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New Technology Research & Development Program
Grant Contract 582-5-65591-0007

Task 6 Deliverable Report

The preparation of this report is based on work funded in part
by the State of Texas through a Grant from the
Texas Commission on Environmental Quality.

In-House Emission Testing

Task # 6

Prepared for the
Texas Commission on Environmental Quality
NTRD Contract No. 582-5-65591-0007
Converter Technology Inc.

February 28, 2007
Revision 0

July 2007
Revision 1

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Executive Summary

CTI performed two major rounds of testing, one on EGR mapping and the ensuing impact on emission reductions and the other round of testing was performed on incinerator particulate converter with incineration option on-the-road. CTI will furnish a supplement to this report representing data collected on-the-road using the “Smart 2000” mobile data acquisition and control system.

The first section of this report identifies the effect of EGR system on emission increases and reductions for the selected EGR injection strategy. These data are tabulated for the 8 AVL steady-state modes plus 4 selected intermediate points. The total of 12 mapping points for the CAT 3406 engine are outlined on a separate diagram identifying each mode in terms of engine RPM and load as well as the definition of each mode as a percentage of maximum RPM and maximum engine load. The emission increases along with the associated 0_2 content, engine operating modes, fuel consumptions, and fuel penalties are all tabulated in a summary report for each mode.

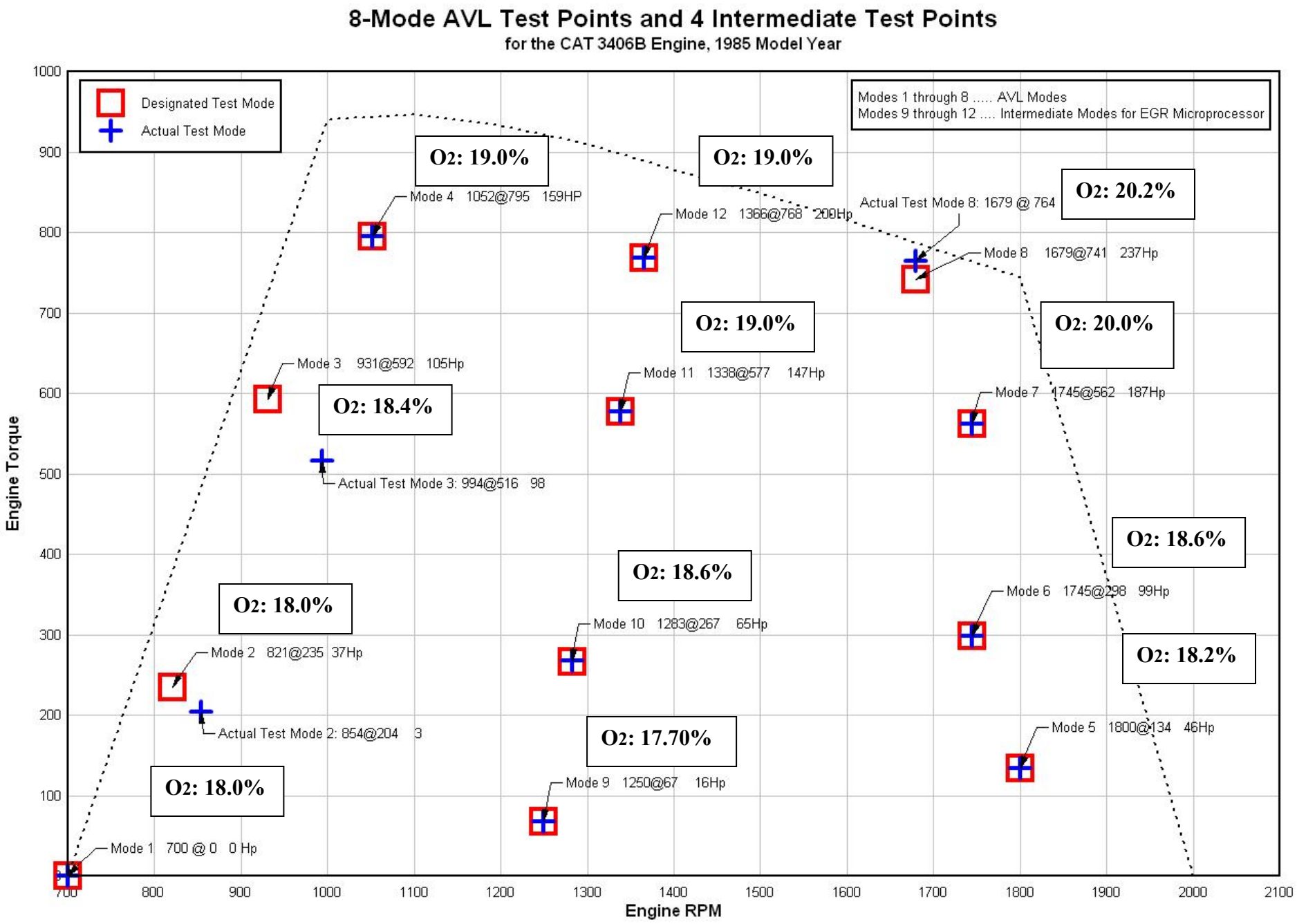
The second section of the report shows selected test data on the incineration converter including back pressure durability data. The back pressure on the 3-candle converter has been upgraded to lower the back pressure and it should be reduced about 35% from the data shown. The particulate reduction should correlate directly with the smoke opacity meter reading. The smoke opacity meter raw exhaust measurements are conditioned and controlled to a lower and fixed temperature for smoke measurement and, as such, the smoke readings can be correlated to particulate mass measurements.

Attached to this report is a video highlighting the incineration converter capabilities in handling high level particulate emissions during a real life on the road testing. The video highlights the converter capabilities in dealing with high particulate emissions, typically associated with old diesel engines, or new diesel engines employing aggressive EGR injection strategy

Definition of Steady State AVL and Blending Testing Modes

For EGR Mapping and EGR Control Logic

Testing Mode		Normalized Mode Data	
		% Engine RPM	% Load
AVL 8 Mode Data	1	0	0
	2	11	25
	3	21	63
	4	32	84
	5	100	18
	6	95	40
	7	95	69
	8	89	95
Blend Points for Smoothing Between the AVL 8 Mode	9	25	25
	10	50	25
	11	75	25
	12	25	50



Target O2 content in exhaust/air mixture- engine air intake.

