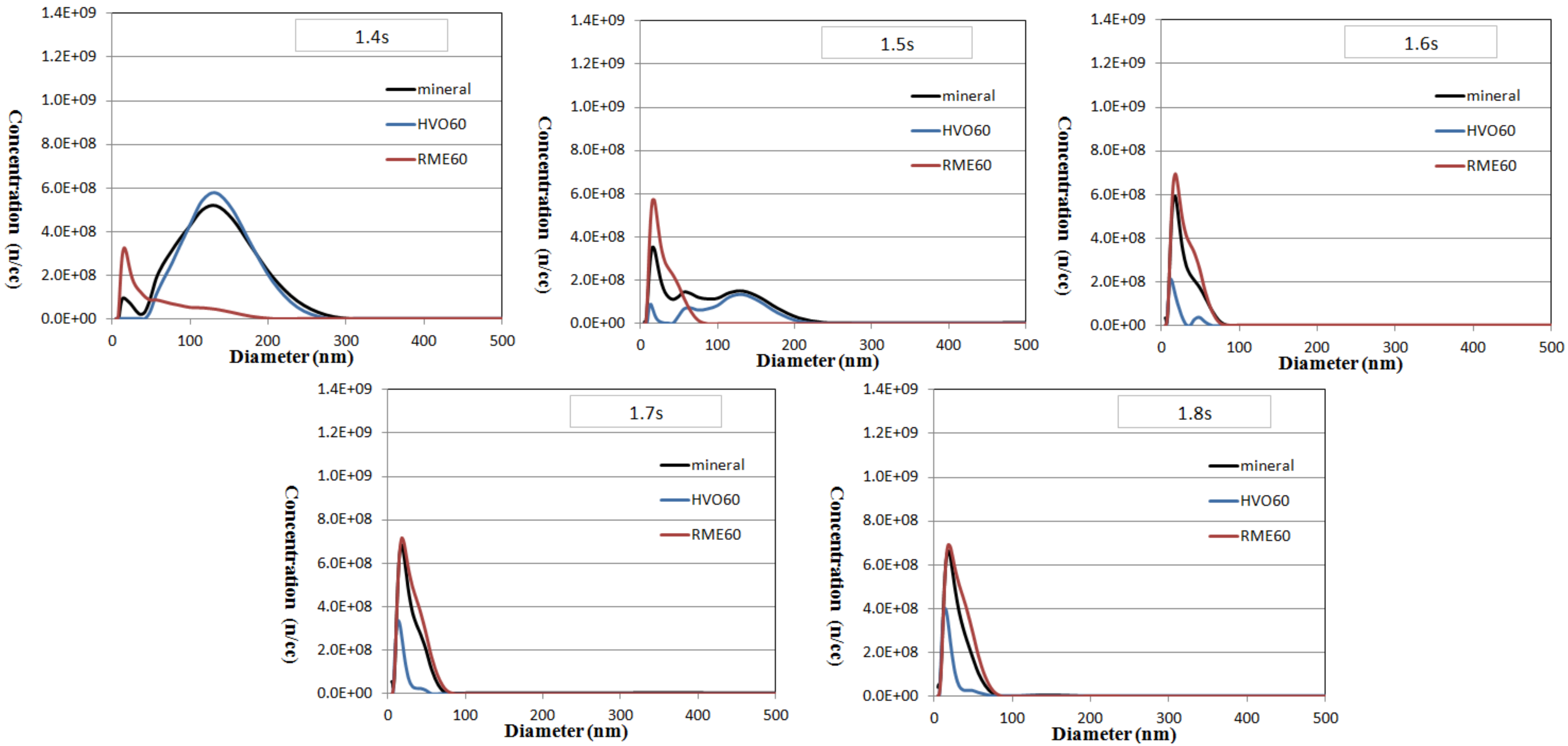

- With engine conditions getting steady, large particulates were oxidized and the size of emitted particle was decreased.
- When the size distribution got steady, the combustion of HVO60 produced the lowest particle emission while the combustion of RME60 produced the highest particle emission.

