

Figure 4, 5 and 6 show the Oxide of Nitrogen (NOx) emissions corrected for oxygen to a standard 15% in line with ISO8178 to remove dilution errors.

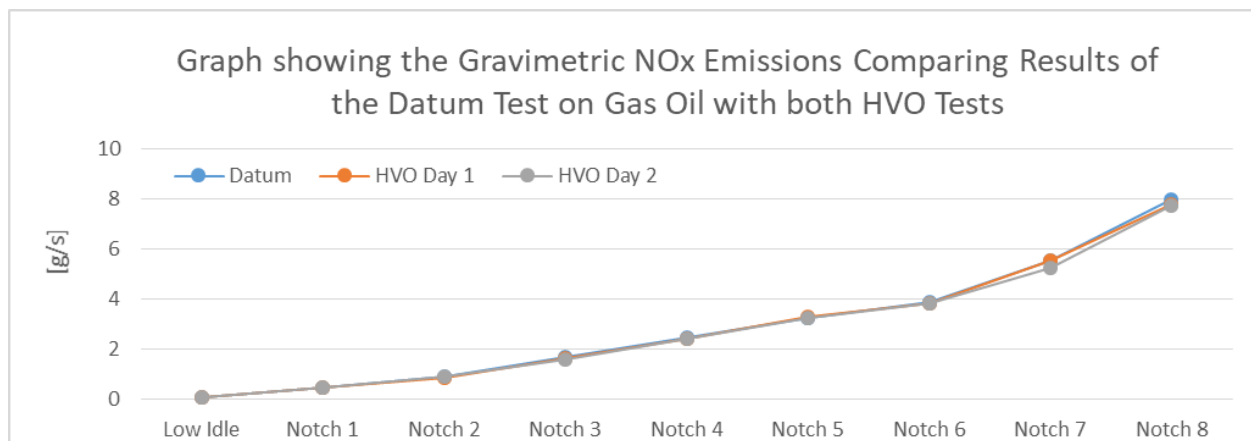


Figure 4

Figure 4 and Table 4 show the gravimetric NOx data [g/s] and compare the results from all three test days.

	NOx [g/s]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	0.088	0.095	0.090	7.4%	2.3%
Notch 1	0.487	0.473	0.473	-2.8%	-2.9%
Notch 2	0.886	0.879	0.892	-0.8%	0.7%
Notch 3	1.662	1.626	1.601	-2.2%	-3.7%
Notch 4	2.438	2.424	2.426	-0.6%	-0.5%
Notch 5	3.239	3.288	3.264	1.5%	0.8%
Notch 6	3.854	3.845	3.805	-0.2%	-1.3%
Notch 7	5.506	5.542	5.239	0.7%	-4.8%
Notch 8	7.947	7.785	7.708	-2.0%	-3.0%
				<b>Average</b>	<b>0.1%</b>
					<b>-1.4%</b>

Table 4

The change in gravimetric NOx emissions is within measurement accuracy, with no significant improvement shown between the tests.

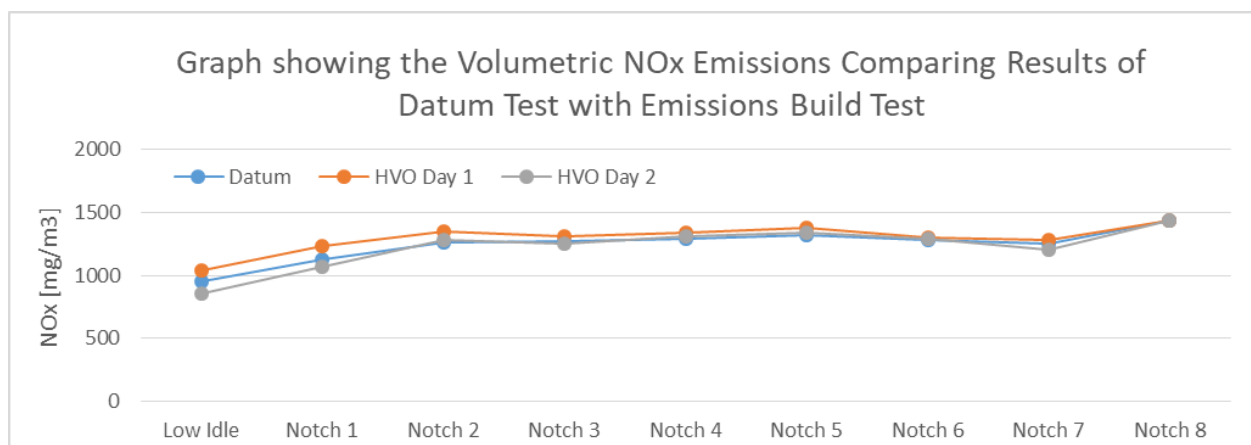


Figure 5

Figure 5 and Table 5 show the results in volumetric emission. Again the results are within the measurement accuracy, there is no significant change between the fuels run.

	NOx [mg/m <sup>3</sup> ]			HVO Change from Gasoil		
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2	
Low Idle	948	1044	857	10.1%	-9.6%	
Notch 1	1130	1234	1066	9.2%	-5.7%	
Notch 2	1260	1350	1285	7.1%	1.9%	
Notch 3	1273	1310	1249	2.9%	-1.8%	
Notch 4	1293	1336	1311	3.4%	1.4%	
Notch 5	1322	1381	1345	4.5%	1.7%	
Notch 6	1281	1305	1296	1.8%	1.1%	
Notch 7	1256	1286	1206	2.4%	-4.0%	
Notch 8	1441	1437	1434	-0.3%	-0.5%	
				<b>Average</b>	<b>4.6%</b>	<b>-1.7%</b>

Table 5

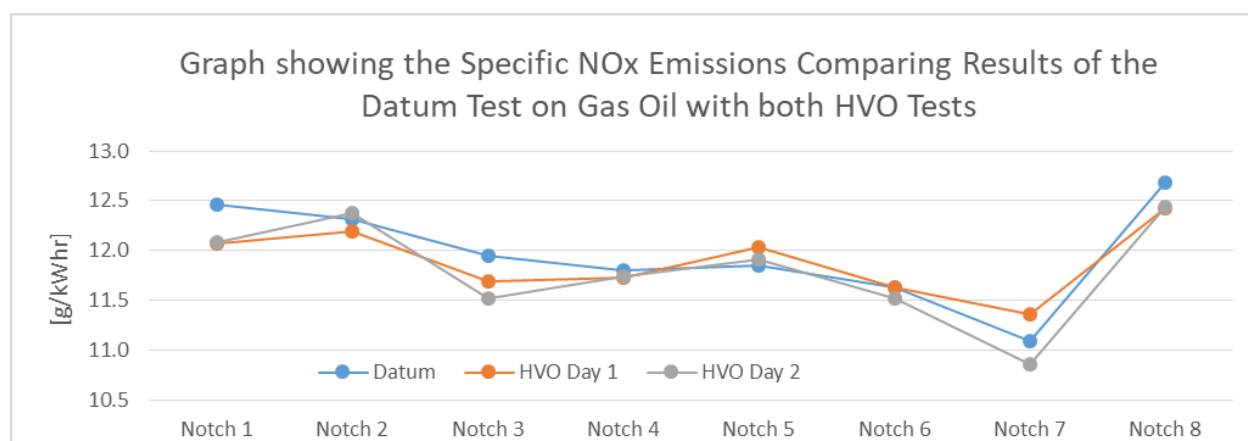


Figure 6

Figure 6 and Table 6 show the results in specific emission. Again the results are within the measurement accuracy, there is no significant change between the fuels run.