In House Emission Testing Data and Mapping for the Effect of EGR Injection

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 23-Jun-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

Sheet 1 Log

EGR Mapping Mode #	1	Engine RPM	700	Engine Torque	0	ft. lb	Engine HP	0

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	-	-	700	-	0	0	-0.69	480	0.69	0	0	-	20.94	0	0	1	18.88	217	180	186	1	254	-	-	87.5	-	2.2	1	-	-	0.2	-	0	0.33
2	19.0%	-	-	700	-	0	0	-0.58	480	0.58	1265	1.625	-	19.01	252	200	45	17.11	491	420	90	2	255	-	-	154	-	3.2	2	-	-	0.2	-	1.25	0.44
3	18.8%	-	-	700	-	0	0	-0.58	480	0.58	1340	1.7	-	18.8	280	310	48	16.92	513	450	84	3	256	-	-	159	-	3.4	3	-	-	0.2	-	1.35	0.25
4	18.6%	-	-	700	-	0	0	-0.61	480	0.61	1365	-	-	18.6	324	380	29	16.68	574	500	60	4	262	-	-	165	-	0.48,3.4	0.54,4.0	-	-	0.16	-	1.5	0.42
5	18.4%	-	-	700	-	0	0	-0.6	480	0.6	1405	-	-	18.4	346	390	29	16.44	608	510	57	4	266	-	-	166	-	0.48,3.4	0.54,4.0	-	-	0.14	-	1.55	0.16
6	18.2%	-	-	700	-	0	0	-0.6	480	0.6	1440	-	-	18.2	368	420	27	16.25	619	540	51	4	268	-	-	169	-	0.49,3.6	0.54,4.0	-	-	0.12	-	1.6	-
7	18.0%	-	-	700	-	0	0	-0.6	480	0.6	1475	-	-	18	390	440	24	16.05	670	570	43	4	268	-	-	169.5	-	0.48,3.6	0.54,4.0	-	-	0.1	-	1.75	0.27

Engine: Caterpillar 3406 B engine, 1985 **Date: 27 June**

Evaluation by: Liz Kammel

EGR Mapping Mode #	1	Engine RPM	700	Engine Torque	0	ft.lb	Engine HP

Sheet 2 Calc

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption		EMISSION DATA														Temperature	Exhaust Mass Flow		Pa S
								Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	
1	21% (no EGR)	-	-	700	0	0.69	-	20.94	0	0	1	18.88	217	180	186	-	0.00%	0.00%	0.00%	0.54%	0.00%	254	2.60	0.00	
2	19.0%	-	-	700	0	0.58	-15.94%	19.01	252	200	45	17.11	491	420	90	51.61%	50.39%	51.32%	47.62%	50.00%	58.16%	255	2.60	3.61	
3	18.8%	-	-	700	0	0.58	-15.94%	18.8	280	310	48	16.92	513	450	84	54.84%	53.23%	54.58%	68.89%	57.14%	59.09%	256	2.60	3.75	
4	18.6%	-	-	700	0	0.61	-11.59%	18.6	324	380	29	16.68	574	500	60	67.74%	54.93%	56.45%	76.00%	48.33%	62.99%	262	2.32	3.96	
5	18.4%	-	-	700	0	0.6	-13.04%	18.4	346	390	29	16.44	608	510	57	69.35%	56.44%	56.91%	76.47%	50.88%	64.91%	266	2.17	4.02	
6	18.2%	-	-	700	0	0.6	-13.04%	18.2	368	420	27	16.25	619	540	51	72.58%	58.42%	59.45%	77.78%	52.94%	67.00%	268	2.01	4.09	
7	18.0%	-	-	700	0	0.6	-13.04%	18	390	440	24	16.05	670	570	43	76.88%	60.12%	58.21%	77.19%	55.81%	69.93%	268	1.84	4.27	
		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Test Runs Highlighted with Yellow Color Indicates Selected Strategy for 60-70% NOx Reduction

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	1	Engine RPM	70	Engine Torque	0 ft.lb	Engine HP	0

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow		EGR Mass Flow		NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	2.60	70,714	0.00	0	186	13.15	-	-	217	15.35	-	-	180	12.73	-	-	0.33	-	-
2	18.0%	1.84	50,003	4.27	116,289	43	2.15	-	-	**670**	33.50	-	-	570	28.50	-	-	**0**	**-18.18%**	-
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 27-Jun-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode #	2	Engine RPM	854	Engine Torque	204	ft. lb	Engine HP	32

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	289	594	854	-	32	0	-2.34	480	2.34	0	-	-	20.94	0	0	0	15.04	290	310	361	22	381	-	-	74	-	4.2, 6.3 V	22, 1.24 V	-	-	1.60	-	0.00	0.11
2	19.0%	290	614	854	-	32	0	-2.38	480	2.38	780	-	-	18.99	154	180	40	12.75	646	490	155	20	404	-	-	160	-	5.2,0.67	20,1.17	-	-	1.00	-	0.09	-
3	18.8%	-	-	854	-	32	0	-2.38	480	2.38	812	-	-	18.80	178	240	38	12.58	692	540	137	20	400	-	-	162	-	5.2,0.67	20,1.15	-	1.29	1.00	0.49	0.10	0.06
4	18.6%	289	597	854	-	32	0	-2.38	480	2.38	844	-	-	18.6	205	310	35	12.23	752	600	128	20	407	-	-	167	-	5.3,0.68	18,1.07	-	1.29	1.00	0.49	0.10	-
5	18.4%	295	592	857	-	32	0	-2.39	480	2.39	852	-	-	18.4	245	350	33	12.09	814	630	123	19	407	-	-	173	-	5.3,0.68	19,1.12	-	1.24	1.00	0.48	0.45	0.53
6	18.2%	291	563	861	-	32	0	-2.39	480	2.39	885	-	-	18.2	273	410	30	11.9	885	680	99	18	400	-	-	176	-	5.3,0.68	18,1.07	-	1.28	1.00	0.53	0.20	-
7	18.0%	291	565	870	-	32	0	-2.4	480	2.4	898	-	-	18	294	430	30	11.55	1009	690	88	17.5	401	-	-	185	-	5.5,0.69	17.5,1.06	-	1.22	1.00	0.55	0.35	0.29
	Fine Tune Tests																																		
8	17.7%	-	-	-	-	-	40.73	38.42	480	2.31	-	-	-	17.7	-	500	35	12.43	-	1000	107	18	355	273	25	194	-	8.0/.67	18.0/1.05	-	0.684	1.00	0.60	1.25	0.69
9	17.4%	-	-	-	-	-	29.75	27.4	480	2.35	-	-	-	17.42	-	640	30	11.05	-	1290	92	11	384	294	273	221	-	7.0/.67	11.0/.93	-	0.71	2.00	0.61	1.35	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985 **Date: 27 June 2005**

