ESDC

PROJECT NO.:
400-163

REPORT NO.:
ARD- 0027

Centre de Développement de Systèmes Moteurs Inc.
Engine Systems Development Center Inc.

AAR 3-MODE EVALUATION OF THE RENTAR IN-LINE FUEL CATALYST

FINAL REPORT

Prepared for
Rentar Environmental Solutions

Compiled By: Fan Su

Approved By: Malcolm Payne

Distribution:
Rentar Environmental Solutions
ESDC Server

LIBRARY REF. NO.: ESDC 00027-ARD

DATE: May 30, 2003

155 Montreal - Toronto Highway Lachine, Quebec, H8S 1B4
Tel: (514) 634-7700 Fax: (514) 634-3932

EXECUTIVE SUMMARY

A Rentar in-line fuel catalyst (RIFC) was evaluated on a single-cylinder medium-speed diesel research engine (SCRE-251) to determine fuel economy and emissions benefits of using the device. Triplicate runs were performed to both baseline and RIFC performance tests. After the baseline test, engine was run at full load with the device for about 35 hours to stabilize conditions before taking RIFC performance test data. Three engine operating modes (idle, 50%-power, and full-load) were applied to each run of the baseline and the RIFC performance test. Engine operating parameters, fuel consumption and emissions were collected during the runs. Engine brake-specific fuel consumption (BSFC) and Association of American Railroads (AAR) 3-mode duty-cycle exhaust emissions were obtained from the runs. Results indicate that the device improves baseline fuel consumption by 1.5% at full load and reduces baseline CO, NOx, THC and PM emissions by 9.1%, 15.3%, 1.8% and 11.8% respectively. Unregulated emissions were also measured and reductions of some of the constituents were observed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

AAR	Association of American Railroads
ASTM	American Society for Testing and Materials
BSFC	Brake-Specific Fuel Consumption
CFR	Code of Federal Register (U.S.)
C_xH_y	Combustibles
CO_2	Carbon dioxide
CO	Carbon monoxide
ECOM	ECOM North America, Ltd.
EPA	Environmental Protection Agency (U.S.)
ESDC	Engine Systems Development Centre, Inc.
F.S.	Full Scale
IMEP	Indicated Mean Effective Pressure
NOx	Oxides of nitrogen
PM	Particulate Matter
RIFC	Rentar In-Line Fuel Catalyst
RP	Recommended Practice
SFAT	Simplified Fuel Additive Test
SwRI	Southwest Research Institute
THC	Total Hydrocarbon
TM	Test Mode

1.0 INTRODUCTION

A Rentar inline fuel catalyst (RIFC) was evaluated on a single-cylinder medium-speed diesel research engine (SCRE-251) at Engine Systems Development Centre (ESDC) in May, 03. The objective of the test is to determine effects of the device on engine performance and emissions. A description of the test approach and test results is presented in this report.

2.0 TECHNICAL APPROACH

2.1 Evaluation Test Procedure

A test program was developed based on RP-503 test procedure [1], AAR 3-mode test procedure and Simplified Fuel Additive Test (SFAT) protocol [2] to evaluate the RIFC. It consists of fuel property test and engine test.

Information about effects of the device on limiting fuel specification requirements was provided by the customer. Therefore the fuel property test was eliminated in the present project.

Engine test manner is "Baseline-Preconditioning-RIFCPerformance". Prior to the RIFC performance test, a preconditioning period (engine operating at full load with the device for about 35 hours) was applied to stabilize engine conditions. Triplicate runs were performed to both the baseline and the RIFC performance test. Each run sequence consisted of operating at three test modes (idle, 50%-power and full-load) for total about 1.5~2 hours. During the runs, engine operating parameters such as engine cooling water temperature, lube oil temperature were maintained as closely as possible for the same test mode. Fuel consumption, engine brake horsepower and exhaust emissions were recorded for comparison analysis.

2.2 Test Engine

The SCRE-251 is a four-stroke medium-speed diesel research engine with 9.0-inch bore and a 10.5-inch stroke. The engine specifications are shown in Table 1.

