ADVANCED POWER SYSTEMS INTERNATIONAL INC.
558 Lime Rock Road
Lakeville, CT 06039
tel 860-435-2525 fax 860-435-2424
Website – www.fitchfuelcatalyst.com

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Technical Bulletin – Effects of Fitch Fuel Catalyst Heavy - Duty Diesel Engine Combustion Test

Topic: Engine Tested DDC Series 60

APSI commissioned fuel economy and emission tests on an in use heavy-duty diesel fueled vehicle. The purpose of the test was to quantify the emissions and fuel economy benefit of employing the Fitch Fuel Catalyst on the equipment.

This test was conducted by Ocean Air Environmental LLC of Somis, California, a test company unrelated to APSI, the manufacturer of the fuel, or the manufacturer of the engine. The Dynamometer employed was a Superflow chassis dynamometer located at Holt Equipment Center in Sacramento. The vehicle was an in use vehicle owned by a Sacramento trucking company.

Test procedure: The vehicle was brought to the facility 11/1/2004 for Baseline data capture. A Fitch Model F 750 was fitted to the vehicle and 600 miles were accumulated. The vehicle was re tested using the procedure identical to the baseline procedure 11/24/2004.

The test procedure consisted of 5 (five) separate constant speed modes or steady-state load points. This makes for ease of data capture and reproducibility. Vehicle operation surveys conducted by EPA and others have shown that true steady-state operation rarely occurs in customer use. Fitch users are likely to experience fuel economy improvement greater than that reflected in this evaluation when engines are operated in a transient mode or a blend of transient and steady-state modes.

In addition to the 5 (five) separate steady state modes a single Max HP mode test was also conducted at Baseline and Retrofit and the results are reported separately.

EMISSIONS AND FUEL ECONOMY TEST
FINAL REPORT
DDC Series 60

FITCH FUEL CATALYST

Prepared by : **OceanAir Environmental, LLC**
4220 Donlon Road
Somis, CA 93066
(805) 386-1882
Fax (805)504-1618, E-Mail Mahesh@oceanairllc.com

Background: Ocean Air Environmental LLC (OAE) was retained to evaluate the impact of the Fitch Fuel Catalyst on an in service vehicle operated on transportation diesel fuel purchased in the State of California at the time of the evaluation, November 2004.

Advanced Power Systems International, Inc. (APSI) the manufacturer of the product describes the product in product literature as follows:

"The Fitch Fuel Catalyst is a polymetalic alloy housed in a canister and connected into an engines fuel system between the fuel tank and the engine after the fuel filter and before the fuel pump. Its purpose is to reformulate fuel on board the vehicle prior to combustion. It performs its function at the temperatures experienced by vehicles in normal service.

The Fitch Fuel Catalyst is not a fuel additive. It is a special alloy that does not dissolve in fuel. The fuel is reformulated by the alloy catalyst to a state where it is capable of a more complete combustion. As a result, an engine converts the chemical energy in the fuel to mechanical energy in a more efficient manner. The engine power is increased as a result and the toxic exhaust emissions are decreased."

Units used for the test were supplied by APSI.

Purpose of the Program: To evaluate the effect of Fitch Fuel Catalyst on emission of NOx, CO, HC, PM, Smoke Opacity and fuel economy.

Test Set Up: A haul truck operated by Lindeman Brothers in Sacramento, CA was used for evaluation. The truck was baseline tested using the procedures outlined in Appendix A. The results are presented in Appendix B. After the baseline test, the truck was equipped with a Fitch Fuel Catalyst installed in the fuel supply line to the engine. The test was repeated after 600 miles of service. The operator did not perform any preventive maintenance between the Baseline and Retrofit tests.

Testing Location: Testing was done at Holt Equipment Company in Sacramento, California, using their Superflow chassis dyno.

Test Results Discussions: The testing was performed in a controlled environment where the same baseline operating parameter can be duplicated for post-Fitch vehicle evaluation. Fuel economy testing on the road can introduce many more variables, like road conditions, driver input, and traffic pattern. The results of testing are as follows:

Baseline Data

Five mode weighted results:

H.P. 208.6
Fuel Consumption: 10.8 gal/hr
Bsfc: 0.0518 gal/bhp-hr
NOx: 9.57 gms/bhp-hr
THC: 0.02 gms/bhp-hr
CO: 0.57 gms/bhp-hr
PM10: 0.12 mg/filter (based on 10 lit/min exhaust flow to PM collection system for five minutes on the filter at each mode)

Snap Idle Opacity: 7.3
Single point fuel economy (374 HP roll power) = 0.05 gal/bhp-hr

