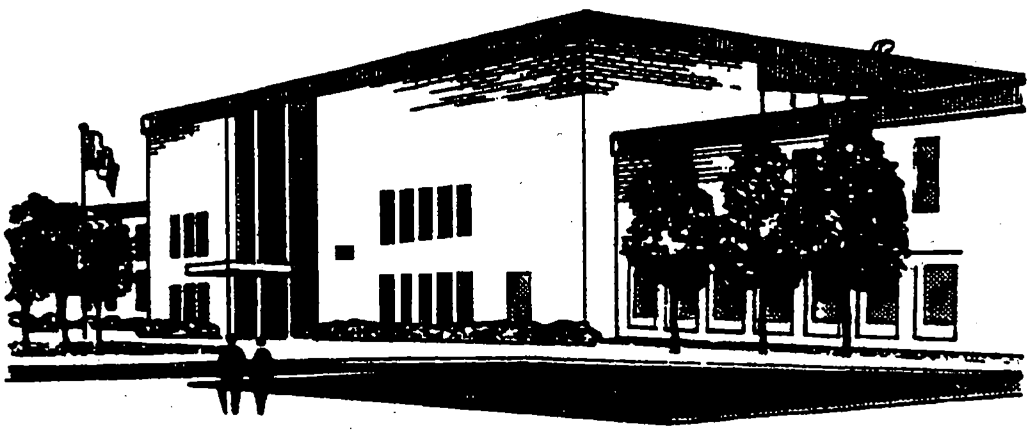
Evaluation of Exhaust Emissions from a Small Utility Engine with Environmental Control Corporation's After-Treatment Systems



ERMD Report # 01-17

Prepared by: Karen Aubin
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Environment Canada Environnement Canada

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1.0 ABSTRACT

In this study the effectiveness of a catalyst/muffler to reduce the exhaust emissions from a small (4.0 kW) gasoline powered utility engine was evaluated. The objective of the program was to test and evaluate 5 catalyst/mufflers, designed and built by Environmental Control Corporation. The results of the initial evaluation were used to select the two systems with the best results and to conduct further evaluation to determine the extent to which they reduced the regulated exhaust emissions without seriously affecting performance or fuel consumption. The engine was evaluated using the State of California Air Resources Board Exhaust Standards and Test Procedures for 1995 and Later, Utility and Lawn and Garden Equipment Engine, amended May 26, 1995.

The engine in the test program was a horizontal shaft utility engine built by Honda. The exhaust emissions quantified included carbon monoxide, nitrogen oxides, and total hydrocarbons. In these tests dilute exhaust measurements, similar to those outlined by SAE J10941 (Constant Velocity Sample System for Exhaust Emissions Measurement) were taken, in place of raw exhaust measurements as specified by SAE Recommended Practice J10882 for small utility engines.

There were significant reductions in carbon monoxide, hydrocarbons and oxides of nitrogen found with the systems.

2.0 BACKGROUND

The USA EPA has implemented Phase 1 Standards for Small Spark-Ignition Utility Engines for non-road small spark-ignition utility engines in 1997. The Canadian Federal government has established a voluntary agreement or a (Memorandum of Understanding (MOU) with manufacturers that reflect the EPA's Phase 1 regulations. A transitory period between 2002 to 2007 or later will see the implementation of Phase 2. At this time Canada will harmonize with the USA. The new standards are projected to result in a 70% reduction in HC & NOx beyond Phase 1 reductions. [2]

Phase 2 standards are thought to be stringent, however regulators are considering measures to ensure cost-effectiveness and achievability. It is anticipated that catalysts will be the technology of choice to meet the standards for the Class III and IV engines. [2]

The emissions speciated in the exhaust gases in this program are: Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), Hydrocarbons, (HCs) and Carbon Dioxide (CO_2). Carbon Monoxide is a poisonous, odorless gas that can cause headaches, dizziness, and comas at lower concentrations and death at higher concentrations. Of the Oxides of Nitrogen, Nitrogen Dioxide plays a principal role in a series of chemical reactions in which ground level ozone or smog is formed. Unburned fuel in exhaust gases consists of many different hydrocarbons. Many hydrocarbons such as benzene, are known carcinogens and are highly volatile (VOCs) and participate in ozone formation along with oxides of nitrogen, sunlight and temperatures greater than 18°C. Ozone and fine particles are the major constituents of smog. Smog can cause some respiratory ailments and damage to the environment. Ozone, carbon dioxide and nitrous oxide are important greenhouse gases and contributors to the changing climate.