Table 1: SCRE-251 Specifications

Cylinder	1
Engine Stroke	4
Bore x Stroke	9.0 in. (228.6mm) x 10.5 in. (266.7 mm)
Displacement	668 cu. in. (10.9 L)
IMEP (max)	23 bar (334 psi)
Engine Speed (max)	1200 rpm
Idle Speed (Normal)	400 rpm
Compression Ratio	11.5:1 (Variable)
Fuel Injection Type	Direct Injection
Fuel Injector	9 holes × 0.40 mm × 145°
Fuel Injection Timing	27.5° CA BTDC (Variable)
Governing	Electronic

2.3 Test Fuel

Regular low sulfur No. 2 diesel fuel to ASTM specifications was used as baseline fuel.

2.4 Engine Power and Fuel Consumption Measurements

The speed of engine is controlled by an electronic engine governor. Engine speed is measured by an electronic-magnetic speed pick-up with accuracy of ±0.1% F.S.. The load on the engine is controlled and measured by the Schenk D1100 hydraulic dynamometer, which has an accuracy of ±0.5% F.S..

Fuel flows to a small weighing tank when a solenoid valve is energized by a signal from floating level sensor located inside the tank. Fuel is drawn from the fuel weighing tank by the engine booster pump which then passes it through a filter to the engine fuel pump, which incorporates a pressure relieve valve for directing returning excess fuel to the weighing tank. The net fuel consumption rate is measured by using a single channel micro-processor based process monitor (Visipak VIP524W, ±0.01%F.S. accuracy) connected to a load cell carrying the weighing tank.

A data acquisition and engine control system was used to monitor engine operating conditions and to record experimental data during the test. Average engine speed, load and fuel consumption data were obtained at each test mode for calculations.

2.5 Exhaust Emissions Measurements

An emission sample probe was mounted in the exhaust stack to sample engine exhaust after a complete mixing of the exhaust gases in the surge tank. The gas samples were drawn from the engine exhaust stack via a high-flow pump assembly with an in-line water trap and particulate filter for proper conditioning prior to the electrochemical gas sensors of the portable ECOM AC+ analyzer. The analyzer is capable of detecting concentrations of carbon monoxide (CO), oxygen (O_2), combustibles (C_xH_y), nitric oxide (NO), and nitrogen dioxide (NO_2), while also calculating carbon dioxide (CO_2). The accuracy of each of these sensors is within 2% of reading. A separate probe was installed to take samples to an AVL smoke meter for measuring BOSCH smoke values. Linearity error of the smoke meter is less than 1% and zero draft is less than 0.004%. Particulate matters were determined using a particulate emission measuring system, which was designed with EPA 40CFR Part 92 specifications. Unregulated emissions were measured using a gas chromatograph/flame ionization detector (GC/FID).

2.6 Rentar Installation

As required by the customer, the RIFC was installed as closely as possible to the engine fuel pump inlet (Figure 1).