Evaluation by: Liz Kammel

EGR Mapping Mode #	2	Engine RPM	854	Engine Torque	204	ft.lb	Engine HP	32

Sheet 2 Calc

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption		EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
								Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	289	594	854	32	2.34	1	20.94	0	0	0	15.04	290	310	361	-	0.00%	0.00%	0.00%	0.00%	0.00%	381	7.35	0.00	0.11
2	19.0%	290	614	854	32	2.38	1.71%	18.99	154	180	40	12.75	646	490	155	57.06%	23.81%	23.84%	36.73%	25.81%	14.29%	404	5.81	0.97	-
3	18.8%	-	-	854	32	2.38	1.71%	18.80	178	240	38	12.58	692	540	137	62.05%	25.60%	25.72%	44.44%	27.74%	14.95%	400	5.81	1.02	0.06
4	18.6%	289	597	854	32	2.38	1.71%	18.6	205	310	35	12.23	752	600	128	64.54%	26.87%	27.26%	51.67%	27.34%	14.95%	407	5.81	1.02	-
5	18.4%	295	592	857	32	2.39	2.14%	18.4	245	350	33	12.09	814	630	123	65.93%	28.70%	30.10%	55.56%	26.83%	27.16%	407	5.81	2.17	0.53
6	18.2%	291	563	861	32	2.39	2.14%	18.2	273	410	30	11.9	885	680	99	72.58%	30.31%	30.85%	60.29%	30.30%	19.91%	400	5.81	1.44	-
7	18.0%	291	565	870	32	2.4	2.56%	18	294	430	30	11.55	1009	690	88	75.62%	31.31%	29.14%	62.32%	34.09%	24.75%	401	5.81	1.91	0.29
8	17.7%	-	-	-	-	2.31	-2.94%	17.7	-	500	35	12.43	-	1000	107	30.97%	38.07%	-	50.00%	32.71%	38.33%	355	5.81	3.61	0.69
9	17.4%	-	-	-	-	2.35	-1.26%	17.42	-	640	30	11.05	-	1290	92	40.65%	35.59%	-	49.61%	32.61%	31.35%	384	8.22	3.75	-
10	17.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	2	Engine RPM	854	Engine Torque	204 ft.lb	Engine HP	32

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow		EGR Mass Flow		NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	7.35	200,011	0.00	0	361	72.20	2.26	-	290	58.00	1.81	-	310	62.00	1.94	-	0.11	-	0.548
2	18.0%	5.81	158,122	1.91	52,006	88	13.91	0.43	**80.73%**	**1009**	159.55	4.99	**175.06%**	690	109.10	3.41	**75.97%**	**0.29**	**163.64%**	0.563
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 28-Jun-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode #	3	Engine RPM	994	Engine Torque	516	ft. lb	Engine HP	95

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	-	-	1000	-	95	4.9	1.28	300	3.62	-	-	-	21	0	0	0	9.7	694	660	591	76	664	466	415	94	-	12/0.84	11/0.592	-	0.425	3.8	0.25	0	0.11
2	19.0%	691	727	1000	-	95	11.9	8.13	300	3.77	-	-	-	19	294	310	32	6.46	2561	860	239	74	715	526	490	251	-	13/0.88	74/2.94	-	0.414	3.0	0.409	-	-
3	18.8%	685	729	1000	-	95	11.12	7.32	300	3.8	-	-	-	18.82	489	480	40	5.53	3553	930	232	79	744	546	508	264	-	13/0.90	79/3.20	-	0.4	3.0	0.42	-	0.62
4	18.6%	686	730	1000	-	95	11.74	7.73	300	4.01	-	-	-	18.61	773	530	37	4.6	4820	830	210	77	761	560	520	282	-	13/0.90	77/3.10	-	0.39	3.0	0.43	-	-
5	18.4%	689	726	1000	-	95	13.02	9.15	300	3.87	-	-	-	18.4	1001	690	36	4.39	4851	660	185	76	786	575	532	284	-	13/0.77	76/2.65	-	-	3.0	-	-	1.02
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fine Tune Tests																																		
8		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 28 June 2005

Evaluation by: Liz Kammel

Sheet 2 Calc

EGR Mapping Mode #	3	Engine RPM	994	Engine Torque	516	ft.lb	Engine HP	95

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	-	-	1000	95	3.62	5.792	-	21	0	0	0	10	694	660	591	-	0.00%	0.00%	0.00%	0.00%	0.00%	664	11.33	0.00	0.11
2	19.0%	691	727	1000	95	3.77	6.032	4.14%	19	294	310	32	6	2561	860	239	59.56%	13.40%	11.48%	36.05%	13.39%	-	715	10.06	-	-
3	18.8%	685	729	1000	95	3.8	6.08	4.97%	19	489	480	40	6	3553	930	232	60.74%	13.76%	13.76%	51.61%	17.24%	-	744	10.06	-	0.62
4	18.6%	686	730	1000	95	4.01	6.416	10.77%	19	773	530	37	5	4820	830	210	64.47%	14.26%	16.04%	63.86%	17.62%	-	761	10.06	-	-
5	18.4%	689	726	1000	95	3.87	6.192	6.91%	18	1001	690	36	4	4851	660	185	68.70%	15.35%	20.63%	104.55%	19.46%	-	786	10.06	-	1.02
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	3	Engine RPM	994	Engine Torque	518 ft.lb	Engine HP	95

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	11.33	308,237	0	0	591	182.17	1.92	-	694	213.92	2.25	-	660	203.44	2.14	-	0.11	-	0.457
2	18.4%	10.06	273,876	-	-	185	50.67	0.53	**72.19%**	**4851**	1328.57	13.98	**521.07%**	660	180.76	1.90	**-11.15%**	**1.02**	**827.27%**	0.489
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 7-Jul-05