Relative cumulative PM in the first 10s

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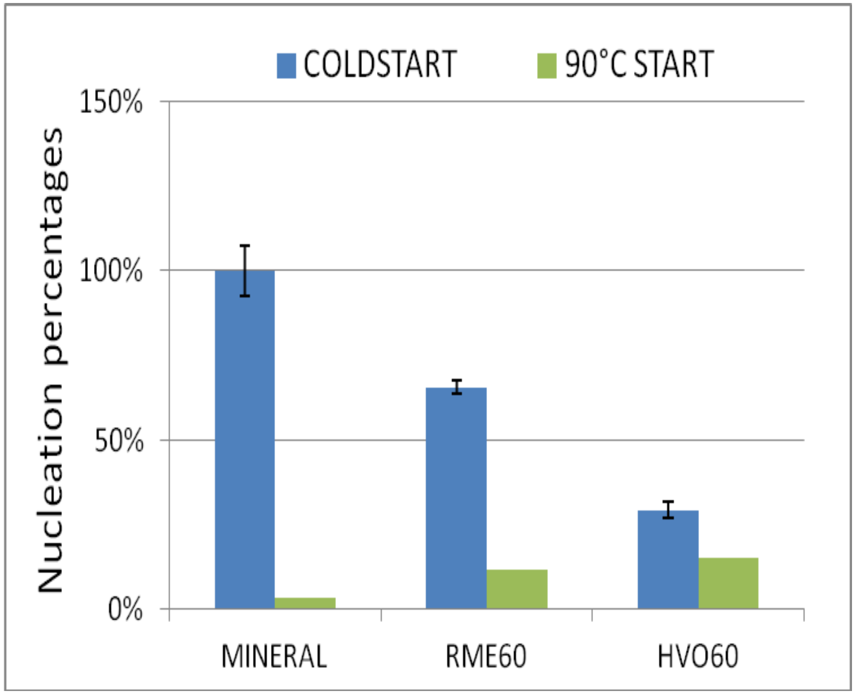

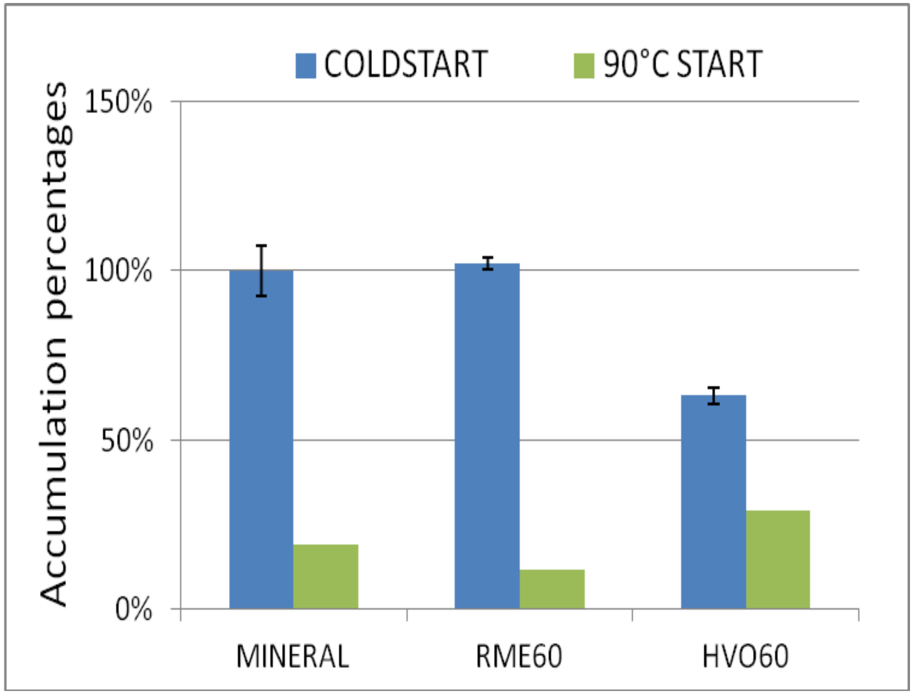

PM of using all fuels decreased. But for HVO60, with lowest PM emissions at cold start, produced highest PM at warm start.