	NOx [g/kWhr]			HVO Change from Gasoil		
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2	
Low Idle	∞	∞	∞	-	-	
Notch 1	12.46	12.08	12.08	-3.1%	-3.0%	
Notch 2	12.31	12.19	12.38	-1.0%	0.6%	
Notch 3	11.95	11.70	11.52	-2.1%	-3.6%	
Notch 4	11.81	11.73	11.75	-0.6%	-0.5%	
Notch 5	11.85	12.03	11.92	1.6%	0.6%	
Notch 6	11.64	11.64	11.52	0.0%	-1.0%	
Notch 7	11.09	11.37	10.87	2.5%	-2.0%	
Notch 8	12.68	12.42	12.44	-2.1%	-1.9%	
				<b>Average</b>	<b>-0.6%</b>	<b>-1.4%</b>

Table 6

Figure 7, 8 and 9 show the Total Particulate Matter (TPM) emissions.

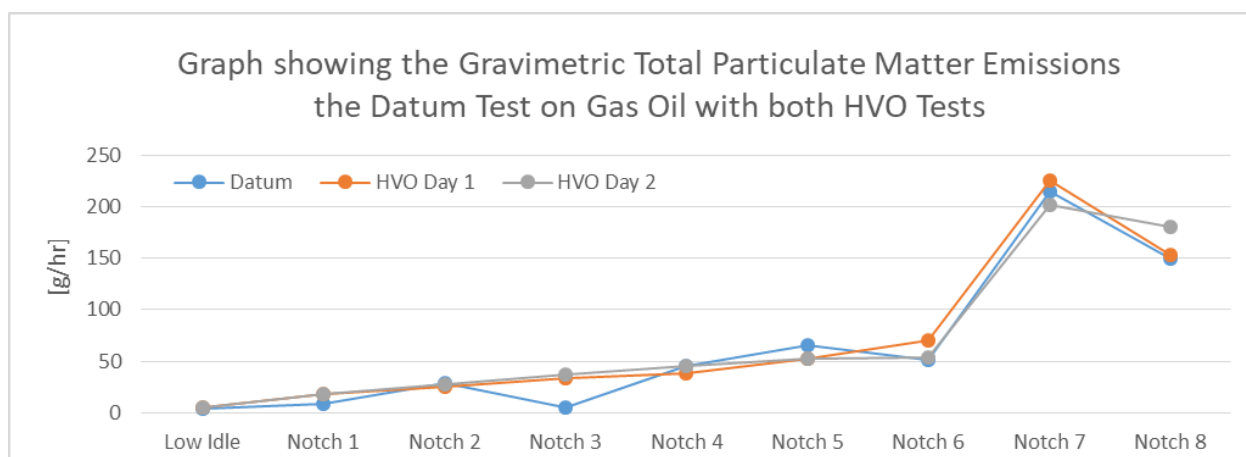


Figure 7

Unfortunately the notch 1 and 3 results from the datum test appear to be erroneous as they are too low to be realistic.

	TPM [g/hr]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	4	5	5	25.0%	25.0%
Notch 1	9	18	18	100.0%	100.0%
Notch 2	29	25	28	-13.8%	-3.4%
Notch 3	5	34	37	580.0%	640.0%
Notch 4	45	38	45	-15.6%	0.0%
Notch 5	66	52	53	-21.2%	-19.7%
Notch 6	51	70	54	37.3%	5.9%
Notch 7	215	225	202	4.7%	-6.0%
Notch 8	150	153	180	2.0%	20.0%
				<b>Average</b>	<b>2.6%</b>
					<b>3.1%</b>

Table 7

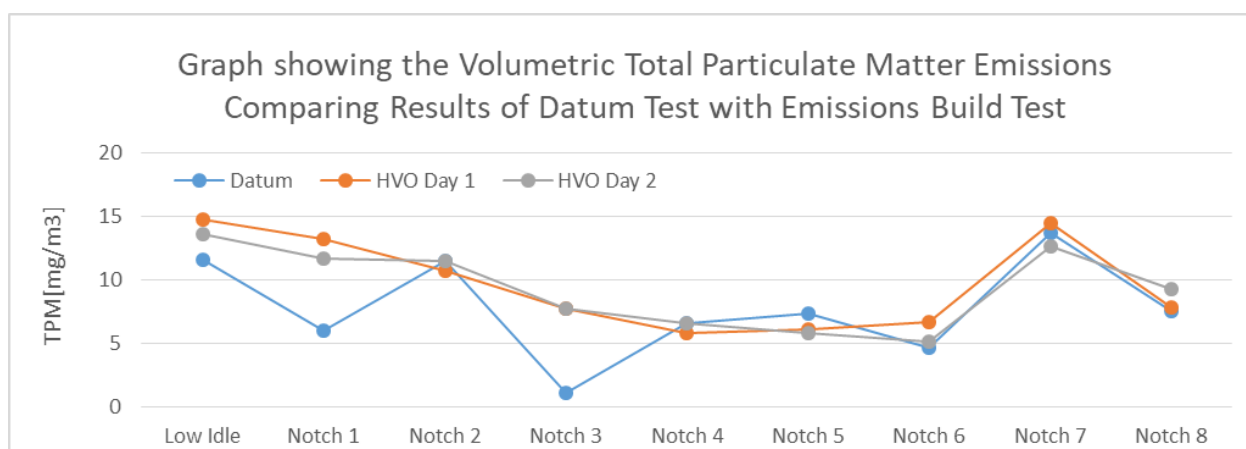


Figure 8

	TPM [mg/m <sup>3</sup> ]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	11.56	14.73	13.6	27.4%	17.6%
Notch 1	6.04	13.25	11.7	119.4%	93.7%
Notch 2	11.52	10.72	11.46	-6.9%	-0.5%
Notch 3	1.07	7.71	7.72	620.6%	621.5%
Notch 4	6.61	5.81	6.59	-12.1%	-0.3%
Notch 5	7.39	6.07	5.83	-17.9%	-21.1%
Notch 6	4.68	6.64	5.18	41.9%	10.7%
Notch 7	13.67	14.43	12.68	5.6%	-7.2%
Notch 8	7.56	7.86	9.28	4.0%	22.8%
				<b>Average</b>	<b>6.0%</b>
					<b>3.1%</b>