Tests Conduted by: James Borgelt, Coordniator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno. OP; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode # 4(a) **Engine RPM** 1052 **Engine Torque** 795 **ft. lb** **Engine HP** 159

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	730	1154	1075	6	160	29.80	26.37	180	3.43	-	-	-	20.94	0	0	0	8.45	482	580	708	100	722	554	514	69	-	20/1.14	100/4.82	-	-	12.0	-	0	0.49
2	19.0%	734	1154	1065	6	160	33.01	29.42	180	3.59	-	-	-	18.99	364	290	38	4.36	2620	940	276	100	820	620	576	350	-	22/1.22	100/4.82	-	0.85	10.0	0.59	-	-
3	19.0%	736	1122	1058	6	155	35.10	31.37	180	3.73	-	-	-	19.03	572	420	39	2.62	ceed lir	1150	291	100	901	698	642	403	-	22/1.21	100/4.82	-	-	10.0	-	-	1.15
4	18.6%	773	1131	1070	6	165	-5.16	-9.10	180	3.94	-	-	-	18.61	636	440	29	3.35	4874	1140	216	100	880	667	624	415	-	25/1.28	100/4.82	-	0.9	12.0	0.73	-	-
5	18.4%	748	1109	1110	6	158	33.34	29.5	180	3.84	-	-	-	18.79	300	310	33	2.97	ceed lir	2670	217	100	880	675	628	411	-	22/1.21	100/4.81	-	0.88	10.0	0.68	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fine Tune Tests																																		
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9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 7 July 2005

Evaluation by: Liz Kammel

Sheet 2 Calc

EGR Mapping Mode #	4(a)	Engine RPM	1052	Engine Torque	795 ft.lb	Engine HP	159

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	730	1154	1075	160	3.43	9.15	-	20.94	0	0	0	8.45	482	580	708	-	0.00%	0.00%	0.00%	0.00%	0.00%	722	20.13	0.00	0.49
2	19.0%	734	1154	1065	160	3.59	9.57	4.66%	18.99	364	290	38	4.36	2620	940	276	61.02%	11.76%	13.89%	30.85%	13.77%	-	820	18.37	-	-
3	19.0%	736	1122	1058	155	3.73	9.95	8.75%	19.03	572	420	39	2.62	excee d limit	1150	291	58.90%	10.43%	-	36.52%	13.40%	-	901	18.37	-	1.15
4	18.6%	773	1131	1070	165	3.94	10.51	14.87%	18.61	636	440	29	3.35	4874	1140	216	69.49%	13.25%	13.05%	38.60%	13.43%	-	880	20.13	-	-
5	18.8%	748	1109	1110	158	3.84	10.24	11.95%	18.79	300	310	33	2.97	excee d limit	2670	217	69.35%	11.96%	-	11.61%	15.21%	-	880	18.37	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	4(a)	Engine RPM	1052	Engine Torque	795 ft.lb	Engine HP	159

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	20.1	547,752	0	0	708	387.81	2.44	-	482	264.02	1.66	-	580	317.70	2.00	-	0.49	-	0.429
2	19.0%	18.4	500,027	-	-	276	138.01	0.87	**64.41%**	**2620**	1310.07	8.24	**396.21%**	940	470.03	2.96	**47.95%**	-	-	0.449
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 1-Jul-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode #	5(a)	Engine RPM	1800	Engine Torque	134 ft. lb	Engine HP	46

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	609	414	1800	4	46	7.16	4.35	300	2.81	-	-	-	20.94	0	0	0	16.35	245	130	231	60	390	327	304	85	-	21/1.13	60/2.48	-	1	17	0.221	0	531
2	19.0%	609	430	1800	4	46	5.40	2.26	300	3.14	-	-	-	18.99	171	210	36	13.03	663	520	132	52	447	371	343	281	-	23/1.22	50/2.27	-	0.8	10	1.34	-	532
3	18.8%	609	420	1800	4	46	8.20	5.07	300	3.13	-	-	-	18.80	199	210	35	12.72	754	540	123	48	451	374	345	285	-	23/1.22	48/2.09	-	0.8	9	1.46	-	533
4	18.6%	609	403	1800	4	46	3.45	0.82	300	2.63	-	-	-	18.59	238	250	33	12.31	887	600	113	42	461	382	352	293	-	23/1.22	42/1.95	-	0.8	8	1.6	-	534
5	18.4%	610	407	1800	4	46	6.77	3.65	300	3.12	-	-	-	18.40	202	280	31	11.93	1010	640	106	40	465	384	355	297	-	23/1.22	40/1.83	-	0.77	8	1.7	-	536
6	18.2%	609	403	1800	4	46	-1.10	-4.19	300	3.09	-	-	-	18.20	344	380	31	11.65	1204	730	89	34	470	388	357	301	-	23/1.22	34/1.61	-	0.76	8	1.87	-	537
7	18.0%	609	409	1800	4	46	-6.45	-9.62	300	3.17	-	-	-	17.99	405	390	31	11.23	1381	750	92	28	483	400	368	309	-	23/1.21	28/1.51	-	0.76	8	1.76	-	538
	Fine Tune Tests																																		
8		-	-	1800	-	46	13.55	10.6	300	2.95	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	20/1.12	40/1.91	-	-	-	-	-	-
9		-	-	1800	-	46	13.9	10.8	300	3.10	-	-	-	-	-	-	-	-	-	-	-	26	-	-	-	-	-	22/1.17	26/1.34	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