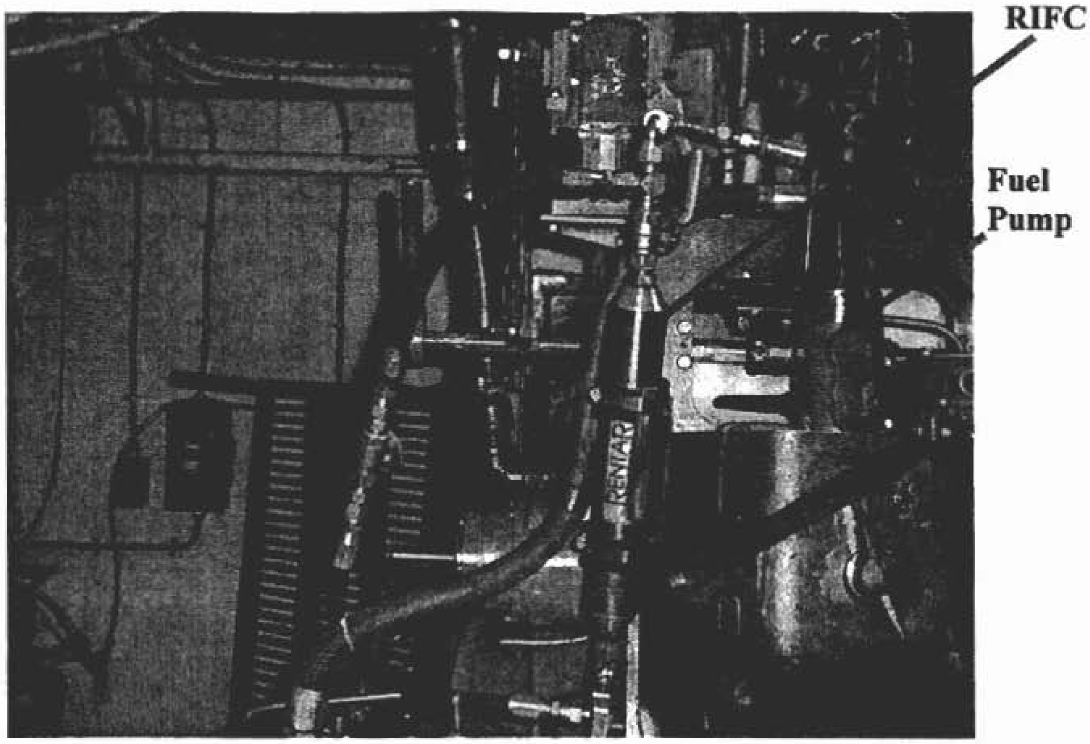


Figure 1: SCRE-251 with RIFC

3.0 TEST RESULTS

3.1 Engine Operating Parameters

Engine operating parameters recorded during the baseline and the RIFC performance test are given in Table 2. Engine coolant, lube oil and fuel temperatures were maintained as closely as possible for the comparative test mode. The variations of temperature and pressure data of the baseline and the RIFC performance test for the same test mode (TM) are within the limits specified in the SFAT [2].

3.2 Fuel Economy

To shorten the conditioning time by using higher fuel consumption rate, the engine was operated at full load during the preconditioning period. Brake specific fuel consumption (BSFC) values of the preconditioning test were plotted in terms of BSFC versus engine hours (Figure 2). The stable improvements on engine fuel consumption after approximate 26 hours are shown.

Engine BSFC values of the baseline and the RIFC performance test are shown in Table 3. Improvements relative to the baseline BSFC at TM-2 and TM-3 of 1.5% and 1.5% respectively were observed.

Table 2: Engine Operating Parameters of Baseline and RIFC Test

Test Mode	Test Run No.	Engine Speed (rpm)	Engine Load (Nm)	Coolant Temp. Eng. Out (°F)	Boost Air Temp. (°F)	Oil Temp. Sump (°F)	Boost Air Press. (psi)	Fuel Temp. Eng. In (°F)
Baseline								
TM-1 (Idle)	#1/3	400	14	171	115	169	2.1	81
	#2/3	402	13	169	111	172	2.1	86
	#3/3	402	15	167	111	174	2.0	90
TM-2 (About 50%-Power)	#1/3	801	854	176	149	189	6.0	82
	#2/3	801	855	174	147	187	6.1	88
	#3/3	801	855	172	149	187	6.0	90
TM-3 (Full-Load)	#1/3	1100	1616	185	192	194	29.1	82
	#2/3	1102	1616	181	194	192	29.1	86
	#3/3	1101	1617	181	192	192	29.0	90
RIFC								
TM-1 (Idle)	#1/3	402	14	174	113	176	2.1	84
	#2/3	401	13	172	111	176	2.1	86
	#3/3	401	15	172	115	174	2.1	88
TM-2 (About 50%-Power)	#1/3	802	854	178	147	189	6.1	86
	#2/3	802	855	176	149	185	6.1	86
	#3/3	800	855	176	149	189	6.1	90
TM-3 (Full-Load)	#1/3	1100	1617	178	192	194	29.0	88
	#2/3	1101	1616	181	192	192	29.0	93
	#3/3	1102	1616	183	192	194	29.1	90