Transient

Transient conditions

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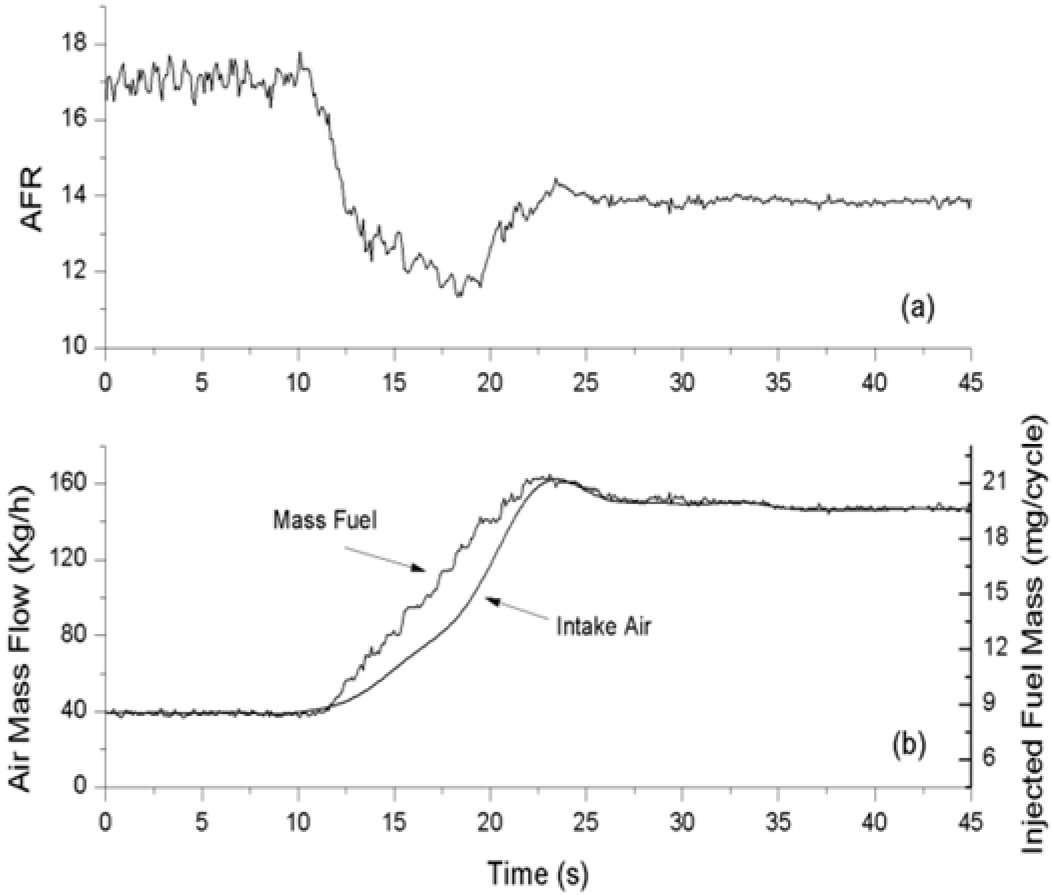

Diesel AFR (a) and Intake Air with Fuel Injection (b) for Mode 1-3 (750RPM, 36Nm-1500RPM, 143Nm in12s)

Emissions for Mode 1-3 (12s)