531-538 filter n

Engine: Caterpillar 3406 B engine, 1985

Date: 1 July 2005

Evaluation by: Liz Kammel

Sheet 2 Calc

EGR Mapping Mode #	5(a)	Engine RPM	1800	Engine Torque	134 ft.lb	Engine HP	46

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	20.9%	609	414	1800	46	2.81	4.50	-	20.94	0	0	0	16.35	245	130	231	-	0.00%	0.00%	0.00%	0.00%	0.00%	390	23.96	0.00	0
2	19.0%	609	430	1800	46	3.14	5.02	11.74%	18.99	171	210	36	13.03	663	520	132	42.86%	24.65%	25.79%	40.38%	27.27%	-	447	18.37	-	0
3	18.8%	609	420	1800	46	3.13	5.01	11.39%	18.80	199	210	35	12.72	754	540	123	46.75%	26.03%	26.39%	38.89%	28.46%	-	451	17.43	-	0
4	18.6%	609	403	1800	46	2.63	4.21	-6.41%	18.59	238	250	33	12.31	887	600	113	51.08%	27.23%	26.83%	41.67%	29.20%	-	461	16.43	-	0
5	18.4%	610	407	1800	46	3.12	4.99	11.03%	18.40	202	280	31	11.93	1010	640	106	54.11%	28.19%	20.00%	43.75%	29.25%	-	465	16.43	-	0
6	18.2%	609	403	1800	46	3.09	4.94	9.96%	18.20	344	380	31	11.65	1204	730	89	61.47%	29.49%	28.57%	52.05%	34.83%	-	470	16.43	-	0
7	18.0%	609	409	1800	46	3.17	5.07	12.81%	17.99	405	390	31	11.23	1381	750	92	60.17%	30.38%	29.33%	52.00%	33.70%	-	483	16.43	-	0
8		-	-	1800	46	2.95	4.72	4.98%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9		-	-	1800	46	3.10	4.96	10.32%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	5(a)	Engine RPM	1800	Engine Torque	795 ft.lb	Engine HP	159

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	23.96	651,955	0.00	0	231	150.60	0.95	-	245	159.73	1.00	-	130	84.75	0.53	-	0	-	0.733
2	18.2%	16.43	447,237	-	-	89	39.80	0.25	**73.57%**	**1204**	538.47	3.39	**237.12%**	730	326.48	2.05	**285.21%**	**0**	-	0.806
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 5-Jul-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode #	6	Engine RPM	1745	Engine Torque	298 ft. lb	Engine HP	99

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	590	901	1745	4	101	15	10.34	300	4.66	-	-	-	20.94	0	0	2	13.26	326	240	392	80	545	455	424	89	-	26/1.33	80/3.30	-	1.09	18.0	2.49	0.0	539, 0.51
2	19.0%	592	887	1745	4	99	-3.16	-7.93	300	4.77	-	-	-	19.00	229	340	39	9.51	1205	910	190	57	640	516	476	350	-	25/1.30	57/2.49	-	0.86	11.0	0.85	-	540
3	18.8%	591	919	1745	4	102	-1.31	-6.24	300	4.93	-	-	-	18.79	327	480	37	8.4	1655	980	187	52	661	531	491	361	-	25/1.30	52/2.30	-	0.86	11.0	0.85	-	541, 1.93
4	18.6%	591	919	1745	4	102	-2.3	-7.33	300	5.03	-	-	-	18.61	434	540	35	7.59	2179	1200	168	46	693	552	511	376	-	25/1.30	46/2.10	-	0.85	11.0	0.86	-	542
5	18.4%	591	913	1745	4	101	-9.1	-13.13	300	5.04	-	-	-	18.4	497	630	35	6.93	3013	1310	145	41	728	586	543	400	-	25/1.28	41/1.86	-	0.83	11.0	0.95	-	543. 1.47
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fine Tune Tests																																		
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Engine: Caterpillar 3406 B engine, 1985

Date: 5 July 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	6	Engine RPM	1745	Engine Torque	298	ft.lb	Engine HP	99

Sheet 2 Calc

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	590	901	1745	101	4.66	7.456	-	20.94	0	0	2	13.26	326	240	392	-	0.00%	0.00%	0.00%	0.51%	0.00%	545	24.65	0.00	0.51
2	19.0%	592	887	1745	99	4.77	7.632	2.36%	19.00	229	340	39	9.51	1205	910	190	51.53%	16.97%	19.00%	37.36%	20.53%	-	640	19.27	-	-
3	18.8%	591	919	1745	102	4.93	7.888	5.79%	18.79	327	480	37	8.40	1655	980	187	52.30%	17.15%	19.76%	48.98%	19.79%	-	661	19.27	-	1.93
4	18.6%	591	919	1745	102	5.03	8.048	7.94%	18.61	434	540	35	7.59	2179	1200	168	57.14%	17.45%	19.92%	45.00%	20.83%	-	693	19.27	-	-
5	18.4%	591	913	1745	101	5.04	8.064	8.15%	18.40	497	630	35	6.93	3013	1310	145	63.01%	18.13%	16.50%	48.09%	24.14%	-	728	19.27	-	1.47
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	6	Engine RPM	1745	Engine Torque	298 ft.lb	Engine HP	99

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	24.65	670,856	0	0	392	262.98	2.66	-	326	218.70	2.21	-	240	161.01	1.63	-	0.51	-	0.554
2	18.6%	19.27	524,432	-	-	168	88.10	0.89	**66.50%**	**2179**	1142.74	11.54	**422.52%**	1200	629.32	6.36	**290.87%**	-	-	0.592
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 22-Jul-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

EGR Mapping Mode #	7	Engine RPM	1745	Engine Torque	562	ft. lb	Engine HP	187

Sheet 1 Log

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	1220	772	1745	6	181	10	5.36	180	4.64	-	-	-	20.94	0	0	0	7.66	812	510	690	100	879	689	643	113	-	25/1.65	100/4.69	-	1.32	28.0	0.22	0	0.01
2	19.0%	1220	805	1745	6	188	32.7	27.78	180	4.92	-	-	-	19	145	130	36	7.35	1279	820	210	100	736	608	571	406	-	43/2.01	100/4.81	-	1.19	19.0	1.16	-	-
3	18.8%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	18.6%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	18.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fine Tune Tests																																		
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Engine: Caterpillar 3406 B engine, 1985

Date: 8 July 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	7	Engine RPM	1745	Engine Torque	562	ft.lb	Engine HP	187

Sheet 2 Calc

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	1220	772	1745	181	4.64	12.37	-	20.94	0	0	0	7.66	812	510	690	-	0.00%	0.00%	0.00%	0.00%	0.00%	879	30.74	0.00	0.01
2	20.0%	1220	805	1745	188	4.92	13.12	6.03%	19.00	145	130	36	7.35	1279	820	210	69.57%	14.28%	11.34%	15.85%	17.14%	-	736	25.33	-	-
3	19.5%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	20.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	18.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	7	Engine RPM	1745	Engine Torque	562 ft.lb	Engine HP	187