EPA's primary reason for controlling emissions from small SI utility engines is the role of the HC emissions in forming ozone. In non-road two stroke engines, twenty-five percent of the exhaust is unburned fuel. This ratio can go up to fifty percent in older, mistuned engines.[6] It is thought that Spark-Ignition engines up to Class V are responsible for about one tenth of the hydrocarbon emissions for mobile sources and the largest contributor to non-road HC inventories. [2]

3.0 RESEARCH FACILITY AND TEST PLAN

3.1 Test Cycle

Exhaust emission testing of small utility engines has been conducted over the past twenty years[1, 3] using the same basic procedure. The majority of these programs have followed the SAE Recommended Practice J1088[4] as indicated in Table 1. which employs raw exhaust measurements and converts the exhaust concentration to a mass emission based upon either engine air flow or fuel flow.

Table 1. SAE J1088 Duty Cycle for Non-Handheld Utility Engines

Test Mode #	Throttle Position	Engine Speed	Torque
1	Closed	Recommended Low Idle	Minimum
3	Full	Max Governed or 85% of Rated Speed	Full Load
4	Part	Max Governed or 85% of Rated Speed	85% of Load Obtained in Mode 3
5	Part	Max Governed or 85% of Rated Speed	75% of Load Obtained in Mode 4
6	Part	Max Governed or 85% of Rated Speed	50% of Load Obtained in Mode 5
7	Part	Max Governed or 85% of Rated Speed	25% of Load Obtained in Mode 6

3.2 Exhaust Sampling

The test procedure used in this study employs dilute exhaust sampling. In general the gaseous emission measurements were obtained using a total dilution constant velocity sampling (CVS) system[5].

A sampling hood that covered the exhaust system of the engine collected the exhaust stream and dilution air from the room. The total of raw exhaust was transferred from the engine to the CVS through a 3 inch diameter flexible stainless steel pipe. The flow through the CVS was at a nominal flow rate of 146 standard cubic feet per minute.

During the exhaust emissions test, a continuously proportioned sample of the dilute exhaust mixture was extracted from the dilution system through an orifice sample probe. In addition, a sample of the dilution air was also collected. Both of the gaseous samples were stored in Teller® bags until analysis could be completed. In diluting the raw exhaust, difficulties such as elevated water content and high exhaust concentrations, normally associated with raw exhaust sampling and analysis were avoided.

3.3 Exhaust Analysis

The stored gaseous sample of dilute exhaust and dilution air, were analyzed for the concentrations of Total Hydrocarbons (THC), Nitrogen Oxide (NOx), and Carbon Monoxide-Carbon Dioxide (CO and CO_2), through the use of a Flame Ionization Detector, a Chemiluminescence Detector, and Non-Dispersive Infrared Detectors, respectively. The dilute exhaust concentrations were then corrected for the dilution air levels and the exhaust emission rates in grams per hour were calculated.

Reference gas standards were used to calibrate the exhaust analyzers over the range of concentrations observed in the exhaust, while tracer gas recovered was used to calibrate and verify sampling apparatus.

3.4 Engine Dynamometer

The engine dynamometer consisted of a hydraulic pump mounted on a pivoting bracket. The load was controlled by adjusting the flow of hydraulic oil through the pump, while a calibrated load cell was used to determine the torque. The dynamometer capacity was 20 horsepower at 4000 rpm.

3.5 Test Fuel

The composition and quality of a fuel may have a significant impact on the operation and emissions from any engine. In this study the engines were preconditioned and tested using emissions certification unleaded gasoline (indolene) This is the same fuel that is used by the ERMD in the light duty vehicle emissions compliance program. The following Table 2. outlines the fuel specification as dictated by the US Code of Federal Regulations, and the Canadian Motor Vehicle Safety Standards.