Table 8

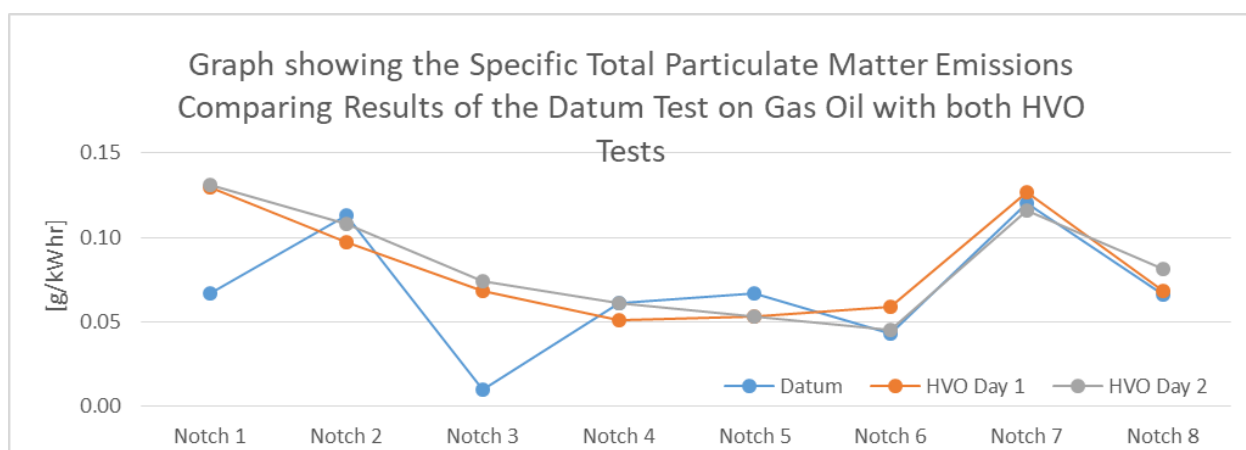


Figure 9

	TPM [g/kWhr]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	∞	∞	∞	-	-
Notch 1	0.067	0.130	0.131	94.0%	95.5%
Notch 2	0.113	0.097	0.108	-14.2%	-4.4%
Notch 3	0.010	0.068	0.074	580.0%	640.0%
Notch 4	0.061	0.051	0.061	-16.4%	0.0%
Notch 5	0.067	0.053	0.053	-20.9%	-20.9%
Notch 6	0.043	0.059	0.045	37.2%	4.7%
Notch 7	0.120	0.127	0.116	5.8%	-3.3%
Notch 8	0.066	0.068	0.081	3.0%	22.7%
				<b>Average</b>	<b>-0.9%</b>
					<b>-0.2%</b>

Table 9

Considering the TPM emissions results presented, the results are within the measurement accuracy, and there is no significant change between the fuels runs.

The particulate filter papers were sent away for further analysis to determine the particulate size distribution. The results can be seen in section 8.

Figure 10, 11 and 12 show the Volatile Organic Compound (VOC) or Hydrocarbon (HC) emissions expressed as carbon corrected for oxygen to a standard 15% in line with ISO8178 to remove dilution errors.

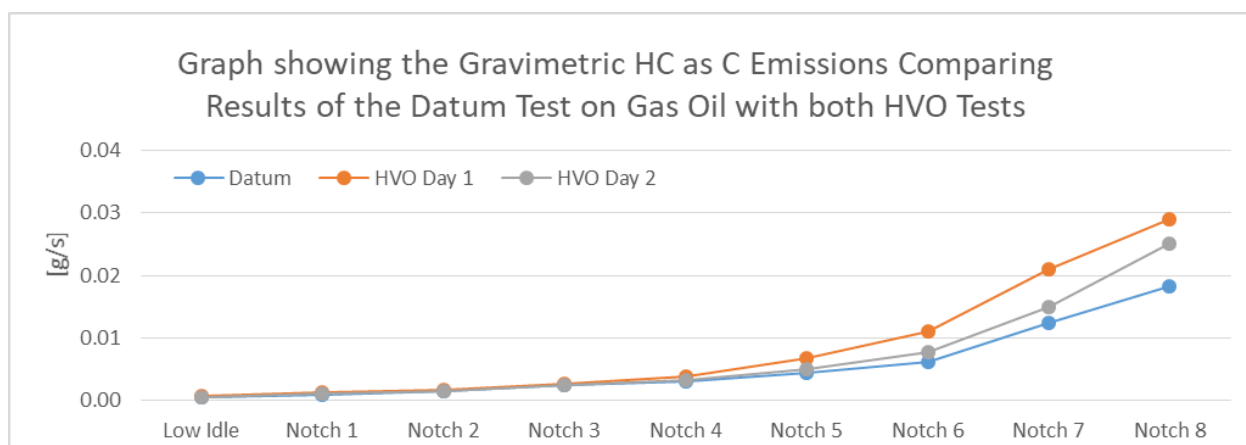


Figure 10

	HC as C [g/s]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	0.0005	0.0008	0.0006	77.8%	33.3%
Notch 1	0.0010	0.0012	0.0011	20.0%	10.0%
Notch 2	0.0015	0.0016	0.0015	10.3%	0.0%
Notch 3	0.0024	0.0028	0.0025	14.6%	4.2%
Notch 4	0.0031	0.0038	0.0033	21.0%	4.8%
Notch 5	0.0045	0.0067	0.0050	48.9%	11.1%
Notch 6	0.0062	0.0111	0.0078	78.2%	25.8%
Notch 7	0.0125	0.0211	0.0150	69.5%	20.1%
Notch 8	0.0182	0.0290	0.0251	59.3%	37.9%
				<b>Average</b>	<b>44.4%</b>
					<b>16.4%</b>

Table 10

The results showed the VOC emissions to be higher on HVO than on Gasoil, particularly at higher load conditions.