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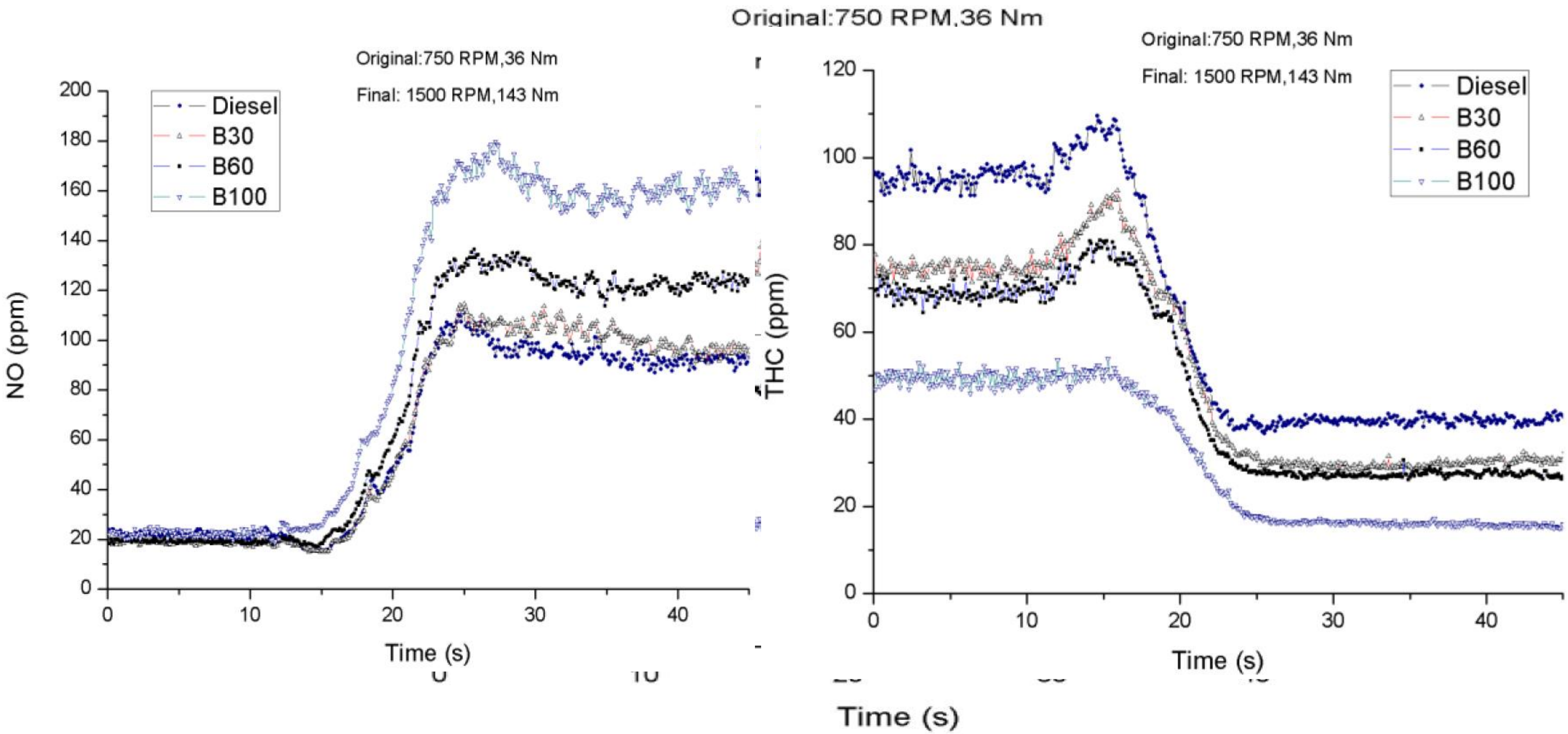

•The spike size (peak to initial ratio) decrease with the increasing biodiesel blend ratio

•The length of the transient recovery period decreased with the biodiesel blend ratio increasing.

•NO decreased slightly and increased during acceleration. B100 produced the highest NO

•THC increased slightly and decreased during acceleration. B100 produced the lowest THC.