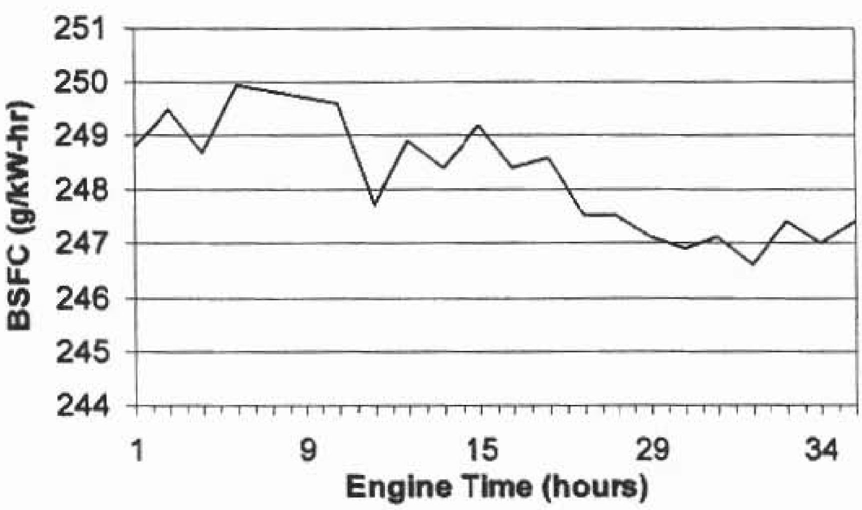


Figure 2: BSFC Data of Preconditioning Test

Table 3: Comparison of BSFC Values

Test Mode	Test Run No.	BSFC (lb/hp-hr)		Changes (%)
		Baseline	RIFC	
TM-1 (Idle)	#1/3	4.259	3.702	
	#2/3	4.261	4.188	
	#3/3	4.000	3.754	
	Mean	**4.173**	**3.881**	**-7.0**
TM-2 (About 50%-Power)	#1/3	0.475	0.463	
	#2/3	0.473	0.466	
	#3/3	0.465	0.463	
	Mean	**0.471**	**0.464**	**-1.5**
TM-3 (Full-Load)	#1/3	0.414	0.406	
	#2/3	0.411	0.406	
	#3/3	0.410	0.407	
	Mean	**0.412**	**0.406**	**-1.5**

3.3 Exhaust Emissions

Raw engine exhaust emissions were converted to specific values. The AAR 3-mode duty-cycle was used to calculate weighted CO, NOx, THC and PM emissions. The weighing factors applied are 50%, 25% and 25% for TM-1, TM-2 and TM-3 respectively. Results are given in Table 4. Duty-cycle emissions of RIFC decrease up to approximate 15% of that of the baseline.

Table 4: Comparison of Engine Exhaust Emissions

Emissions	Test Run No.	Baseline	RIFC	Changes (%)
CO (g/hp-hr)	#1/3	4.2	4.0	
	#2/3	4.7	3.9	
	#3/3	4.4	4.1	
	Mean	**4.4**	**4.0**	**-9.1**
NOx (g/hp-hr)	#1/3	16.6	13.1	
	#2/3	15.5	12.6	
	#3/3	13.0	12.4	
	Mean	**15.0**	**12.7**	**-15.3**
THC* (g/hp-hr)	#1/3	1.67	1.59	
	#2/3	1.65	1.60	
	#3/3	1.61	1.63	
	Mean	**1.64**	**1.61**	**-1.8**
PM (g/hp-hr)	#1/3	0.36	0.33	
	#2/3	0.33	0.30	
	#3/3	0.32	0.27	
	Mean	**0.34**	**0.30**	**-11.8**

*Note: * – Values were calculated based on exhaust carbon balance.*

Smoke (BOSCH) data for the RIFC and the baseline test are given in Table 5. Smoke value of RIFC is very similar to that of the baseline at idle, however, decreases about 15% of baseline value at TM-2 and 4% at TM-3.