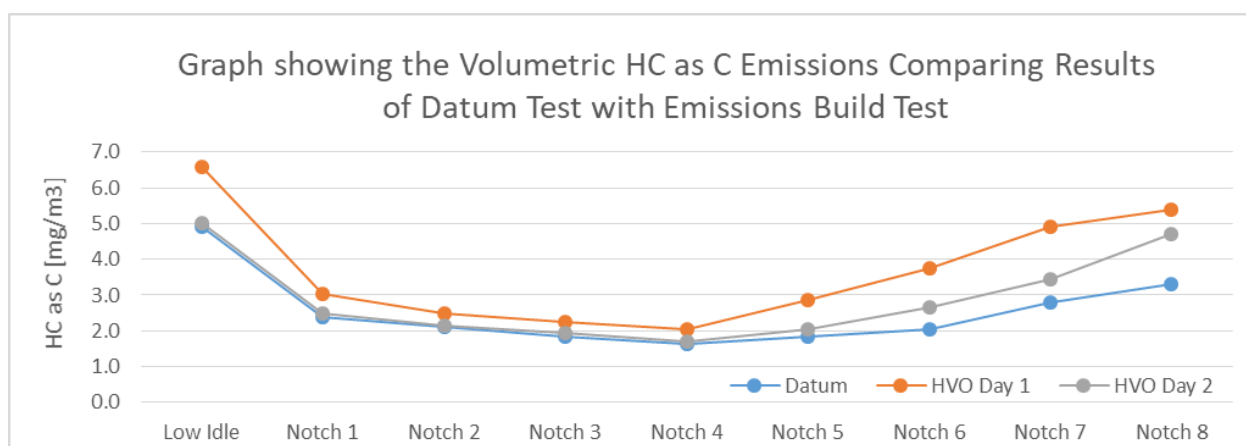


Figure 11

	HC as C [mg/m <sup>3</sup> ]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	4.9	6.6	5.0	34.7%	2.0%
Notch 1	2.4	3.1	2.5	27.1%	4.2%
Notch 2	2.1	2.5	2.2	19.0%	2.4%
Notch 3	1.9	2.3	2.0	21.6%	5.4%
Notch 4	1.7	2.1	1.7	24.2%	3.0%
Notch 5	1.9	2.9	2.1	54.1%	10.8%
Notch 6	2.1	3.8	2.7	82.9%	29.3%
Notch 7	2.8	4.9	3.5	75.0%	23.2%
Notch 8	3.3	5.4	4.7	63.6%	42.4%
				<b>Average</b>	<b>44.7%</b>
					<b>13.6%</b>

Table 11

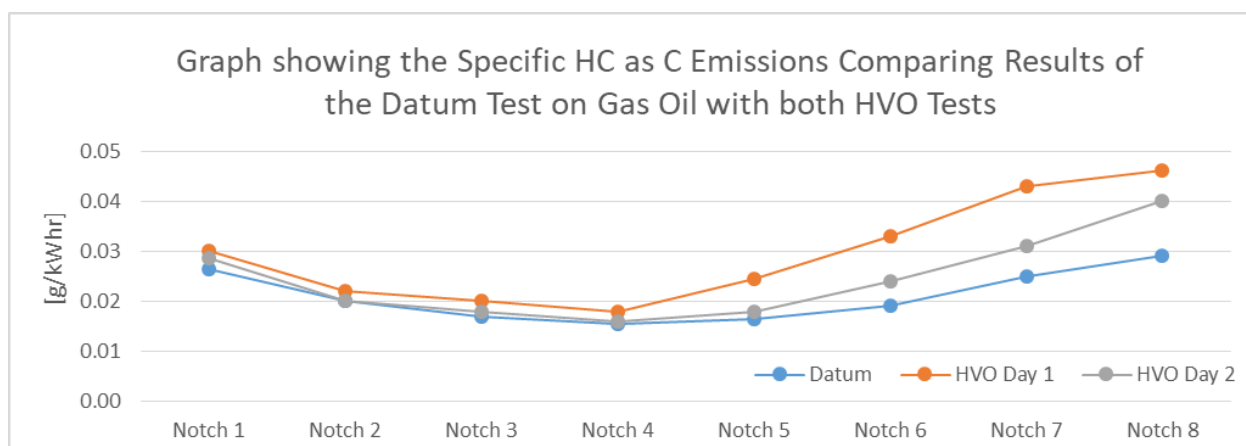


Figure 12

	HC as C [g/kWhr]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	∞	∞	∞	-	-
Notch 1	0.027	0.030	0.029	13.2%	7.5%
Notch 2	0.020	0.022	0.020	10.0%	0.0%
Notch 3	0.017	0.020	0.018	17.6%	5.9%
Notch 4	0.016	0.018	0.016	16.1%	3.2%
Notch 5	0.017	0.025	0.018	48.5%	9.1%
Notch 6	0.019	0.033	0.024	73.7%	26.3%
Notch 7	0.025	0.043	0.031	72.0%	24.0%
Notch 8	0.029	0.046	0.040	58.6%	37.9%
				<b>Average</b>	<b>38.7%</b>
					<b>14.2%</b>

Table 12

When comparing the two HVO test runs, there are considerable differences between the two tests which is greater than when comparing the datum test results with the HVO Day 2 test results. However, in all cases the VOC emissions were found to be worse for the HVO when comparing to the datum test on Gas Oil.

Figure 13, 14 and 15 show the Carbon Monoxide (CO) emissions corrected for oxygen to a standard 15% in line with ISO8178 to remove dilution errors.

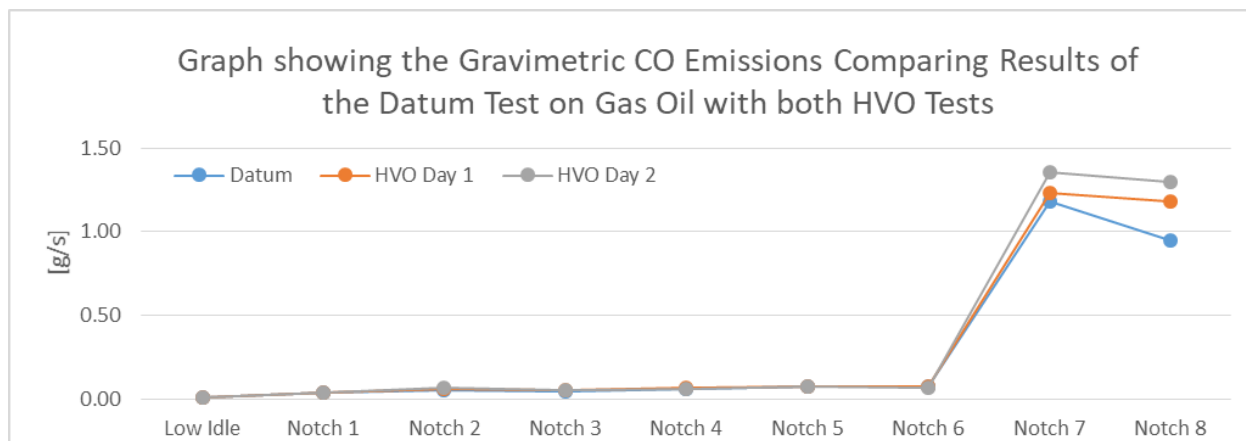


Figure 13

	CO [g/s]			HVO Change from Gasoil	
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2
Low Idle	0.0075	0.008	0.008	6.7%	6.7%
Notch 1	0.0375	0.0385	0.035	2.7%	-6.7%
Notch 2	0.052	0.058	0.064	11.5%	23.1%
Notch 3	0.044	0.0545	0.052	23.9%	18.2%
Notch 4	0.0575	0.0635	0.062	10.4%	7.8%
Notch 5	0.0705	0.0745	0.0765	5.7%	8.5%
Notch 6	0.0765	0.072	0.067	-5.9%	-12.4%
Notch 7	1.1815	1.231	1.3565	4.2%	14.8%
Notch 8	0.948	1.184	1.297	24.9%	36.8%
				<b>Average</b>	<b>9.3%</b>
					<b>10.8%</b>

