OSU-CAR ES TEST REPORT – PUREFLOW TECHNOLOGIES, INC.

NOVEMBER 16, 2020

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Introduction

The Ohio State University Center for Automotive Research was retained by Pureflow Technologies to complete an independent evaluation of two products for emissions and fuel economy improvements. The products were labeled Champ II Spin-On Air Separation System and AirDog Heavy Duty Diesel Fuel System respectively. The Engineering Services group (CAR-ES) was fully responsible for the design of the test plan and completion of the test program. The products were delivered and installed on the vehicle by the customer. The test vehicle was provided by the customer.

Test Plan

The approach to testing was to generate baseline data for the test vehicle using standard commercial diesel fuel over a series of tests. The test sequence was then repeated using each of the customer's two products separately. The test sequence was performed a final time using both the customer's products at the same time. The baseline data was directly compared to data generated over the same test cycles using the customer's products. All testing was conducted using the same test vehicle with the same test driver provided by CAR-ES. The vehicle dynamometer loading conditions and fuel supply were consistent throughout the program. The program testing was completed across two test days.

One test cycle was used for this program. The EPA Heavy-Duty Urban Dynamometer Driving Schedule (UDDS). The UDDS was developed for the chassis dynamometer testing of heavy-duty vehicles (40 CFR 86 App. I).

The vehicle was tested in the following sequence for the evaluation program:

1. The vehicle was installed on the chassis dynamometer and secured
2. The vehicle was warmed up and Coastdown tests were completed to determine appropriate dynamometer simulation settings per Petrushov (SAE 970408)
3. All tests were completed using the same tank of on-board diesel fuel as delivered. No fuel was added or removed from the vehicle during testing.

Test Day 1 – November 3, 2020

<u>Baseline Testing</u>

1. Vehicle warmup for 20 minutes
2. UDDS Test Cycle #1
3. UDDS Test Cycle #2
4. UDDS Test Cycle #3
5. UDDS Test Cycle #4

6. UDDS Test Cycle #5

Product Testing – Champ II Spin-On Air Separation System (Condition A)

7. The Champ II Spin-On Air Separation System was installed by the customer
8. Vehicle warmup for 20 minutes
9. UDDS Test Cycle #6
10. UDDS Test Cycle #7
11. UDDS Test Cycle #8
12. UDDS Test Cycle #9
13. UDDS Test Cycle #10

Baseline Testing

14. The Champ II Spin-On Air Separation System was removed by the customer and the stock vehicle system reinstalled
15. UDDS Test Cycle #11
16. UDDS Test Cycle #12
17. UDDS Test Cycle #13
18. UDDS Test Cycle #14

Test Day 2 – November 4, 2020

Baseline Testing

1. Vehicle warm-up for 20 minutes
2. UDDS Test Cycle #1
3. UDDS Test Cycle #2
4. UDDS Test Cycle #3
5. UDDS Test Cycle #4
6. UDDS Test Cycle #5

Product Testing –

7. The AirDog Heavy Duty Diesel Fuel System was installed by the customer (Condition B)
8. UDDS Test Cycle #6
9. UDDS Test Cycle #7
10. UDDS Test Cycle #8
11. UDDS Test Cycle #9
12. UDDS Test Cycle #10
13. The AirDog Heavy Duty Diesel Fuel System was removed by the customer and the stock system reinstalled
14. UDDS Test Cycle #11
15. UDDS Test Cycle #12
16. UDDS Test Cycle #13
19. The Champ II Spin-On Air Separation and AirDog Heavy Duty Diesel Fuel Systems were installed by the customer (Condition C)
17. UDDS Test Cycle #14
18. UDDS Test Cycle #15
19. UDDS Test Cycle #16
20. UDDS Test Cycle #17
21. UDDS Test Cycle #18

End of Test Program

The complete test program performed 32 HD UDDS tests conducted in two days including:

- 17 Baseline HD UDDS tests
- 5 Champ II Spin-On Air Separation System (Condition A) tests
- 5 AirDog Heavy Duty Diesel Fuel System (Condition B) tests
- 5 Champ II Spin-On Air Separation and AirDog Heavy Duty Diesel Fuel Systems (Condition C) tests

Test Vehicle

The test vehicle was provided by the customer. This vehicle was a representative "in-use" vehicle which fulfilled the customer's target vehicle type. The vehicle was checked for road and dyno worthiness prior to starting the test program. All fluids were verified to be at manufacturer specified levels and the tires and exhaust system were found to be in good condition and leak free. There were no mechanical problems or check engine lights present during the program.