Emissions for Mode 2-3 (12s)

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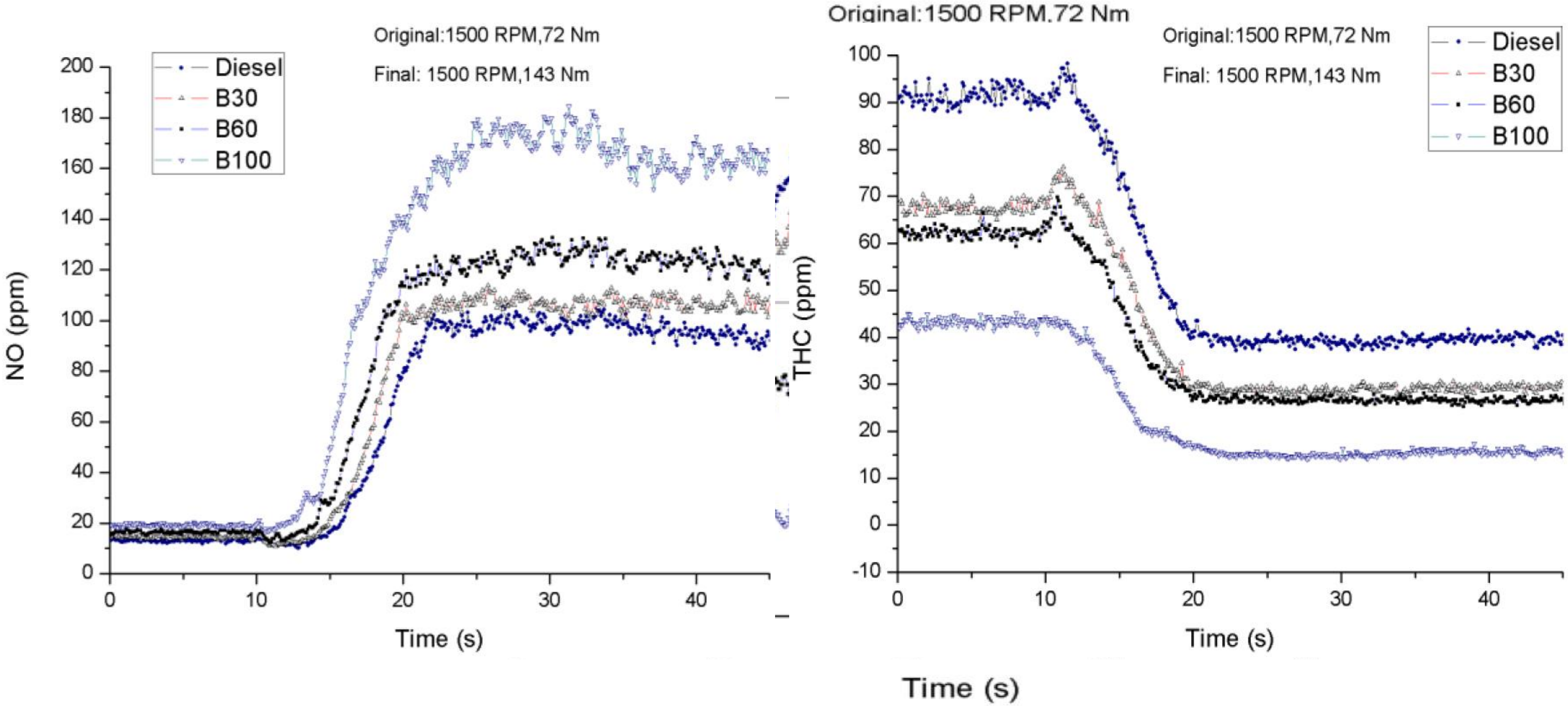

- The initial decrease of NO was small compared with previous test. B100 produced the highest NO
- The initial increase of THC was small compared with previous test. B100 produced the lowest THC.

- Recovery period characteristics as same as mode 1-3
- The spike size (peak to initial ratio) became smaller when biodiesel blending ratio increased
- The PN spike almost disappeared for B100.