Table 13

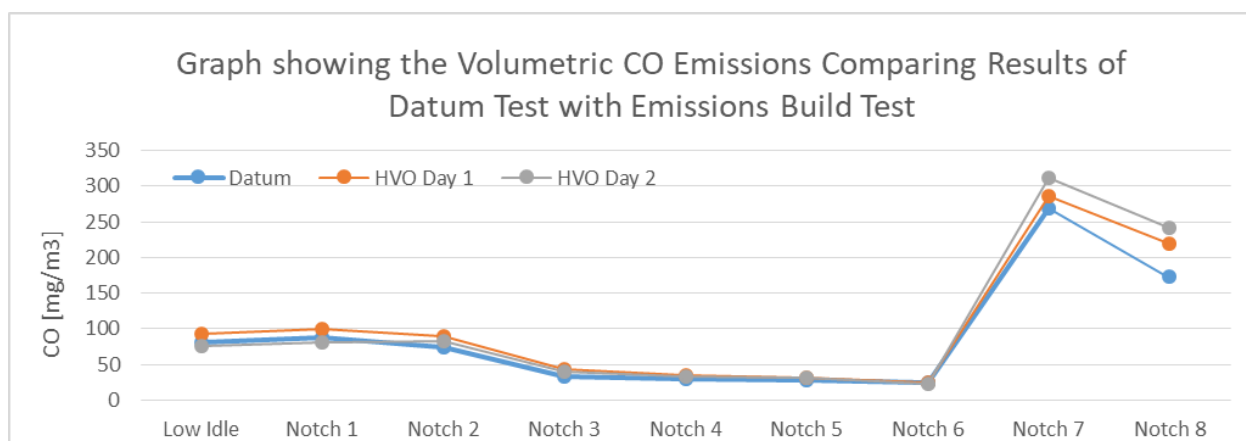


Figure 14

	CO [mg/m3]			HVO Change from Gasoil		
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2	
Low Idle	80.75	93.50	76.13	15.8%	-5.7%	
Notch 1	87.52	99.60	81.82	13.8%	-6.5%	
Notch 2	74.46	89.25	83.45	19.9%	12.1%	
Notch 3	34.04	43.74	40.64	28.5%	19.4%	
Notch 4	30.40	35.24	33.44	15.9%	10.0%	
Notch 5	28.77	31.44	31.56	9.3%	9.7%	
Notch 6	25.51	24.49	23.27	-4.0%	-8.8%	
Notch 7	269.54	285.65	311.89	6.0%	15.7%	
Notch 8	172.01	218.50	241.27	27.0%	40.3%	
				<b>Average</b>	<b>14.7%</b>	<b>9.6%</b>

Table 14

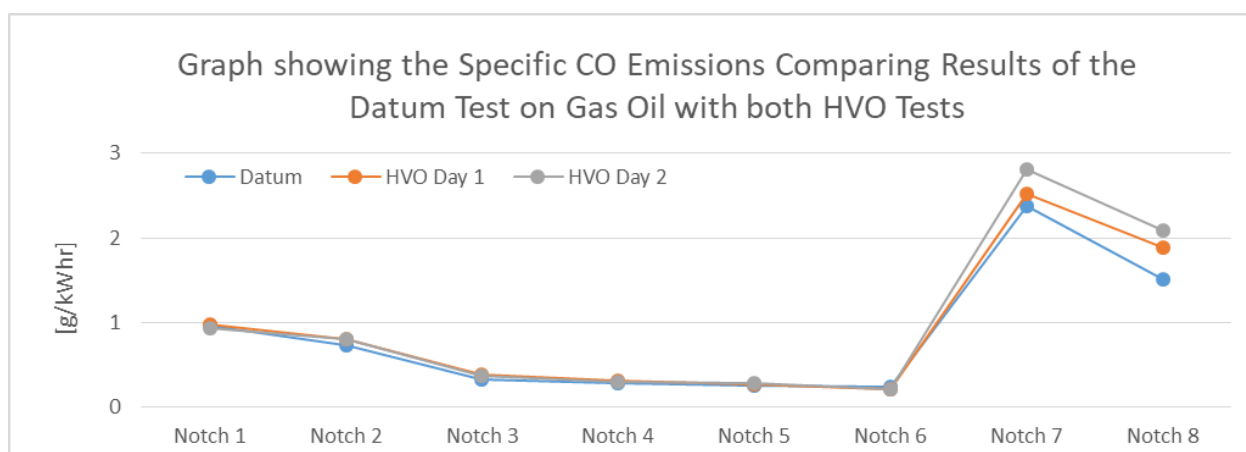


Figure 15

	CO [g/kWhr]			HVO Change from Gasoil		
	Datum	HVO Day 1	HVO Day 2	HVO Day 1	HVO Day 2	
Low Idle	∞	∞	∞	-	-	
Notch 1	0.963	0.975	0.927	1.2%	-3.8%	
Notch 2	0.728	0.806	0.802	10.8%	10.2%	
Notch 3	0.320	0.391	0.375	22.2%	17.2%	
Notch 4	0.278	0.310	0.300	11.5%	7.9%	
Notch 5	0.258	0.274	0.281	6.4%	8.9%	
Notch 6	0.232	0.217	0.204	-6.5%	-12.1%	
Notch 7	2.381	2.525	2.814	6.0%	18.2%	
Notch 8	1.514	1.889	2.094	24.8%	38.3%	
				<b>Average</b>	<b>9.6%</b>	<b>10.6%</b>

Table 15

The results showed the CO emissions to be slightly higher on HVO than on Gasoil, particularly at higher load conditions.



## CO<sub>2</sub> Emissions

Carbon Dioxide (CO<sub>2</sub>) emissions are a function of fuel consumption and fuel composition as it is assumed that 100% is burned or oxidised.

CO<sub>2</sub> emissions are directly proportional to mass fuel consumption and can be calculated as follows:

Carbon content of Gas Oil = 85.44%

Carbon content of HVO = 84.54%

Atomic mass Carbon = 12.011

Atomic mass Oxygen = 15.999

### CARBON : CARBON DIOXIDE RATIO

$$\frac{\text{CO}_2}{\text{C}} = \frac{12.011 + 15.999 + 15.999}{12.011} = \frac{44.009}{12.011} = 3.664$$

So for each kg of Carbon in the fuel burned 3.664 kg of Carbon Dioxide is emitted out of the exhaust.