During testing the vehicle simulation was set for a vehicle mass of 35,000 lbs. which represents a partial cargo load for this model. The vehicle transmission was place in "P" mode for all testing and a 3,500 lbs block was secured over the drive axel while on the chassis dynamometer for all testing.

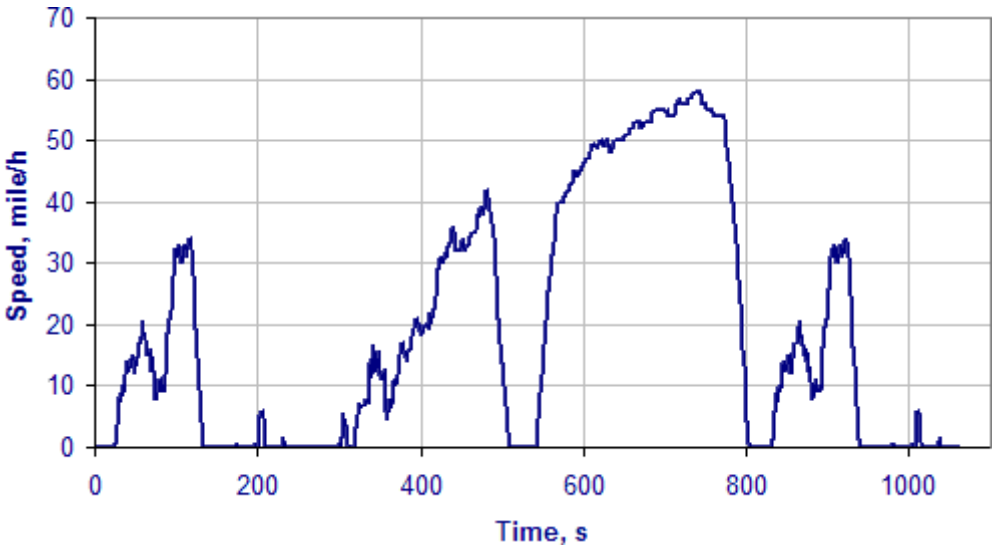
Make	Volvo
Engine Model	D13TC 425HP 1750 LBF D13/1274305
Transmission	ATO2612F, 14 Speed 0710918658
VIN #	4V4NB9EH5LN255290

Test Procedures

Description of Testing:

UDDS Test. Each UDDS test completed during this program was performed with the vehicle warmed up and running in idle at the start of the test. Engine crank emissions were not collected during this program. The UDDS simulates typical city driving and raw emissions were continuously sampled to calculate a grams/mile emissions result for total hydrocarbons (THC), carbon monoxide (CO), and oxides of nitrogen (NO_x). Fuel economy, in miles per gallon, is determined via emissions measurements using representative diesel fuel properties.

Accuracy of Repeat Measurements. Chassis dynamometer emissions measurements do not have an established industry test-to-test variance. Fuel economy measured on OSU's chassis dynamometer is viewed as repeatable within ±2.5%. Any variation within ±2.5% can be influenced by test-to-test measurement scatter. The "±" listed for each result in this report is based on a 95% confidence interval.



The UDDS Driving Cycle

Test Results

The UDDS emissions and fuel economy results are summarized in the following table.