Emissions for Mode 2-4 (12s)

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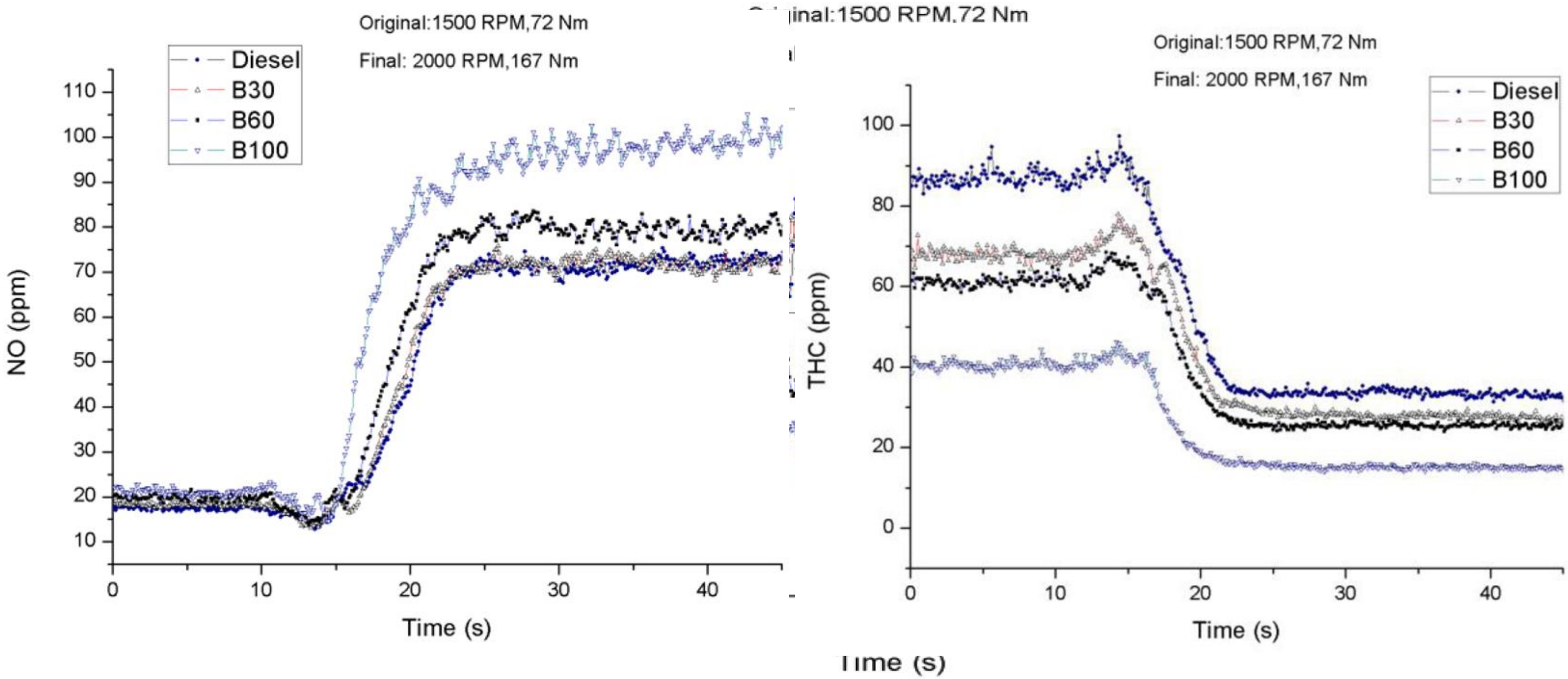

- NO emissions for all fuels are almost the same initially.
- B100 produced the highest NO and lowest THC during acceleration.