### FUEL CONSUMPTION : CARBON DIOXIDE RATIO

0.8544 x 3.664 = 3.1305 kg CO<sub>2</sub> per kg of fuel for Gas Oil

0.8454 x 3.664 = 3.0976 kg CO<sub>2</sub> per kg of fuel for HVO

The Carbon Dioxide emissions are around 1% lower on HVO fuel than the Gasoil fuel for each kg of fuel burned.

## 7.0 Particulate Size Distribution

The particulate filters were sent away for further analysis using laser diffraction by Particle Technology Limited. The full analysis report can be seen separately in report PTL 22321.

The extracted results have been summarised in Table 16 below and Figures 16 and 17 show graphs of the mean and median size particulate for each load point.

Test Point	PTL Sample ID	EMT Sample Identification	Mean Size (µm)	Median Size(µm)	D10(µm)	D50(µm)	D90(µm)	PM10(%)	PM5(%)	PM2.5(%)
Datum Idle	35763	47-82963	6.38	6.14	3.88	6.14	9.26	94.29	29.50	1.30
Datum Notch 1	35771	47-82867	16.96	8.70	1.81	8.70	49.86	55.41	31.98	15.74
Datum Notch 2	35764	47-84131	1.32	0.84	0.51	0.84	3.00	100.00	98.12	87.05
Datum Notch 3	35770	47-76477	13.14	8.08	1.54	8.08	31.14	57.45	36.97	20.93
Datum Notch 4	35765	47-84130	4.16	3.05	0.87	3.05	9.18	92.73	68.06	45.00
Datum Notch 5	35769	47-76443	8.43	5.68	0.75	5.68	19.79	69.27	46.88	31.02
Datum Notch 6	35766	47-84129	7.86	3.89	1.23	3.89	21.31	73.28	57.31	37.05
Datum Notch 7	35768	47-82535	1.56	1.14	0.63	1.14	3.13	100.00	98.51	84.67
Datum Notch 8	35767	47-83752	5.49	2.56	0.68	2.56	14.83	78.33	63.00	50.26
HVO 2 Idle	35772	47-84376	18.38	9.19	3.85	9.19	49.90	54.43	20.22	2.75
HVO 2 Notch 1	35780	47-84377	9.25	6.49	1.78	6.49	20.74	69.13	40.05	18.00
HVO 2 Notch 2	35773	47-84380	2.51	2.32	0.84	2.32	4.47	100.00	94.96	56.69
HVO 2 Notch 3	35779	47-84361	13.91	7.24	1.71	7.24	38.79	59.47	40.50	21.67
HVO 2 Notch 4	35774	47-84379	10.50	6.07	1.55	6.07	28.36	66.93	44.33	23.43
HVO 2 Notch 5	35778	47-84362	2.25	1.99	0.95	1.99	3.91	100.00	97.43	67.45
HVO 2 Notch 6	35775	47-84100	3.77	3.65	2.28	3.65	5.45	100.00	86.40	16.90
HVO 2 Notch 7	35777	47-84123	2.69	2.52	1.47	2.52	4.15	100.00	97.21	52.85
HVO 2 Notch 8	35776	47-84105	2.34	2.12	1.07	2.12	3.90	100.00	97.58	65.25

Table 16

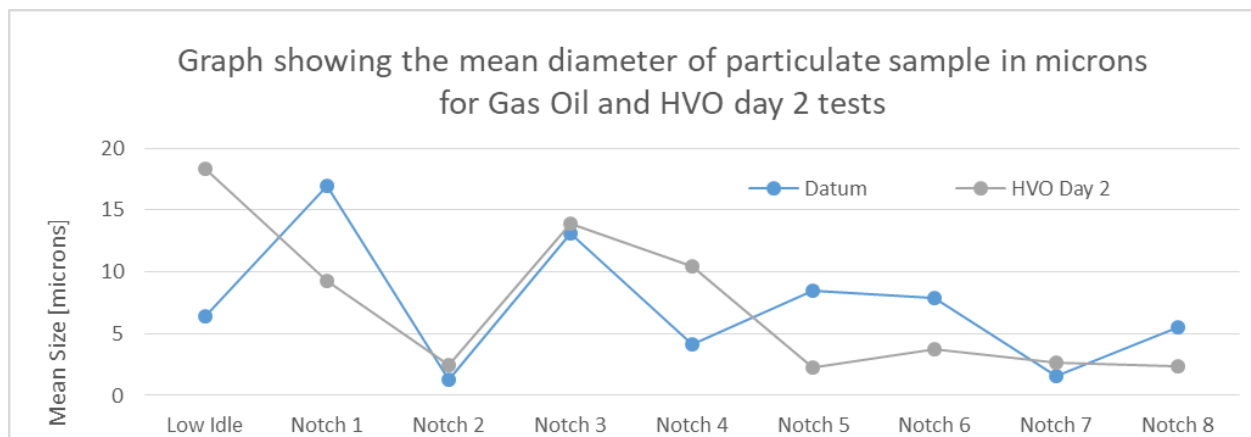


Figure 16

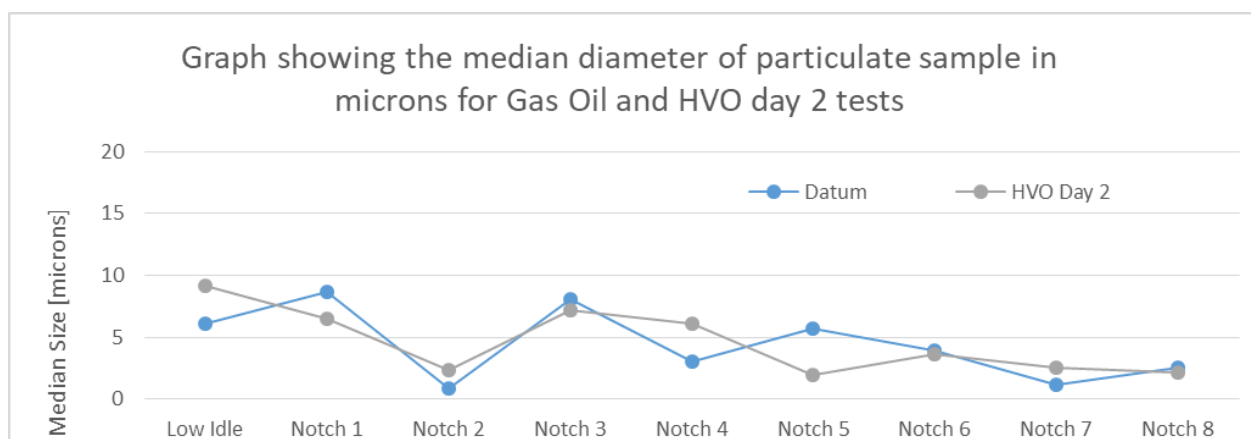


Figure 17

Generally, with the exception of notch 2, the mean size tends to reduce as the load increases and the amount of PM2.5 tends to increase with load. Notch 2 is seen to comprise of finer particulate for both fuels but more so for gasoil.