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	30.74	836,705	0	0	690	577.33	3.09	-	812	679.40	3.63	-	510	426.72	2.28	-	0.01	-	0.513
2	20.0%	25.33	689,239	-	-	210	144.74	0.77	**74.93%**	**1279**	881.54	4.71	**29.75%**	820	565.18	3.02	**32.45%**	-	-	0.523
3																				
4																				
5																				
6																				
7																				

Engine: Caterpillar 3406 B engine, 1985 **EGR Valve: CTI Model** **Date:** 8-Jul-05

Tests Conduted by: James Borgelt, Coordinator, Data Collection; Mark Job, Data Collection; Troy Prendel, Dyno Op.; Jeff Lige, Driver

Supervised by: R.A. Kammel

Sheet 1 Log

EGR Mapping Mode #	8	Engine RPM	1679	Engine Torque	764	ft. lb	Engine HP	237

Test Conditions		PTO Dyno & Engine Data					Fuel Consumption				EGR Valve Data			Emission Data								Turbo Charger	Exhaust System Pressure & Temperature Data								Exhaust Mass Flow				Raw Particulate Samples
														Engine Air Intake				Engine Exhaust					Temperature Data				Pressure Data				Tailpipe, 5-3 Venturi		EGR, 3-2 Venturi		
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Gear Ratio	Dyno Horsepower	Initial Tank Wt.	Final Tank Wt.	Time Seconds	ΔW	Command (No. of Steps)	Valve Position (Inches)	EGR Flow Mass flow meter	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	Manifold Pressure inches H2O	A	B	C	D	ΔP1	ΔP2	ΔP3	ΔP4	Voltage Reading	Inches of water	Voltage Reading	Inches of water	ΔW mg over 60 seconds
1	21% (no EGR)	1174	1040	1400	6	234	32.93	27.80	180.00	5.13	-	-	-	20.89	0	90	1	9.26	330	620	671	100	728	612	548	107	-	58/2.53	100/4.81	-	1.77	36.0	0.22	0.0	0.01
2	20.2%	-	990	-	-	234	31.98	23.35	300.00	8.63	-	-	-	20.22	-	28	48	7.36	-	920	479	-	783	657	624	332	-	56/2.5	100/4.8	-	0.363	30.0	1.6	0.6	-
3	18.8%	NOTE: Excessive EGR Results in Loss of Power									-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	18.6%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	18.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fine Tune Tests																																		
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Engine: Caterpillar 3406 B engine, 1985

Date: 8 July 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	8	Engine RPM	1679	Engine Torque	764	ft.lb	Engine HP	237

Sheet 2 Calc

Test Conditions		PTO Dyno & Engine Data				Fuel Consumption			EMISSION DATA														Temperature	Exhaust Mass Flow		Raw Particulate Samples
									Engine Air Intake				Engine Exhaust					Calculation of EGR Ratios						Tailpipe	EGR	
Test No.	Engine Air Intake O_2%	Dyno RPM	Dyno Torque ft/lb.	Engine RPM	Dyno Horsepower	ΔW	Normalized ΔW	Fuel Penalty %	O_2%	CO PPM	HC PPM	NOx PPM	O_2%	CO PPM	HC PPM	NOx PPM	NOx Reduction	EGR % Based on O_2	EGR % Based on CO	EGR % Based on HC	EGR % Based on NOx	EGR % Based on Mass Flow	Exhaust Manifold Temperature	5-3 Venturi, lbs/min	3-2 Venturi, lbs/min	ΔW mg over 60 seconds
1	21% (no EGR)	1174	1040	1400	234	5.13	13.68	-	20.89	0	90	1	9.26	330	620	671	-	0.43%	0.00%	14.52%	0.15%	0.00%	728	34.86	0.00	0.01
2	20.2%	-	990	-	234	8.63	13.81	0.94%	20.22	-	28	48	7.36	-	920	479	28.61%	5.30%	-	3.04%	10.02%	7.29%	783	31.82	2.50	-
3	18.8%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	18.6%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	18.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	18.2%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	18.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Engine: Caterpillar 3406 B engine, 1985

Date: 18 August 2005

Evaluation by: Liz Kammel

EGR Mapping Mode #	8	Engine RPM	1679	Engine Torque	764 ft.lb	Engine HP	237

Sheet 3 Stats

Test Conditions		Exhaust Mass Flow				NOx Emissions				CO Emissions				HC Emissions				PM Emissions		Fuel Rate
Test No.	Engine Air Intake O_2%	Lbs/min	Grams/ hour	Lbs/min	Grams/ hour	PPM	gms/hr	Specific NOx Emissions, gms/bhp.hr	Emission Reduction	PPM	gms/hr	Specific CO Emissions, gms/bhp.hr	Emission Increase	PPM	gms/hr	Specific HC Emissions, gms/bhp.hr	Emission Increase	Wt, mg	Emission Increase	lbs/bhp.hr
1	21% (no EGR)	34.86	948,734	0	0	671	636.60	2.69	-	330	313.08	1.32	-	620	588.21	2.48	-	0.01	-	0.438
2	20.2%	31.82	866,072	2.50	68,092	479	414.85	1.75	**34.83%**	-	-	-	-	920	796.79	3.36	**35.46%**	-	-	0.443
3																				
4																				
5																				
6																				
7																				

Calculation of Mass Emissions

for the CAT 3406B Engine, 1985 Model Year
Average of the Sum of weighted power and final NOx reductions

Mode (Baseline)	Mass Emission gms/hour	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	Mass Emission x Weight Factor	Mode (Selected) EGR	Mass Emission gms/hour	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	Mass Emission x Weight Factor	NOx Reduction
1	13.2	35.00	460	1	2.2	35.00	75	83.65%
2	72.2	6.34	458	2	13.9	6.34	88	80.73%
3	182.2	2.91	530	3	50.7	2.91	147	72.19%
4	387.8	3.34	1,295	4	138.0	3.34	461	64.41%
5	150.6	8.40	1,265	5	39.8	8.40	334	73.57%
6	263.0	10.45	2,748	6	88.1	10.45	921	66.50%
7	577.3	10.21	5,895	7	144.7	10.21	1,478	74.93%
8	636.6	7.34	4,673	8	414.8	7.34	3,045	34.83%
		Σ Mass Emission x Weight Factor =	**17,324**			**Σ Mass Emission x Weight Factor =**	**6,550**	