- The duration of the recovery period decreased with the biodiesel blending ratio increasing
- The spike size (peak to initial ratio) lower than mode 1-3

Comparison between different modes

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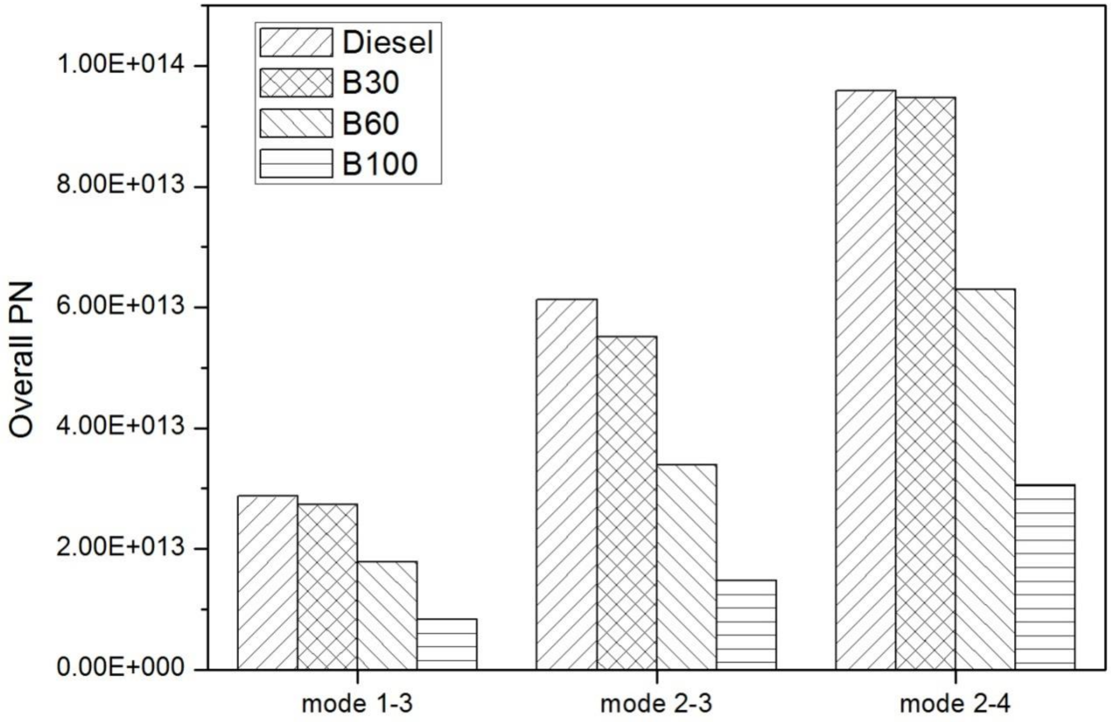

- Mode 2-4 emitted highest particles then the other two
- Mode 2-3, B100 emitted extremely low PM emission, nearly 75% less than B0
- PN of both B30 and B0 were almost the same for each mode