Table 2. Fuel Composition

ITEM	ASTM	STANDARD
Octane	D2699	93
Distillation Range		
IBP °C	D86	24 – 35
10% Point °C	D86	49 – 57
50% Point °C	D86	93 – 110
90% Point °C	D86	149 – 163
EP, °C max	D86	213
Sulfur, wt% max	D1266	0.1
RVP (kPa)	D323	55.2 – 63.4
Hydrocarbon Composition		
Olefins, % max	D1319	10
Saturates, %	D1319	Remainder

3.6 Test Engine

The engine tested in this study was new and had not been broken in at the time of receipt at the ERMD. The engine was a single cylinder, horizontal shaft utility engine with an advertised power rating of five and one half horsepower (4.0 kW). This engine is typical of what is used in walk behind snow blowers. This engine was equipped with an engine speed governor that in actual field operations provides a more uniform engine speed under varying loads.

For the purposed of engine dynamometer testing, The SAE J1088 and the CARB procedure allow testing with either the governor installed or disconnected. Generally engine testing is conducted in the configuration that the engine will be used in its final application.

The following Table 3. provides a brief description of the engine.

Table 3. Description of the Tested Nonhandheld Class I Engine

Engine Manufacturer and Model Number	Rated Power kW (HP)	Displacement cm^3 (cu-in)	Operating Cycle	Shaft Orientation
Honda GX-160	4.0 (5.4)	163 (9.9)	4 Stroke	Horizontal

3.7 Test Procedures

The objective of the program was to determine the extent to which the catalyst/mufflers reduced the regulated exhaust emissions test procedure for 1995 and Later Utility and Lawn and Garden equipment engines.

The 'A' cycle is a test sequence consisting of a series of steady-state operating modes. The modes represent a combination of engine speed and percent loads. Table 4. lists the test sequence. The engine is stabilized at each point following at which the exhaust emissions are sampled.

The engine was equipped with an engine speed governor, which as described previously, controls the engine power output while maintaining an intermediate engine speed. The CARB test procedure describes two duty cycles to address those engines equipped with and without engine speed governors. One cycle is conducted with the engine running at the "rated" speed and the other with the engine operating at an intermediate speed which would be the governed engine speed.

The specified percentage load on the engine is the same regardless of whether the engine is running at rated or the intermediate speed which would be the governed engine speed.

Table 4. CARB Standard Test Sequence

"A" cycle points	1	2	3	4	5	6 idle
Load % "A" cycle	100	75	50	25	10	0
Emissions Weighting (%)	9	20	29	30	7	5

The engine was tested with the engine speed governor operational. For each engine tested, a separate power curve is developed. A power curve is the torque the engine produces at a specific engine speed. The power generated is the product of the torque and the engine speed. The results of the power curves for each configuration can be found in the report appendix.

Before any testing was undertaken, the engine was run on the dynamometer at approximately 2000 rpm and a light load for a period of eight hours.

4.0 RESULTS

4.1 Exhaust Emissions

In this section the results of the exhaust emission measurements are presented. The results of the tests conducted over the CARB "A" cycle procedure are calculated as a weighted average of the modal emission rates. All results were presented in terms of grams of exhaust compound per horsepower-hour. Table 5. provides the emission results for the engine in each configuration.

Table 5. Emissions Results Summary

	Composite Results (g/kW-hr)					
	CO	CO2	NOx	THC	F.C.	NOx+THC
Baseline	274.79	800	3.39	11.99	402.90	15.37
Catalyst #1	187.81	1039	0.18	4.62	427.64	4.80
% difference	-31.65	29.74	-94.69	-61.48	6.14	-68.79
Statistically Significant	**YES**	**YES**	**YES**	**YES**	**NO**	**YES**
Catalyst #2	207.17	969	0.24	5.20	415.69	5.44
% difference	-24.61	21.00	-92.80	-56.63	3.17	-64.60
Statistically Significant	**YES**	**YES**	**YES**	**YES**	**NO**	**YES**

Table 6. Small SI Engine Classes

Nonhandheld				Handheld		
Class I-A	Class I-B	Class I	Class II	Class III	Class IV	Class V
<66cc	66 to <100cc	100 to <225cc	≥225cc	<20cc	20cc to<50cc	≥50cc

Table 7. Phase 2 HC+NOx Emission Standards for Nonhandheld Engines (in g/kW-hr) by Model Year

Engine Class	2001	2002	2003	2004	2005 & later	2007
I	16.1	16.1	16.1	16.1	16.1	
I-A						50**
I-B						40**
II	18.0	16.6	15.0	13.6	12.1	