Retrofit - with Fitch Data

Five mode weighted results:

H.P. 207.6 (horsepower was maintained the same on purpose to be able to compare the two results)
Fuel Consumption: 10.18 gal/hr
Bsfc: 0.049 gal/bhp-hr
NOx: 9.47 gms/bhp-hr
THC: 0.02 gms/bhp-hr
CO: 0.89 gms/bhp-hr
PM10: 0.12 mg/filter (based on 10 lit/min exhaust flow to PM collection system for five minutes on the filter at each mode)

Snap Idle Opacity: 2.3
Single point fuel economy (423 roll power) = 0.049 gal/bhp-hr

Discussion of Results

Effect of Fitch Catalyst

PM emissions from the baseline vehicle and post-Fitch were negligible, which is typical of electronic engines from DDC and Cat. The PM filters looked white with almost no smoke when sampled. The filter weight was within the measurement error band therefore OceanAir decided not to do PM filter analysis in post-Fitch as the result would have been same, no PM collected. However, the snap opacity was reduced in post-Fitch test indicating transient smoke reduction. Five mode PM is more an indication of steady state smoke.

All emissions were reduced and fuel economy was improved as a result of the installation of the Fitch Fuel Catalyst unit on the test vehicle.

NOx + THC (ozone precursors) = 1.13% reduction
PM10 = 0% reduction
CO = 55.14% increase
Five mode weighted fuel economy = 5.8% improvement

Single point (max power) fuel economy = 1.44% improvement. Roll HP at the wheel increased from 374 HP to 423 HP, a 49 HP increase from baseline to retrofit in conjunction with this fuel economy improvement.

Snap Idle Opacity = 68.49% reduction

References:

Ocean Air Environmental LLC 805-386-1882 http://www.oceanairllc.com/
Test Location Holt Equipment Company Sacramento California
Chassis Dynamometer - Superflow SF-601602 http://www.superflow.com/
Engine DDC Series 60 http://www.detroitdiesel.com/Public/specs/3sa353.pdf

Appendix A

Heavy-Duty Diesel, Gasoline, and Alternative Fuel Vehicle Engines Emissions Testing

OceanAir Environmental
Tomorrow's Technologies Today

4220 Donlon Road
Somis, California 93066 USA
Ph (805) 386-1882
Fax (805) 504-1618
E-Mail mahesh@oceanairllc.com

Heavy-Duty Vehicle Emissions Testing Program

OceanAir Environmental has over ten years experience in emissions testing of heavy-duty diesel, gasoline, and alternative fuel vehicle engines.

Emissions Test Cycle Description

Engines used in heavy-duty vehicles are certified by the engine manufacturers using the EPA transient test procedures.

OceanAir's testing program is a cost effective method for measuring emissions and fuel economy without the time and expense of conducting the transient test cycle on a full chassis dyno. Prior to EPA's heavy-duty transient test procedures for engine certification, engines were certified using the 13-mode steady state test procedure below.

: EPA 13-Mode Test Cycle For Heavy-Duty Vehicles

Mode #	RPM	Load	Weighting Factor
1	**Idle**	**Idle**	**0.067**
2	**Intermediate**	**2%**	**0.08**
3	**Intermediate**	**25%**	**0.08**
4	**Intermediate**	**50%**	**0.08**
5	**Intermediate**	**75%**	**0.08**
6	**Intermediate**	**100%**	**0.08**
7	**Idle**	**Idle**	**0.067**
8	**Rated**	**100%**	**0.08**
9	**Rated**	**75%**	**0.08**
10	**Rated**	**50%**	**0.08**
11	**Rated**	**25%**	**0.08**
12	**Rated**	**2%**	**0.08**
13	**Idle**	**Idle**	**0.067**

The 13-mode test procedure is still widely used to certify heavy-duty engines. The Euro 2 standard (for Europe) requires certification on the 13- mode cycle.

OceanAir Environmental (OAE) used the 13-mode steady state test cycle as the basis for a shorter, more cost effective test, after determining the five mode test cycle compared favorably with the standard 13-mode test procedure. OAE's five mode test cycle is as follows:

OAE's Five Mode Test Cycle

Mode	RPM	Load	Weighting Factor
1	**Rated**	**100%**	**0.15**
2	**Rated**	**75%**	**0.25**
3	**Rated**	**50%**	**0.25**
4	**Rated**	**25%**	**0.2**
5	**Rated**	**Idle**	**0.15**

A comparison of OAE's five mode test cycle with the 13-mode test cycle has provided statistically insignificant deviation. OAE's five mode test procedure provides a reliable estimate of the effect of a technology change on in-use vehicle emissions and fuel economy. Moreover, the shorter test method is ideally suited to operator testing at or close to the operator's area of operation where cost and down time are at a premium. The calculation procedures employed here include the adjustment factors via data reduction software developed by OAE.