UDDS Test Results:

# of Tests	Condition	THC (g/mile)	±	CO (g/mile)	±	NOx (g/mile)	±	Fuel Economy mpg	±
9	Baseline	0.03	0.001	0.03	0.015	0.95	0.209	5.09	0.087
5	Condition A	0.03	0.001	0.02	0.006	0.66	0.303	5.21	0.095
7*	Baseline	0.04	0.009	0.02	0.007	1.92	1.477	5.17	0.181
5	Condition B	0.04	0.005	0.02	0.006	2.44	1.429	5.39	0.100
5	Condition C	0.03	0.005	0.02	0.011	1.19	1.439	5.22	0.148

* Baseline Test #6 conducted 11/4/2020 was removed from the data set following a post-test quality review

Impact of Product(s) on emissions and fuel economy UDDS Test results:

	THC	CO	NOx	Fuel Economy
Condition A vs Baseline	-9.1%	-24.6%	-31.0%	+2.3%
Condition B vs Baseline	-5.0%	-20.2%	+27.0%	+4.3%
Condition C vs Baseline	-24.2%	-10.8%	-38.3%	+0.8%

UDDS Results Discussion

Condition A, B, and C test data were only evaluated against baseline data collected on the same test day. Condition A was evaluated against baseline data collected 11/3/2020 while conditions B and C were evaluated against baseline data collected 11/4/2020.

Champ II Spin-On Air Separation System (Condition A)

The use of the Champ II Spin-On Air Separation System resulted in minor reductions in THC emissions, CO emissions, and NOx emissions during the UDDS tests completed as compared to the same day baseline results. Measured fuel economy slightly improved as compared to the same day baseline results. Both the emissions and fuel economy results fall within expected test-to-test variance.

AirDog Heavy Duty Diesel Fuel System (Condition B)

The use of the AirDog Heavy Duty Diesel Fuel System produced similar results for THC emissions, CO emissions, and NOx emissions during the UDDS tests completed as compared to the same day baseline results. Measured fuel economy improved as compared to the same day baseline results. The emissions results fall within expected test-to-test variance. The fuel economy improvement was measureable and exceed the expected test-to-test variance.

Champ II Spin-On Air Separation and AirDog Heavy Duty Diesel Fuel System (Condition C)

The use of both the AirDog Heavy Duty Diesel Fuel System and the Champ II Spin-On Air Separation System resulted in minor reductions in THC emissions, CO emissions, and NOx emissions during the UDDS tests completed as compared to the same day baseline results. Measured fuel economy slightly improved as compared to the same day baseline results. Both the emissions and fuel economy results fall within expected test-to-test variance.

Removal of Baseline tests #6, 7, and 8 from 11/4/2020 Data Set

At the request of the customer, the performance changes under conditions B and C were recalculated without including Baseline Tests #6, 7, and 8. Due to time constraints there were only three rather than the planned five baseline tests conducted in this set. The recalculated results indicate a slight reduction in all three measured emissions pollutants. The AirDog Heavy Duty Diesel Fuel System fuel economy improvement was still measureable and exceed the expected test-to-test variance.

	THC	CO	NOx	FE
Condition B vs Baseline #1-5	-16.6%	-33.5%	-2.1%	5.1%
Condition C vs Baseline #1-5	-33.4%	-25.7%	-52.4%	1.7%

Summary

The Ohio State University Center for Automotive Research observed a measureable increase in vehicle fuel economy during testing of the customer's AirDog Heavy Duty Diesel Fuel System over the UDDS test cycle.

The duration of the test program was short by design and did not include extensive mileage accumulation or extended operation. No observations on the possible effects of extended product use can be drawn from this data set.