Figures 18, 19 and 20 show the percentage of the particulate sample captured which comprises of PM10, PM5 and PM2.5 respectively.

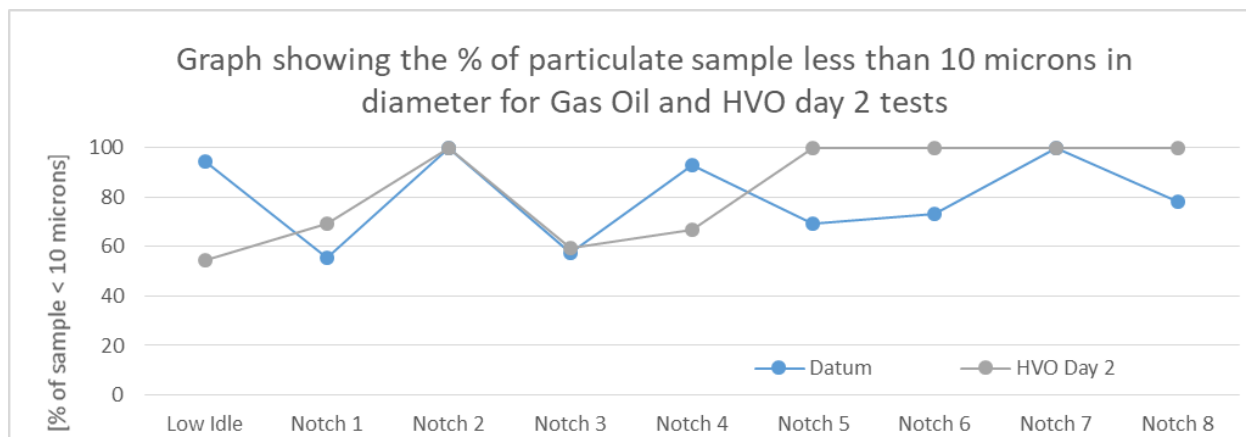


Figure 18

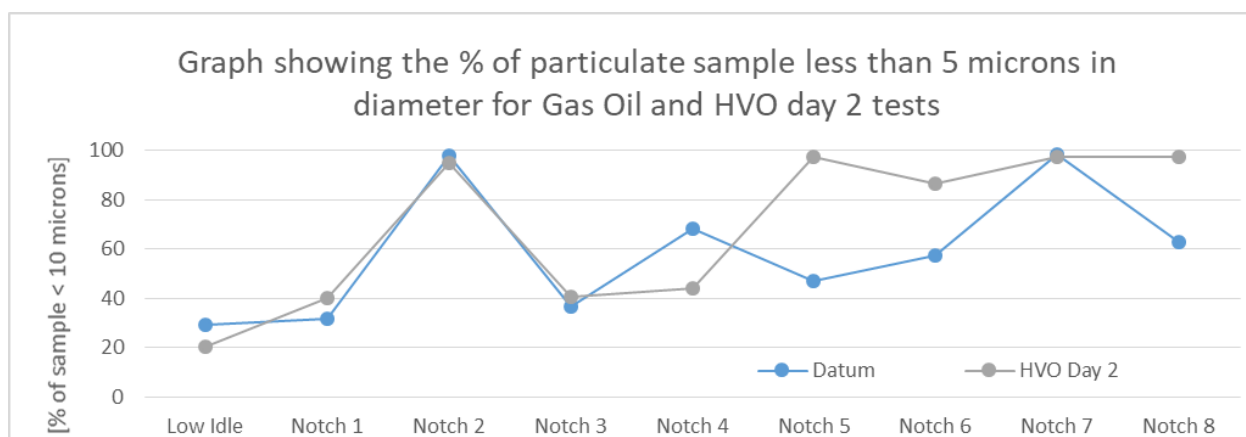


Figure 19

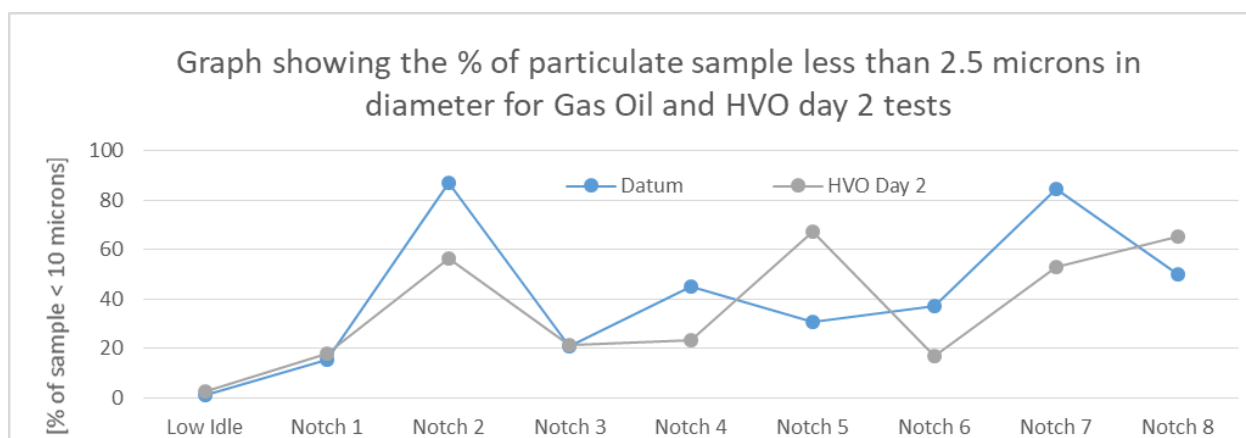


Figure 20

It is interesting to consider the particulate size distribution as the characteristics clearly vary depending on load and fuel with the charts showing single and multiple peaks. The sample particle size distribution charts can be seen in figured 20 and 21.



Figure 21

Gasoil starts with a single peak at idle of around 6 micron diameter, whereas the HVO seems to have two peaks at around 7 and 50 microns. At other points double and triple peaks are observed but HVO tends towards a single peak for load point 5 to 8.

