SUPPORTING INFORMATION

A physico-chemical characterisation of particulate emissions from a compression ignition engine employing two injection technologies and three fuels

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Table S1: Engine specifications.

Item	Specification
Model	Perkins 1104C-44
Cylinders	4 in-line
Capacity (L)	4.41
Bore × stroke (mm)	105 × 127
Maximum power (kW/rpm)	64/2400
Maximum torque (Nm/rpm)	302/1400
Compression ratio	19.25:1
Aspiration	Naturally aspirated
Emissions certification	EU Stage II non-road

Table S2: Speed and load settings investigated in this study.

Mode number	Speed (rpm)	Load (%)
1	1400 (Intermediate)	50
2	1400 (Intermediate)	100
3	2400 (Rated)	50
4	2400 (Rated)	100

Table S3: Fuel specifications.

Property	ULSD	B20	Synthetic
Density (kg/L) ASTM D4052	0.8354	0.8393	0.8308
Kinematic viscosity (mm^2/s) @ 40 ^{o}C ASTM D445	2.7189	3.1228	3.2195
Flash point (^{o}C) ASTM D93	66.5	71.5	73.5
Distillation (^{o}C) ASTM			
D86	205	220	225
10%	266	289	277
50%	327	335	335
90%	340	344	344
95%			
Calculated cetane index ASTM D4737	51.6	55.2	57.4
Sulphur content (mg/kg) ASTM D 5453	4.5	5.9	5.0
Carbon (% mass) ASTM D5291	84.6	85.4	84.2
Hydrogen (% mass) ASTM D5291	14.2	13.4	14.4
Water and sediment (%	< 0.01	< 0.01	< 0.01

volume) ASTM D2709			
Polycyclic aromatic hydrocarbons (% mass) IP 391	1.2	0.96	1.5
Fatty Acid Methyl Ester content (% volume) EN 14078	-	19.6	-
Acid number ASTM D664 (mg KOH/g)	-	0.07	-

Table S4: Tabulated results for all emissions parameters reported in this study. Uncertainties are calculated as ± one standard error of the mean. NC denotes that the standard error was not computed as the measurement was not replicated.

Fuel	Speed/load (rpm/%)	Injection configuration	Primary Dilution Ratio	Secondary Dilution Ratio	Total Dilution Ratio	$PM_{2.5}$ (g/kWh)	Particle number concentration ($\#/cm^3$)	CMD (nm)	ROS (nmol/mg)	PAHs (mg/kWh)	Organic volume percentage (%)
ULSD	1400/50	Direct Injection	26.7	10.2	270.6	0.20 ± 0.003	2.6E+14 ± 2.0E+13	72.3 ±1.6	14.2 ± 5.3	10.8 ± 7.4	0.004
ULSD	1400/100	Direct Injection	26.8	10.0	266.6	3.03 ± 0.18	1.2E+15 ± 1.3E+13	115.6 ± 0.4	0.1 ± 0.1	4.7 ± 1.8	20.2
ULSD	2400/50	Direct Injection	20.4	9.8	163.7	0.25 ± 0.01	1.0E+15 ± 2.3E+13	68.3 ± 0.3	12.1 ± 2.7	5.8 ± 0.5	0.2
ULSD	2400/100	Direct Injection	14.2	10.7	151.6	0.68 ± 0.01	1.3E+15 ± 8.0E+13	82.0 ± 0.3	3.8 ± 0.9	7.0 ± 1.8	0.8
B20	1400/50	Direct	30.1	9.6	288.6	0.16	2.3E+14	71.7	32.8 ± 17.8	9.1 ± 8.2	17.6