Comparison between different fuels

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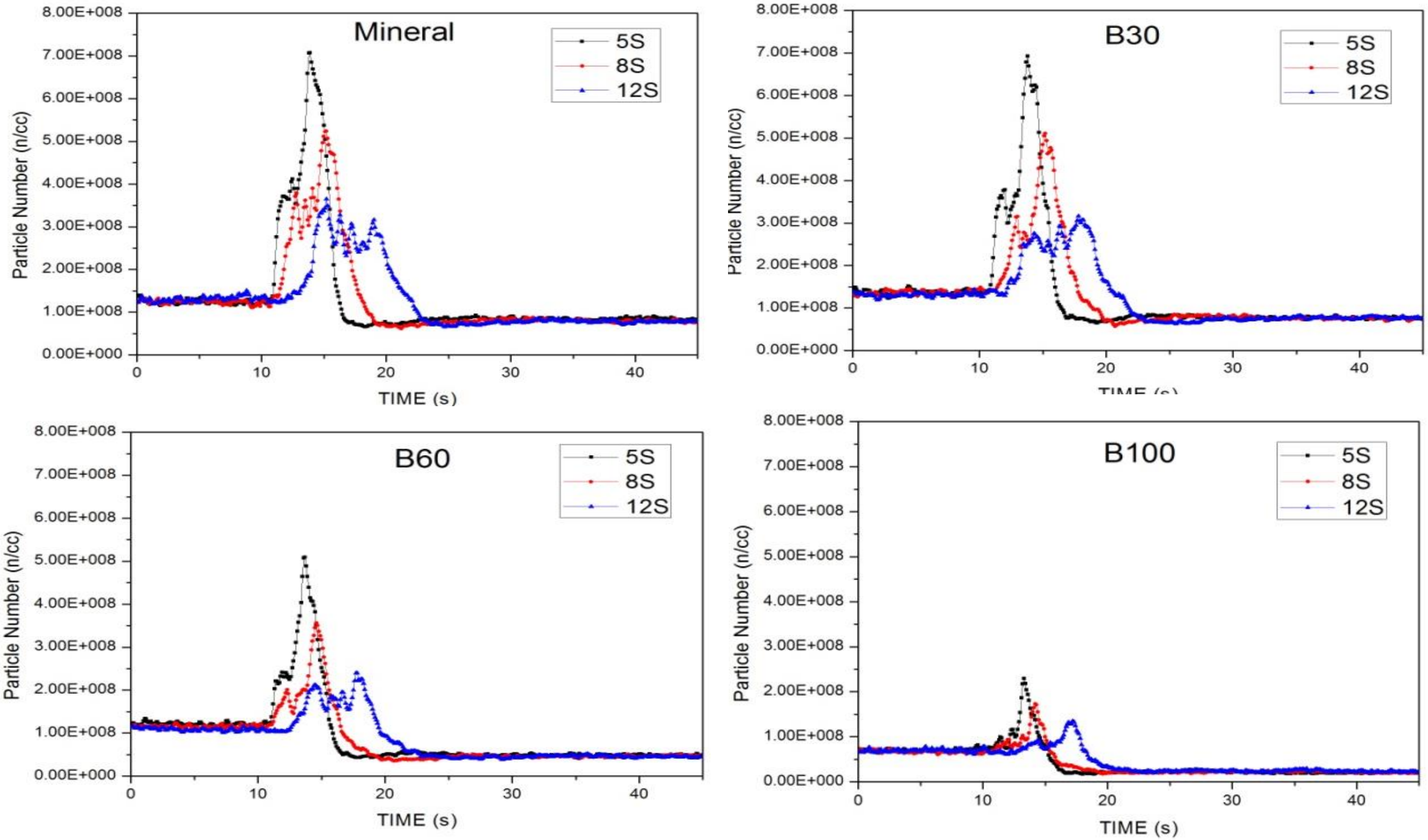

- The spikes’ peak value ratios between the different recovery period are nearly the same.
- B100 has the shortest recovery period difference compare with the others

Conclusions

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- **Cold and warm start**
  1. Low PN was observed with using RME60 during the acceleration period of the cold start. However, the level of nucleation particles with using RME60 was similar to that of mineral diesel.
  2. During the acceleration period of the cold start, using of HVO60 produced slightly higher accumulation particles but almost halved nucleation particles with respect to using of mineral diesel.
  3. As engine coolant temperature was increased, the emissions of PM were decreased for all the fuel. However, at warm start, the combustion of biodiesel led to higher PM than the cases of using mineral diesel, due to the fuel impinging effect.

Conclusions

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- **Transient conditions**
  1. As biodiesel blending ratio increased, PN decreased for all the three transient conditions.
  2. Due to turbocharger lag problem, AFR was highly influenced during the entire transient recovery period.
  3. Spikes in transient PM were observed in all the transient tests. The ratio between the maximum PN and its initial value (i.e. the size of spikes) decreased with biodiesel blending ratio increasing.
  4. The duration of the PM emission recovery period decreased with biodiesel blending ratio increasing for all the engine transient tests.
  5. The engine with higher initial/final engine load and speed operating conditions emitted smaller PN spikes compared with low speed and load engine transient operation.

Acknowledgement

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Thanks for your attention

Questions?