** For 2001 Model year

Table 8. Phase 2 CO Emission Standards for Nonhandheld Engines (in g/kW-hr) by Model Year

Engine Class	2001	2002	2003	2004	2005 & later	2007
I	610	610	610	610	610	
I-A						610**
I-B						610**
II	610	610	610	610	610	

** For 2001 Model year

4.2 Discussion

The objective of this study was to investigate the improvements in exhaust emissions for "a state of the art" four-stroke utility engine that could be realized through the use of a catalyst/muffler combination in place of the regular engine muffler system.

The comparison testing was conducted with the engine configured to reflect its end-use application speed governor "on" or as it was installed by the manufacturer and as a consumer would use the engine. "Baseline" tests were conducted with the engine in its OEM configuration with OEM muffler. Five catalyst/mufflers were initially tested with over one CARB Standard Test Sequence. Two of the five catalysts were chosen from the screening based on the best reduction results. These two catalyst/mufflers were then tested with over three test sequences.

The results from the catalyst #1 tests showed a reduction in the exhaust emissions NO_x and Total Hydrocarbons of 94.7% and 33.8% respectively. The Total "NO_x + THC" reduction was 68.1%. Carbon Dioxide increased by 28.0% There was no statistically significant increase in fuel consumption.

The results from the catalyst #2 tests showed a reduction in exhaust emissions NO_x and Total Hydrocarbons of 92.8% and 24.6% respectively. The Total "NO_x + THC" reduction was 64.6%. Carbon Dioxide increased by 21.0%. There was no statistically significant increase in fuel consumption.

The total carbon emissions and fuel consumption marginally increased. The significant increase in carbon dioxide reflects the oxidation of unburned fuel in the exhaust by the catalyst/muffler system to carbon dioxide.

4.3 Conclusion

Both catalysts from Environmental Control Corporation reduced all regulated emissions CO, NO_x, and THC. A large reduction was seen in the NO_x and THC, in particular. The increase in CO_2 was primarily due to the conversion of

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Fax

To:	Nils	**From:**	Karen Aubin
Fax:	709-74[illegible]-0003	**Date:**	Friday, November 09, 2001
Phone:		**Pages:**	
Re:	Correction Sheet for report	**CC:**	

☐ **Urgent** ☐ **For Review** ☐ **Please Comment** ☐ **Please Reply** ☑ **Please Recycle**

•Comments:

Hi Nils:

Please find the correction of values to read :

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Best regards,

Karen Aubin *Karen Aubin*

Project Manager,

Emissions Research and Measurement Division,

Environment Canada

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The comparison testing was conducted with the engine configured to reflect its end-use application speed governor "on" or as it was installed by the manufacturer and as a consumer would use the engine. "Baseline" tests were conducted with the engine in its OEM configuration with OEM muffler. Five catalyst/mufflers were initially tested with over one CARB Standard Test Sequence. Two of the five catalysts were chosen from the screening based on the best reduction results. These two catalyst/mufflers were then tested with over three test sequences.

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Both catalysts from Environmental Control Corporation reduced all regulated emissions CO, NO_x, and THC. A large reduction was seen in the NO_x and THC, in particular. The increase in CO_2 was primarily due to the conversion of unburned fuel, the exhaust emissions THC and CO to CO_2. The fuel consumption did not change significantly.

5.0 ACKNOWLEDGEMENTS

The author would like to acknowledge the efforts of the Emissions Research and Measurement Division for conducting this emissions test work. In particular, I would like to thank Mr. Pete Barton for his advice and technical help, Mr. Greg Rideout for his advice, Doug Corke for his diligence in the test cell.