		Injection				± 0.02	± 1.7E+12	±2.2			
B20	1400/100	Direct Injection	30.0	9.7	290.9	2.16 ± 0.11	1.1E+15 ± 1.4E+13	109.9 ± 1.7	2.1 ± 1.0	5.1 ± 4.6	14.1
B20	2400/50	Direct Injection	17.3	11.4	197.0	0.22 ± 0.01	1.1E+15 ± 4.3E+13	67.5 ± 1.4	18.6 ± 8.3	21.5 ± 9.7	20.1
B20	2400/100	Direct Injection	16.7	10.5	175.0	0.55 ± 0.002	1.3E+15 ± 9.5E+12	79.0 ± 0.7	0.9 ± 0.9	3.2 ± 0.3	31.4
Synthetic	1400/50	Direct Injection	38.1	8.2	313.6	0.20 ±0.01	2.4E+14 ± 1.5E+13	71.9 ±0.6	27.8±3.3	10.2 ± 7.5	1.0
Synthetic	1400/100	Direct Injection	41.2	7.9	326.3	3.38 ± 0.07	1.1E+15 ± 3.3E+13	120.0 ± 0.4	1.1± 0.3	6.6 ± 3.8	10.9
Synthetic	2400/50	Direct Injection	21.1	9.2	192.5	0.29 ± 0.01	9.1E+14 ± 4.3E+13	69.9 ± 0.3	8.4 ± 2.1	20.9 ± 9.6	0.4
Synthetic	2400/100	Direct Injection	21.3	9.2	196.2	0.81 ± 0.005	1.3E+15 ± 6.4E+13	86.0 ± 0.4	2.1 ± 0.9	28.7 ± 28.3	6.1
ULSD	1400/50	Common	24.5	8.1	198.2	0.048 ±	1.2E+14	68.1 ±	284.1	28.6	3.2

		Rail				0.03	± 2.8E+12	0.6	± NC	± NC	
ULSD	1400/100	Common Rail	26.6	8.8	234.4	1.59 ± 0.17	8.6E+14 ± 5.2E+13	120.8 ± 2.8	7.9 ± NC	26.8 ± 5.8	10.7
ULSD	2400/50	Common Rail	15.8	9.9	155.4	0.36 ± 0.03	2.1E+14 ± 6.6E+12	60.9 ± 0.9	149.0 ± NC	16.9 ± 9.5	0.8
ULSD	2400/100	Common Rail	16.2	9.2	148.5	0.805 ± 0.12	1.3E+15 ± 4.7E+13	91.9 ± 1.3	13.2 ± NC	6.4 ± 2.6	12.5
B20	1400/50	Common Rail	19.9	10.9	215.1	0.029 ± 0.05	9.1E+13 ± 9.4E+12	65.8 ± 1.2	202.2 ± 43.4	7.5 ± 0.6	7.9
B20	1400/100	Common Rail	24.5	10.3	251.4	0.972 ± 0.14	7.2E+14 ± 5.9E+13	110.4 ± 0.3	8.1 ± 4.5	34.6 ± 20.8	38.4
B20	2400/50	Common Rail	16.9	10.7	180.7	0.028 ± 0.04	1.7E+14 ± 2.4E+13	58.3 ± 0.03	233.0 ± 18.7	14.0 ± NC	11.7
B20	2400/100	Common Rail	17.5	9.63	168.6	0.538 ± 0.10	1.1E+15 ± 5.2E+13	84.8 ± 0.5	5.1 ± 2.9	14.7 ± 11.7	36.3
Synthetic	1400/50	Common	28.8	6.9	200.1	0.035	7.9E+13 ±	66.9	139.9	10.5	35.7

		Rail				±0.03	1.2E+13	±1.2	±139.9	±NC	
Synthetic	1400/100	Common Rail	32.5	8.4	272.4	0.954 ± 0.11	6.3E+14 ± 2.6E+13	113.2 ± 0.4	6.2 ± 0.1	29.7 ± NC	56.9
Synthetic	2400/50	Common Rail	18.3	9.5	175.2	0.030 ± 0.03	1.6E+14 ± 2.0E+12	60.2 ± 0.7	358.4 ± 21.1	80.4 ± NC	30.5
Synthetic	2400/100	Common Rail	20.2	9.3	188.8	0.522 ± 0.03	9.7E+14 ± 2.2E+13	89.9 ± 1.0	12.7 ± 2.1	5.9 ± NC	54.3

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Table S5: Weighting factors for the 4 mode test cycle adopted in this study.