The smoke opacity measurements are taken using the snap acceleration test and a smoke opacity meter. The smoke measurements are taken by consecutive smoke reading during snap acceleration and the peak smoke recorded. When the difference between the two readings is less than 10%, that reading is recorded as the final smoke opacity number. The above procedure complies with California Sections 2190-2194, Title 13, California Code of Regulations, "Heavy-duty Diesel Powered Vehicle Periodic Smoke Inspection."

Emissions Test Instruments

The following instruments are used by OAE for emissions testing and performance verification:

Dynamometer: Superflow SF-601/602 water brake chassis dynamometer. The dyno is capable of measuring roll power (power applied/absorbed by the rear wheel). Testing of tandem axle rear wheel is possible with this dyno. The dyno sensors provide information on vehicle speed, fuel flow, and engine rpm. For the purpose of test, vehicle speed is generally kept at 50-60 mph with radiator fan continuously on for maximum horsepower absorption.

Fuel Meter: Available as part of chassis dynamometer. Fuel measurement is done using the gravimetric method where engine fuel tank is by passed and the engine fuel system is connected to a small fuel canister that is weighted continuously for the duration of the test.

Smoke Meter: An Bosch RTP 100 Infra red opacity meter is used for this purpose. The smoke meter complies with SAE J1243. Five snap idle opacity readings are taken, the first two are to clear the system, the last three readings are then averaged for the results. The smoke meter is calibrated at zero and 100% opacity.

Emissions Analyzer: Enerac 3000E emissions analyzer was employed for these tests. The emissions analyzer is capable of measuring NO, NO_2, NOx (calculated), CO, SOx, oxygen, exhaust temperature, percent combustibles, excess air (calculated), and CO_2 (calculated). The sample conditioning system includes a permeation drier (silica gel) which is capable of drying samples up to 20% moisture content to a 50 deg F dew point level. The dry exhaust gas is then introduced to electrochemical sensors to measure concentration. NO and NO_2 are each measured independently without the use of an NO_2 to NO converter. The standard emissions measurement equipment at engine manufacturer's test cells are based on chemi-luminescent analyzers which measure only NO; the NO_2 in exhaust gases is converted to NO in the converter and is read as NO. The sample rate in the Enerac 3000 is approximately 800 cc/min. A filter housing at the probe tip filters out particulate matter. The Enerac 3000 is an approved analyzer under EPA Conditional Test Method CTM - 022. OAE follows the same calibration and span check procedures as specified in the CTM.

HC Analyzer: HC measurements are taken via bag samples. The sampling procedure is in accordance with EPA Method 18. The exhaust sample is drawn via an evacuated canister through a stainless steel/teflon probe into a Tedlar bag.

The samples are stored out of sunlight, packaged, and sent to an analytical laboratory for analysis of C_1 to C_6 + species by gas chromatograph. Lab analysis is done according to EPA Method 25C

PM Analyzer: Total particulate matter sampling is done by the filter weighing method. A pre-weighed dry filter is inserted into the holder close to the exhaust stack to collect the particulate sample. Exhaust gases are sent to the filter through a vacuum pump connected to a gas flow meter. The sampled filter is then baked in the oven at 105 deg C to exclude the moisture from the analysis. USEPA approved factors are applied to the analyzed total particulate matter to derive PM10 fraction or PM2.5 fractions.

Horsepower: Roll power (power at wheel) is measured through the chassis dynamometer. The maximum roll power is then compared with the engine rated horsepower to derive losses between the engine output and power at wheels.

Engine RPM: Chassis dynamometer speed sensor is used for the RPM measurement.

Ambient Temperature, Pressure, and Humidity: A hand-held digital meter is used for this purpose.

Instrument Calibration

Emissions Analyzer: Enerac 3000 is calibrated prior to the in-field test assignment using the procedures outlined in the CTM-022. For diesel engine testing, the NOx sensor is calibrated at 1,011 ppmv and 200 ppmv using calibration gas. Mid range PCM sensor is utilized for NO (1000-3500 ppm). NO_2 sensor can read up to 500 ppmv. NO_2 calibration is done at 200 ppmv calibration gas. SO_2 sensor is set at low-range (500 ppm-2000 ppm). CO sensor is set at low range (500 ppm-2000 ppm). CO sensor is calibrated at 500 ppm. SO_2 sensor is calibrated at 200 ppm. The analyzer is auto zeroed prior to each test. After the completion of in-field testing, the analyzer is checked for drift by introducing the calibration gases and comparing the Enerac readings. The sensors are calibrated in accordance with the procedures specified in the CTM.