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Vehicle Model	Honda 5.5hp GX160
Vehicle Serial#	
Engine Family	THN163U1G1RA
Engine Serial#	GC02-4372579
Modifications	

Engine Displacement (cc):	163 cm^3		
	hp	Kw	
Engine Power Rating:	5.5	4.103	
Test Fuel:	Indolene Certified Unleaded Gasoline		

		Composite Results g/hp-h						Composite Results g/kW-hr						Weighted Powe	
		CO	CO2	NOx	THC	Fuel Consumption	NOx+THC	CO	CO2	NOx	THC	Fuel Consumption	NOx+THC	hp	kW
Baseline Testing															
1	30-May	213	603	2.46	9.47	307	11.93	285	808	3.30	12.69	411	15.99	2.05	1.53
2	31-May	214	579	2.26	8.77	299	11.03	286	776	3.03	11.75	401	14.78	2.05	1.53
3	31-May	212	605	2.53	8.69	306	11.22	284	811	3.39	11.65	410	15.04	2.06	1.53
4	10-Jul	182	601	2.85	8.85	290	11.71	244	806	3.83	11.87	389	15.69	2.04	1.52
Average		**205**	**597**	**2.53**	**8.94**	**301**	**11.47**	**275**	**800**	**3.39**	**11.99**	**403**	**15.37**	**2.05**	**1.53**
Standard Deviation		**15**	**12**	**0.25**	**0.35**	**8**	**0.42**	**21**	**16**	**0.33**	**0.47**	**10**	**0.56**	**0.01**	**0.00**
Catalyst #1															
	6-Jul	134	765	0.14	3.39	313	3.52	180	1026	0.18	4.54	420	4.72	2.04	1.52
	6-Jul	146	784	0.13	3.50	325	3.63	196	1051	0.18	4.70	436	4.87	2.01	1.50
Average		**140**	**775**	**0.13**	**3.45**	**319**	**3.58**	**188**	**1039**	**0.18**	**4.62**	**428**	**4.80**	**2.03**	**1.51**
Standard Deviation		**8**	**14**	**0.00**	**0.08**	**9**	**0.08**	**11**	**18**	**0.00**	**0.11**	**12**	**0.10**	**0.02**	**0.02**
Coefficient of Variance		6.00	1.76	2.17	2.35	2.69	2.18	6.00	1.76	2.17	2.35	2.69	2.18	1.05	1.05
sigma		13.95	12.53	0.21	0.31	7.91	0.36	18.70	16.80	0.29	0.41	10.60	0.49	0.01	0.01
t distribution		5.37	-16.37	12.94	20.54	-2.69	25.05	5.37	-16.37	12.94	20.54	-2.69	25.05	2.38	2.38
95% confidence level		2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
n =N1+N2-2		4	4	4	4	4	4	4	4	4	4	4	4	4	4
% difference		**-31.65**	**29.74**	**-94.69**	**-61.48**	**6.14**	**-68.79**	**-31.65**	**29.74**	**-94.69**	**-61.48**	**6.14**	**-68.79**	**-1.17**	**-1.17**
Statistically Signific		**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**NO**	**NO**
Catalyst #3															
	9-Jul	158	724	0.13	3.84	312	3.97	212	971	0.18	5.15	419	5.33	2.01	1.50
	9-Jul	157	715	0.16	3.73	309	3.89	211	959	0.22	4.99	414	5.21	2.02	1.50
	10-Jul	149	728	0.25	4.07	309	4.32	199	976	0.33	5.46	414	5.79	2.02	1.51
Average		**155**	**723**	**0.18**	**3.88**	**310**	**4.06**	**207**	**969**	**0.24**	**5.20**	**416**	**5.44**	**2.01**	**1.50**
Standard Deviation		**5**	**7**	**0.06**	**0.18**	**2**	**0.23**	**7**	**9**	**0.08**	**0.23**	**3**	**0.30**	**0.01**	**0.00**
Coefficient of Variance		3.33	0.94	32.73	4.51	0.61	5.60	3.33	0.94	32.73	4.51	0.61	5.60	0.31	0.31
sigma		12.34	10.35	0.19	0.30	6.06	0.35	16.54	13.87	0.26	0.40	8.12	0.47	0.01	0.00
t distribution		5.35	-15.86	15.78	22.43	-2.06	27.40	5.35	-15.86	15.78	22.43	-2.06	27.40	8.11	8.11
95% confidence level		2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
n =N1+N2-2		5	5	5	5	5	5	5	5	5	5	5	5	5	5
% difference		**-24.61**	**21.00**	**-92.80**	**-56.63**	**3.17**	**-64.60**	**-24.61**	**21.00**	**-92.80**	**-56.63**	**3.17**	**-64.60**	**-1.77**	**-1.77**
Statistically Signific		**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**	**YES**