Mode number	Speed (rpm)	Load (%)	ECE R49 weighting	Test cycle averaging (this study)
1	1400	50	0.08	0.178
2	1400	100	0.25	0.556
3	2400	50	0.02	0.044
4	2400	100	0.10	0.222

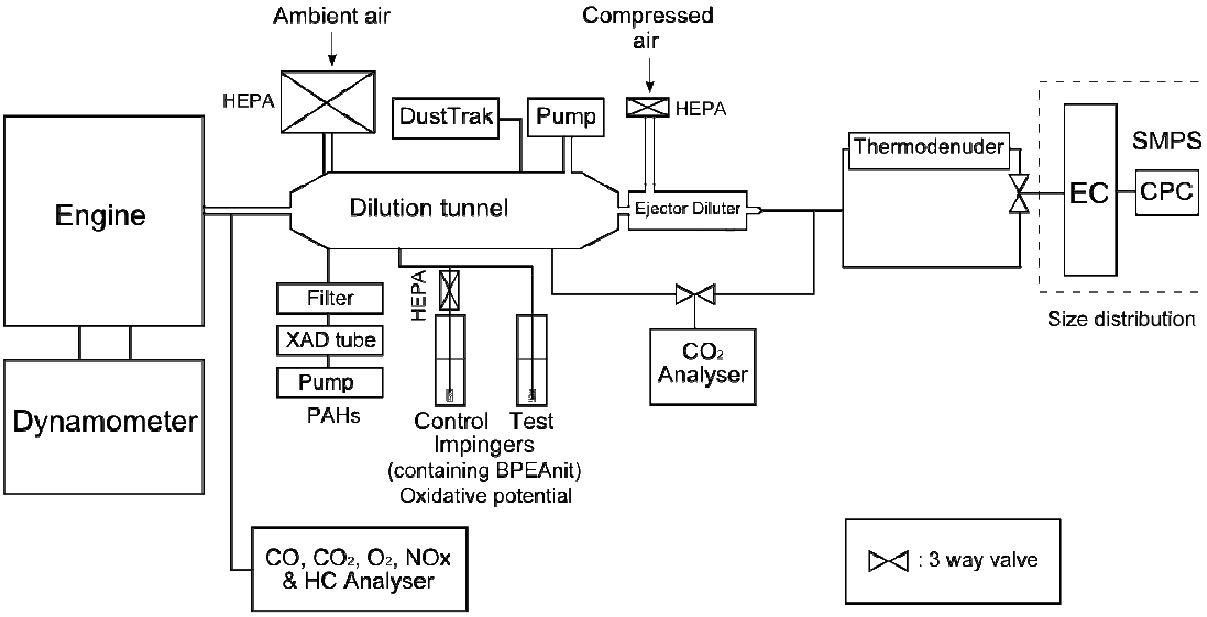

Figure S1: A schematic of the experimental set-up utilised in this study.