Smoke Meter: Opacity meter is calibrated at 100%, 0%, and mid range opacity.

Dynamometer: Dynamometer is calibrated by the dealership in accordance with their calibration schedule.

Test Procedures (Emissions Test)

Baseline Test

- Calibrate the emissions test instruments
- Secure the vehicle to a chassis dynamometer, hook up fuel flow meter (supply and return), engine RPM sensor.
- Hook up emissions test instruments
- Allow the vehicle to warm up as determined by the engine coolant temperature and oil temperature
- For Mode 1 of the test, run the engine at wide open throttle, keep the vehicle speed to around 50 mph in lower gear, set the RPM to rated engine RPM, determine the maximum stable roll power. Record the emission, fuel consumption, RPM, roll power, and vehicle speed
- For Mode 2, keep all of the parameters same as above, except the roll power is now reduced to 75%
- For Mode 3, the roll power is reduced to 50%
- For Mode 4, the roll power is reduced to 25%
- For Mode 5, the roll is locked, readings are taken at idle
- Record snap idle opacity

Controlled Test

- Same procedures as above except the test is now done with the control or retrofit technology installed.

Test Results Calculations

The exhaust gas flow rate is calculated based on EPA Method 19 calculation which defines the procedure for calculating stoichiometric exhaust gas flow rate (0% oxygen in the exhaust) based on fuel flow rate. The stoichiometric flow rate calculated from Method 19 is then increased based on oxygen concentration measured in the exhaust (excess air) to provide actual SCFH of exhaust flow rate. The pollutant concentration is then multiplied by this calculated exhaust gas flow rate to come up with mass flow rate (lbs/hr) of pollutants in the exhaust. This calculation is repeated for each mode. A mode weighted horsepower is then calculated. The sum of total mass flow rate of pollutants for the five modes is then divided by the weighted horsepower to derive total weighted gms/bhp-hr. Similarly lbs of pollutants/1,000 gallons of fuel burned is calculated by dividing total pollutant mass by the weighted average fuel flow.

The NOx results are adjusted for humidity according to the following equation:

Humidity correction factor = $1/(1-0.0182(H-10.71))$

Where H = Absolute humidity of engine intake air in grams of water per kg of dry air.

Single Point / Max Power Fuel Economy Test Procedures

The max power fuel economy test is done at 400-500 rpm below the engines maximum rpm, at maximum achievable engine power. This is to simulate engine operation at or near peak torque condition. The five mode test provides mode weighted fuel economy that is indicative of actual road conditions. The maximum torque fuel economy is listed as single point fuel economy on the output table.

ENGINE EXHAUST EMISSIONS TEST

On-Road Five Mode Test Cycle

Purpose of Test:	Evaluate Fitch Fuel Catalyst				
Test Date: 11/1/2004	Test Number:	1	Engine Tech:	Bob	
Fuel Type: D2	Test Cycle: On Road Five Mode		Emissions Tech	MT	
Engine Type:	DDC		Project Leader:	MT	
Aspiration: Turbo	Owner	Lindeman Brothers	Test Location	Holt,	Sacramento, CA
Engine Rating:	H.P.	400 @ RPM	2,100		
Comments:					
File Name	ddcfitch.xls				

A. ENGINE PERFORMANCE DATA

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Roll Power	324	240	161	80	0
Engine Power (bhp)	374	290	211	130	8
Engine power (kw)	279	216	157	97	6
Fuel Flow (kg/hr)	60.22	46.52	35.37	23.90	0.96
Intake Air (dry kg/hr)	1894	1581	1325	1067	102
Exhaust flow (dry kg/hr)	1954	1627	1361	1091	103
Engine RPM	2123	2136	2162	2184	600
Engine RPM % of Rated	1.01	1.02	1.03	1.04	0.29
Engine Load % of Rated	0.94	0.73	0.53	0.33	0.02
Fuel Flow (gal/hr)	18.90	14.60	11.10	7.50	0.30
B. GASEOUS EMISSIONS					
THC	4.2	5	10	5.2	7.6
NOx (dry ppmv)	1083	1160	858	597	266
CO (dry ppmv)	81	119	87	81	14
O2 (%)	12.6	13.2	13.9	15	18.4
PM10 mg/filter	0.100	0.100	0.100	0.200	0.100
C. EXHAUST EMISSIONS ANALYSIS					
Mode Weighting Factors	0.15	0.25	0.25	0.2	0.15
Weighted Specific THC (gms/kw-hr)	0.00	0.01	0.01	0.00	0.00
Weighted Specific NOx (gms/kw-hr)	3.35	4.98	3.08	1.38	0.04
Weighted Specific PM10, mg/filter	0.015	0.025	0.025	0.040	0.015
Weighted Specific CO (gms/kw-hr)	0.15	0.31	0.19	0.11	0.00