Calculation of Average of sum of weighted power of the AVL 8-modes

Mode (Baseline)	Horse Power (HP)	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	HP x WF	Mode (Selected) EGR	Horse Power (HP)	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	HP x WF
1	0	35.00	0	1	0	35.00	0
2	32	6.34	203	2	32	6.34	203
3	95	2.91	276	3	95	2.91	276
4	160	3.34	534	4	158	3.34	528
5	46	8.40	386	5	46	8.40	386
6	101	10.45	1,055	6	102	10.45	1,066
7	181	10.21	1,848	7	188	10.21	1,919
8	234	7.34	1,718	8	234	7.34	1,718
		Σ HP x WF =	**6,021**			**Σ HP x WF =**	**6,096**

Baseline AVL Composite Brake Specific Emission = $\frac{\Sigma \text{ Mass Emission x Weight Factor}}{\Sigma \text{ HP x WF}}$ = 2.88 gms/bhp.hr

Selected Modes (EGR) Composite Brake Specific Emission = $\frac{\Sigma \text{ Mass Emission x Weight Factor}}{\Sigma \text{ HP x WF}}$ = 1.07 gms/bhp.hr

Composite AVL NOx Reduction = $\frac{(2.88-1.07)x100}{2.88}$ = **63%**

Note: The average NOx emission reduction of 63% is equivalent to that generated from EPA transient test procedures according to AVL procedures.

Calculation of Fuel Rate & Penalty

for the CAT 3406B Engine, 1985 Model Year

Mode (Baseline)	Fuel Consumption gms/hr	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	Fuel Consumption x Weight Factor	Fuel Rate lbs/bhp.hr	Mode (Selected) EGR	Fuel Consumption gms/hr	Weight Factor for AVL 8-Mode Heavy Duty Cycle (WF)	Fuel Consumption x Weight Factor	Fuel Rate lbs/bhp.hr
1	5.2	35.00	181	-	1	4.5	35.00	158	-
2	17.6	6.34	111	0.548	2	18.0	6.34	114	0.563
3	43.4	2.91	126	0.457	3	46.4	2.91	135	0.489
4	68.6	3.34	229	0.429	4	71.8	3.34	240	0.449
5	33.7	8.40	283	0.733	5	37.1	8.40	311	0.806
6	55.9	10.45	584	0.554	6	60.4	10.45	631	0.592
7	92.8	10.21	947	0.513	7	98.4	10.21	1,005	0.523
8	102.6	7.34	753	0.438	8	103.6	7.34	760	0.443
Σ Fuel Consumption x Weight Factor =			**3,216**		**Σ Fuel Consumption x Weight Factor =**			**3,354**	

$$\textbf{Fuel Penalty} = \frac{(\Sigma \text{ Selected Fuel Consumption x Weight Factor} - \Sigma \text{ Baseline Fuel Consumption x Weight Factor}) \text{ x } 100\%}{\Sigma \text{ Baseline Fuel Consumption}} = \mathbf{4.28\%}$$

Note: The fuel penalty calculated here in equivalent to that generated from EPA transient test procedure according to AVL.

EGR Effect on Emission Reduction and Increases for Targeted Injection Strategy

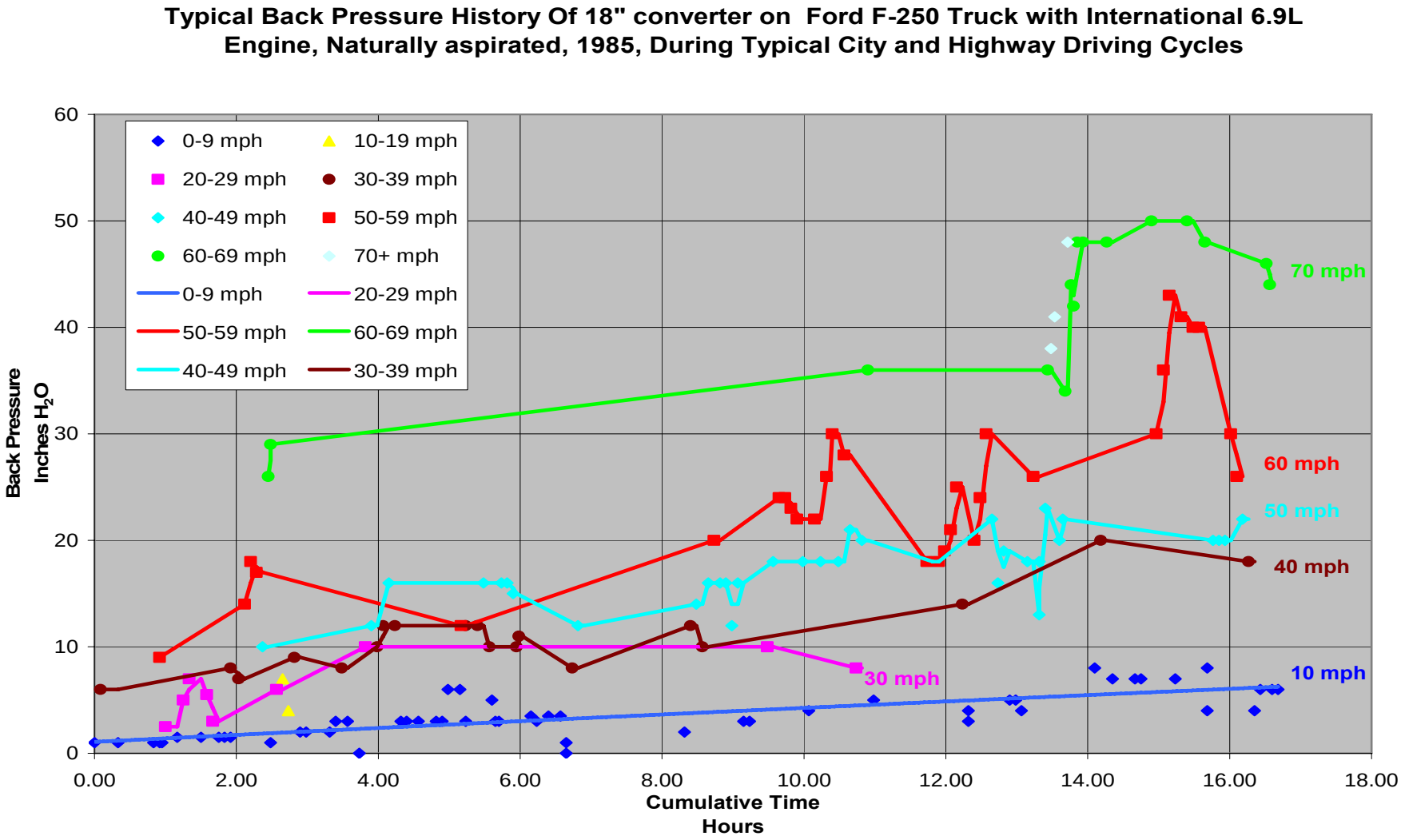
	Testing Mode	Percentage decrease in NOx	Increase in Visible Emissions			% Fuel Penalties
			Particulate	CO	HC	
			% Increase	% Increase	% Increase	
AVL Modes	1	76.88%	N/C	208.76%	216.67%	-13.04%
	2	75.62%	163.64%	247.93%	122.58%	2.56%
	3	68.70%	N/C	598.99%	0.00%	6.91%
	4	61.02%	N/C	443.57%	62.07%	4.66%
	5	61.47%	N/C	391.43%	461.54%	9.96%
	6	57.14%	N/C	568.40%	400.00%	7.94%
	7	69.57%	N/C	57.51%	60.78%	6.03%
	8	28.61%	N/C	N/C	48.39%	0.94%
Supplementary Modes	9	74.16%	122.22%	201.26%	204.76%	1.64%
	10	61.19%	N/C	297.52%	25.40%	5.19%
	11	62.55%	N/C	N/C	104.48%	8.21%
	12	63.87%	N/C	N/C	153.33%	5.36%