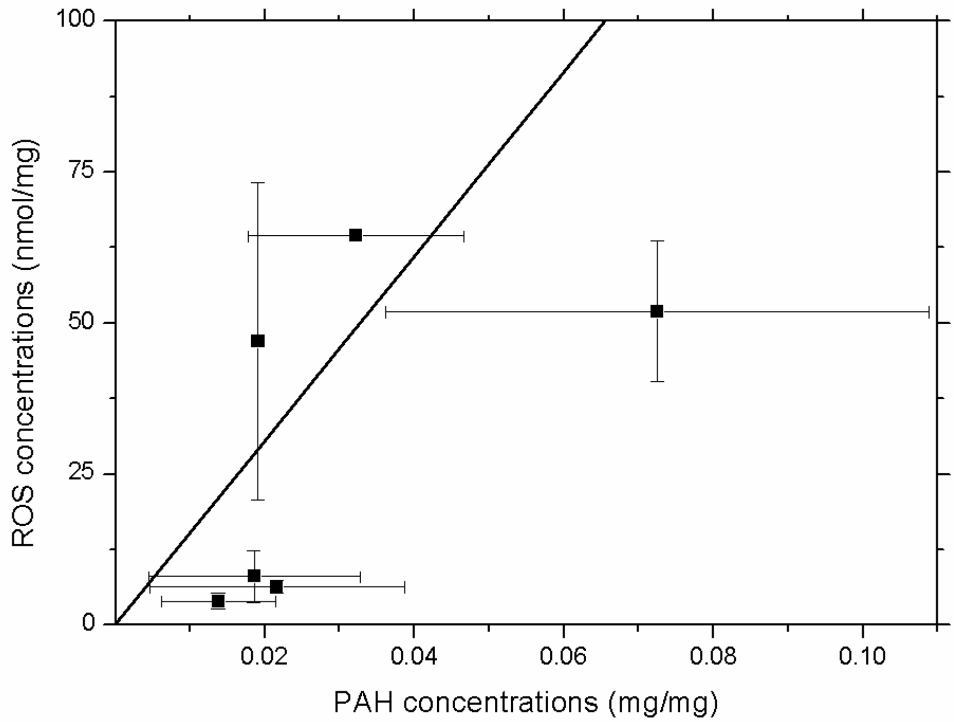

Figure S2: A graph demonstrating correlation between the ROS and PAH measurements. Note: both the PAHs and ROS are expressed on a per unit mg of DPM basis. The Pearson correlation co-efficient, r, is 0.913.

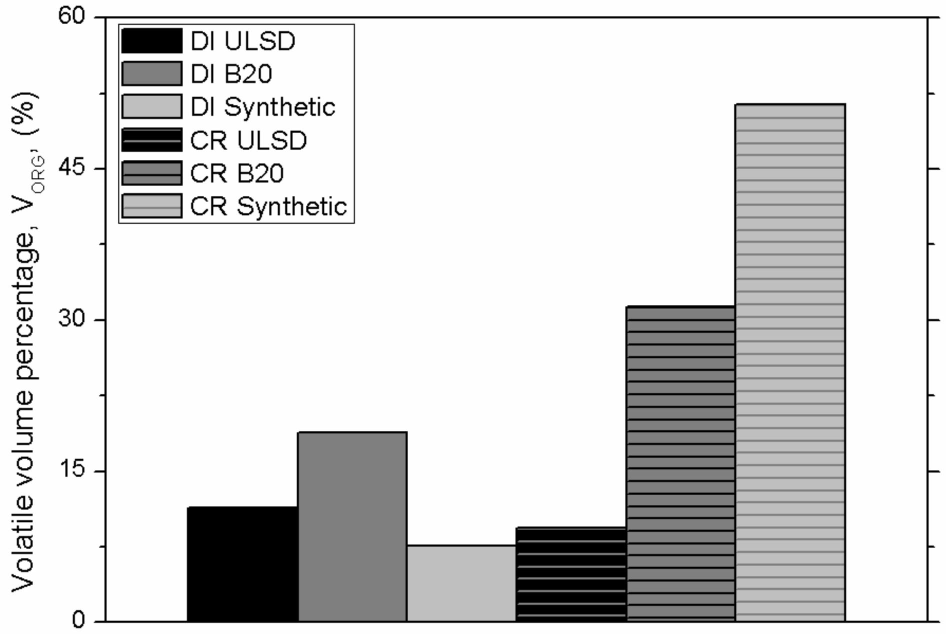

Figure S3: Test cycle averaged volatile volume percentage of particles for both injection technologies, and all three fuels.