D. RESULTS

Total Mode Weighted NOx	**12.83 gms/kw-hr**	**9.57 gms/bhp-hr**
Total Mode Wieghted THC	**0.03 gms/kw-hr**	**0.02 gms/bhp-hr**
Total Mode Weighted PM10	**0.12 mg/filter for five minute sample @10lit/min**	
Total Mode Weighted CO	**0.77 gms/kw-hr**	**0.57 gms/bhp-hr**

Mode Weighted h.p.	**208.55**	**h.p.**
Mode wieghted fuel consumption	**10.805**	**gal/hr**
Mode wieghted bsfc	**0.05181**	**gal/bhp-hr**

Single Point Fuel Economy Test

Roll Power	374	
H.P.	424	
Fuel	21.1	gal/hr
bsfc	0.050	gal/bhp-hr

Snap Opacity Test (average of last three readings from Bosch partial flow meter) 7.3

ENGINE EXHAUST EMISSIONS TEST

On-Road Five Mode Test Cycle

Purpose of Test:	Evaluate Fitch Fuel Catalyst				
Test Date: 11/24/2004	Test Number:	2		Engine Tech:	Bob
Fuel Type: D2	Test Cycle: On Road Five Mode			Emissions Tech:	MT
Engine Type:	DDC Series 60			Project Leader:	MT
Aspiration: Turbo	Owner	Lindeman Brothers		Test Location	Holt, Sacramento, CA
Engine Rating:	H.P.	400 @ RPM		2,100	
Comments:					
File Name	ddcfitch.xls Fitch installed				

A. ENGINE PERFORMANCE DATA

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Roll Power	315	238	163	82	0
Engine Power (bhp)	365	288	213	132	8
Engine power (kw)	272	215	159	98	6
Fuel Flow (kg/hr)	55.12	43.97	33.78	22.94	0.96
Intake Air (dry kg/hr)	1594	1436	1266	1061	150
Exhaust flow (dry kg/hr)	1649	1480	1299	1084	151
Engine RPM	2118	2139	2167	2187	600
Engine RPM % of Rated	1.01	1.02	1.03	1.04	0.29
Engine Load % of Rated	0.91	0.72	0.53	0.33	0.02
Fuel Flow (gal/hr)	17.30	13.80	10.60	7.20	0.30
B. GASEOUS EMISSIONS					
THC	10	5.7	7.4	5.1	4.8
NOx (dry ppmv)	1500	1119	837	614	260
CO (dry ppmv)	167	190	155	103	19
O2 (%)	11.9	12.9	13.9	15.2	19.2
PM10 mg/filter	0.1	0.1	0.1	0.2	0.1
C. EXHAUST EMISSIONS ANALYSIS					
Mode Weighting Factors	0.15	0.25	0.25	0.2	0.15
Weighted Specific THC (gms/kw-hr)	0.01	0.01	0.01	0.00	0.00
Weighted Specific NOx (gms/kw-hr)	3.94	4.39	2.88	1.41	0.06
Weighted Specific PM10 mg/filter	0.015	0.025	0.025	0.040	0.015
Weighted Specific CO (gms/kw-hr)	0.27	0.45	0.33	0.14	0.00

D. RESULTS

Total Mode Weighted NOx	**12.69 gms/kw-hr**	**9.47 gms/bhp-hr**
Total Mode Wieghted THC	**0.03 gms/kw-hr**	**0.02 gms/bhp-hr**
Total Mode Weighted PM10	**0.12 mg/filter for five minute sample @10lit/min**	
Total Mode Weighted CO	**1.19 gms/kw-hr**	**0.89 gms/bhp-hr**

Mode Weighted h.p. **207.6 h.p.**
Mode wieghted fuel consumption **10.18 gal/hr**
Mode weighted bsfc **0.049037 gal/bhp-hr**

Single Point Fuel Economy Test

Roll Power	423
H.P.	473
Fuel	23.2 gal/hr
bsfc	0.049 gal/bhp-hr

Snap Opacity Test (average of last three readings from Bosch partial flow meter) 2.3

Discussion of Results

NOx+THC Reduction	1.1%
PM10 Reduction	0.0%
CO Reduction	-55.1%
Five Mode Fuel Consumption Reduction	5.8%
Single Point Fuel Consumption Reduction	1.4%
Opacity Reduction	68.5%