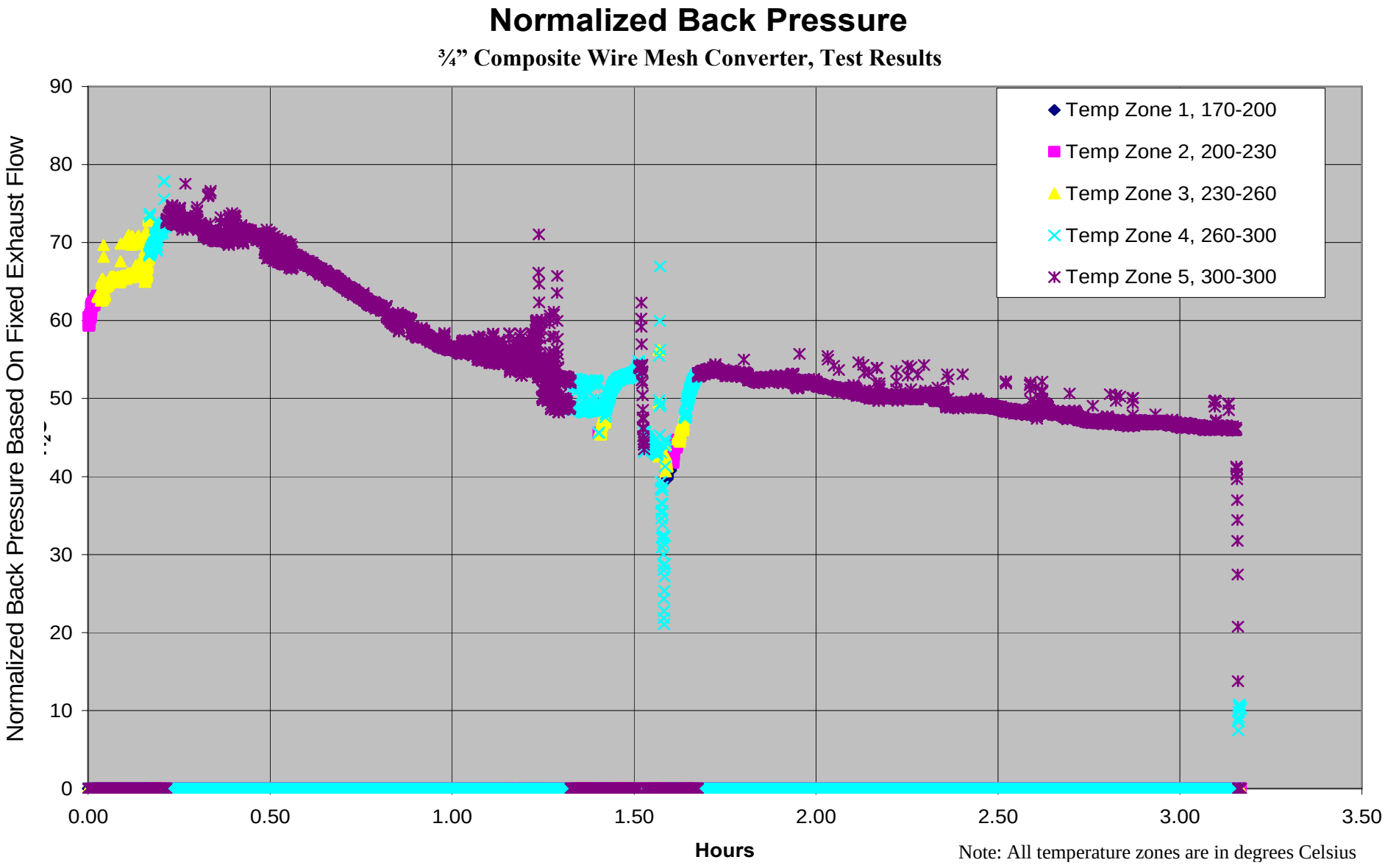
Note: N/C denotes "not credible test data". Such data were deemed not accurate enough and as such were omitted from this table

Selected Smoke/Particulate Reduction Test Data for a Single Candle Converter with Incineration on-the-road

On-the-Road Test, Single Candle					
Time	Speed (mph)	Back Pressure Inches H_2O	Smoke Opacity %		Temp. at Converter Inlet (°F)
			Raw	Clean	
1:00 PM	2	2	8.4	0.6	210
1:03 PM	30	10	24.1	5.8	299
1:07 PM	15	8	15.2	0	316
1:13 PM	40	12	41.5	9.6	318
1:19 PM	50	18	14.2	0	379

Back Pressure Test Data for a Single Candle Converter with Incineration, 20 hours durability on-the-road





Back-pressure drop due to incineration at about 300°C