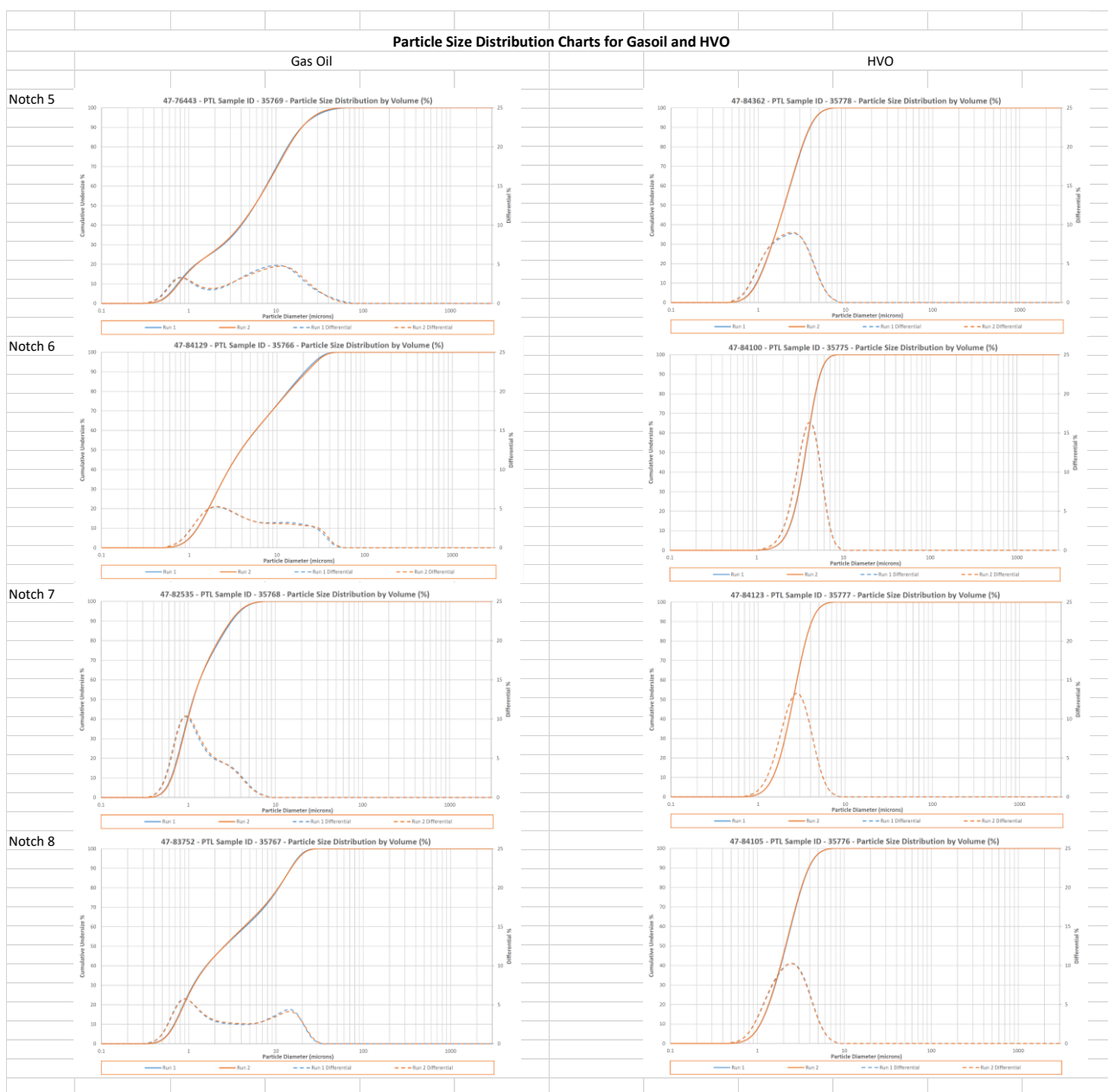


Figure 22

Table 17 shows the approximate peak size in terms of approximate diameter and approximate percentage of sample for the peaks observed.

Peak Analysis											
Test Point	PTL Sample ID	EMT Sample Identification	Mean Size (µm)	Peak 1			Peak 2		Peak 3		Total
				Mean Size approx (µm)	% approx	Mean Size approx (µm)	% approx	Mean Size approx (µm)	% approx	Mean Size approx (µm)	
Datum Idle	35763	47-82963	6.38	6.0	100					6.0	
Datum Notch 1	35771	47-82867	16.96	1.5	15	9.0	60	60.0	25.0	20.6	
Datum Notch 2	35764	47-84131	1.32	0.7	80	3.0	20			1.2	
Datum Notch 3	35770	47-76477	13.14	1.5	35	14.0	50	60.0	15.0	16.5	
Datum Notch 4	35765	47-84130	4.16	1.2	45	7.0	55			4.4	
Datum Notch 5	35769	47-76443	8.43	0.7	30	10.0	70			7.2	
Datum Notch 6	35766	47-84129	7.86	2.0	50	15.0	30	25.0	20.0	10.5	
Datum Notch 7	35768	47-82535	1.56	0.9	80	3.0	20			1.3	
Datum Notch 8	35767	47-83752	5.49	0.9	60	3.0	15	15.0	35.0	6.2	
HVO 2 Idle	35772	47-84376	18.38	7.0	70	50.0	30			19.9	
HVO 2 Notch 1	35780	47-84377	9.25	1.5	10	8.0	65	50.0	15.0	12.9	
HVO 2 Notch 2	35773	47-84380	2.51	1.0	30	3.5	70			2.8	
HVO 2 Notch 3	35779	47-84361	13.91	2.0	30	9.0	50	40.0	20.0	13.1	
HVO 2 Notch 4	35774	47-84379	10.50	2.0	25	8.0	55	40.0	20.0	12.9	
HVO 2 Notch 5	35778	47-84362	2.25	1.4	45	2.5	55			2.0	
HVO 2 Notch 6	35775	47-84100	3.77	4.0	100					4.0	
HVO 2 Notch 7	35777	47-84123	2.69	2.7	100					2.7	
HVO 2 Notch 8	35776	47-84105	2.34	2.4	100					2.4	

Table 17

It is difficult to conclude findings from this particulate size analysis as the data sample is relatively limited and the results are so varied. If we step back and just consider the most concerning particulates from a health perspective PM<sub>2.5</sub>, and consider the average for each fuel type, see Table 18, then Gas Oil particulates are finer and HVO is slightly better, however the advantage could not be seen at all load points.

Test Point	GasOil PM <sub>2.5</sub> (%)	HVO PM <sub>2.5</sub> (%)
Datum Idle	1.3	2.8
Datum Notch 1	15.7	18.0
Datum Notch 2	87.1	56.7
Datum Notch 3	20.9	21.7
Datum Notch 4	45.0	23.4
Datum Notch 5	31.0	67.5
Datum Notch 6	37.1	16.9
Datum Notch 7	84.7	52.9
Datum Notch 8	50.3	65.3
Average	41.4	36.1

Table 18