Appendix A – Test Results

11/3/2020 Test Data

	Time Start	Total Distance miles	Calc THC g	Calc THC g/mile	Calc CO g	Calc CO g/mile	Calc CO2 g	Calc CO2 g/mile	Calc NOx g	Calc NOx g/mile	mpg
Baseline #1	9:21:25 AM	5.51	0.17	0.031	0.223	0.040	11,645	2112.7	3.678	0.6672	4.8161
Baseline #2	9:46:53 AM	5.55	0.20	0.036	0.508	0.092	11,436	2062.4	8.174	1.4742	4.9333
Baseline #3	10:05:10 AM	5.53	0.18	0.032	0.135	0.024	11,033	1994.3	6.465	1.1686	5.1022
Baseline #4	10:23:26 AM	5.51	0.18	0.032	0.137	0.025	10,779	1957.1	6.000	1.0895	5.1991
Baseline #5	10:41:40 AM	5.52	0.18	0.033	0.089	0.016	10,822	1961.1	5.704	1.0337	5.1884
Condition A #1	12:44:49 PM	5.5	0.15	0.028	0.095	0.017	10,372	1884.6	0.322	0.0585	5.3991
Condition A #2	1:02:58 PM	5.5	0.16	0.029	0.092	0.017	10,756	1956.4	3.648	0.6634	5.2011
Condition A #3	1:21:12 PM	5.5	0.16	0.029	0.161	0.029	10,966	1985.3	4.736	0.8573	5.1253
Condition A #4	1:39:31 PM	5.6	0.16	0.029	0.141	0.025	10,972	1976.8	4.689	0.8448	5.1472
Condition A #5	1:57:55 PM	5.5	0.17	0.030	0.182	0.033	10,877	1961.2	4.801	0.8657	5.1881
Baseline #6	2:42:52 PM	5.5	0.16	0.029	0.079	0.014	10,996	1996.4	1.863	0.3382	5.0967
Baseline #7	3:01:37 PM	5.5	0.17	0.031	0.141	0.025	10,820	1955.3	4.829	0.8727	5.2039
Baseline #8	3:20:16 PM	5.5	0.17	0.030	0.121	0.022	10,921	1974.1	5.003	0.9044	5.1542
Baseline #9	3:39:15 PM	5.5	0.18	0.032	0.168	0.030	10,932	1979.6	5.740	1.0394	5.1399

11/4/2020 Test Data

	Time Start	Total Distance miles	Calc THC g	Calc THC g/mile	Calc CO g	Calc CO g/mile	Calc CO2 g	Calc CO2 g/mile	Calc NOx g	Calc NOx g/mile	mpg
Baseline #1	8:11:45 AM	5.6	0.20	0.035	0.125	0.022	11,609	2089.0	1.723	0.3100	4.8708
Baseline #2	8:29:51 AM	5.6	0.19	0.034	0.150	0.027	11,559	2078.3	5.374	0.9663	4.8959
Baseline #3	8:47:56 AM	5.6	0.20	0.036	0.176	0.032	11,260	2024.7	9.165	1.6479	5.0254
Baseline #4	9:06:01 AM	5.6	0.29	0.052	0.182	0.033	10,559	1892.0	26.866	4.8139	5.3777
Baseline #5	9:24:11 AM	5.6	0.31	0.055	0.170	0.031	10,343	1852.2	26.348	4.7182	5.4933
Condition B #1	10:16:33 AM	5.5	0.20	0.037	0.171	0.031	10,647	1929.8	2.692	0.4879	5.2725
Condition B #2	10:34:43 AM	5.6	0.21	0.037	0.083	0.015	10,394	1863.0	19.815	3.5514	5.4617
Condition B #3	10:52:48 AM	5.6	0.22	0.039	0.105	0.019	10,227	1838.6	20.344	3.6574	5.5340
Condition B #4	11:10:55 AM	5.6	0.22	0.039	0.091	0.016	10,465	1876.5	20.475	3.6714	5.4224
Condition B #5	11:28:58 AM	5.6	0.15	0.026	0.082	0.015	10,735	1925.7	4.638	0.8320	5.2838
Baseline #6	1:02:45 PM	5.5	0.18	0.033	0.142	0.026	10,172	1834.5	0.243	0.0438	5.5465
Baseline #7	1:21:27 PM	5.5	0.13	0.024	0.078	0.014	10,649	1919.4	2.206	0.3977	5.3012
Baseline #8	1:39:38 PM	5.6	0.14	0.025	0.055	0.010	10,790	1936.4	3.325	0.5966	5.2548
Condition C #1	2:35:40 PM	5.5	0.15	0.028	0.118	0.021	10,452	1885.6	0.174	0.0313	5.3962
Condition C #2	2:53:46 PM	5.5	0.14	0.025	0.050	0.009	11,021	1993.7	3.020	0.5463	5.1037
Condition C #3	3:11:46 PM	5.6	0.14	0.025	0.232	0.042	11,192	2006.0	3.452	0.6187	5.0724
Condition C #4	3:29:47 PM	5.6	0.14	0.026	0.111	0.020	11,126	1991.8	3.600	0.6444	5.1085
Condition C #5	3:47:57 PM	5.6	0.22	0.039	0.085	0.015	10,492	1881.6	22.803	4.0893	5.4078