Table 5: Comparison of Smoke Values

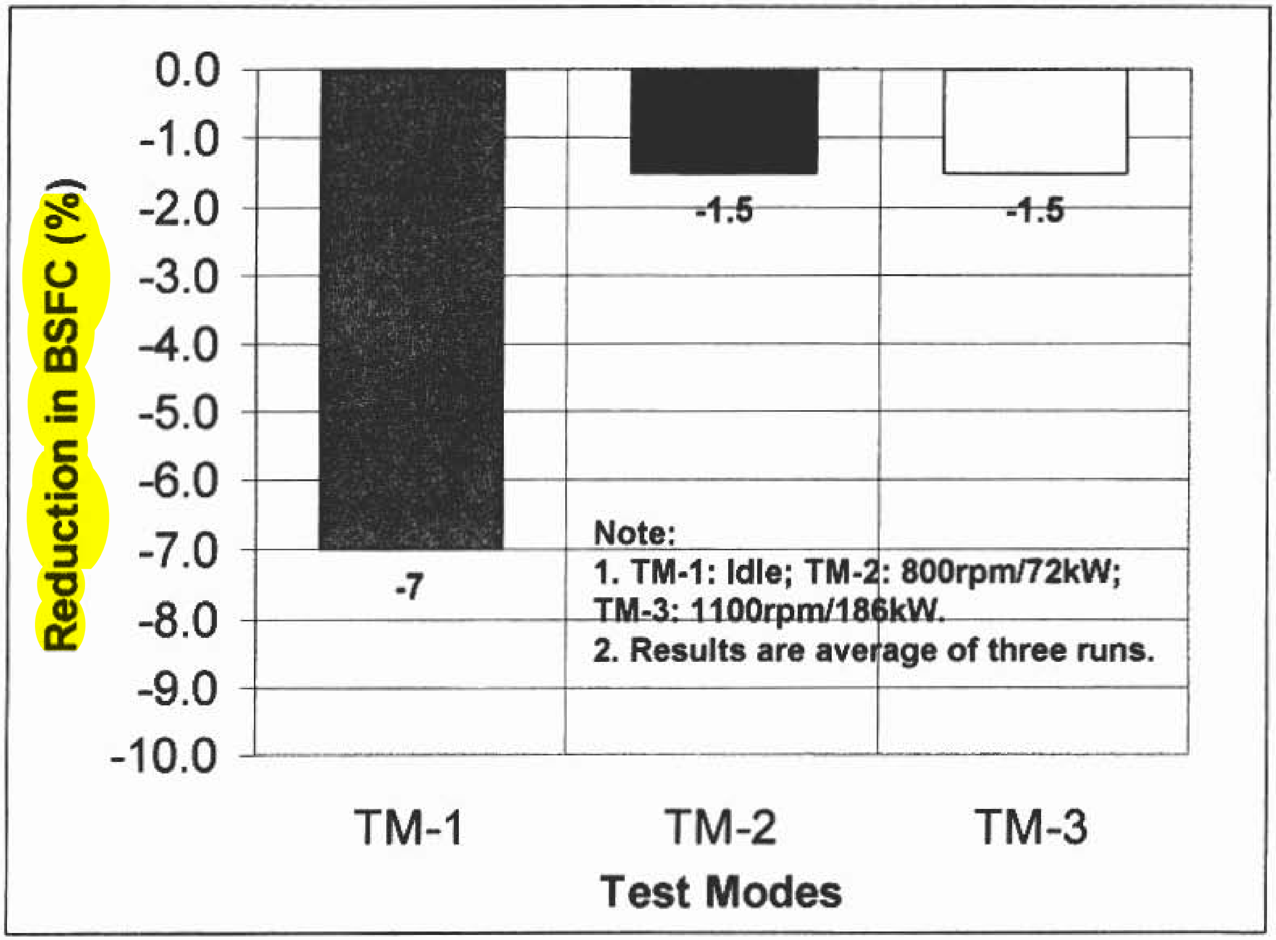
Test Mode	Smoke (BOSCH) *		Changes (%)
	Baseline	RIFC	
TM-1 (Idle)	0.10	0.10	0.0
TM-2 (About 50%-Power)	1.10	0.93	-15.5
TM-3 (Full-Load)	0.50	0.48	-4.0

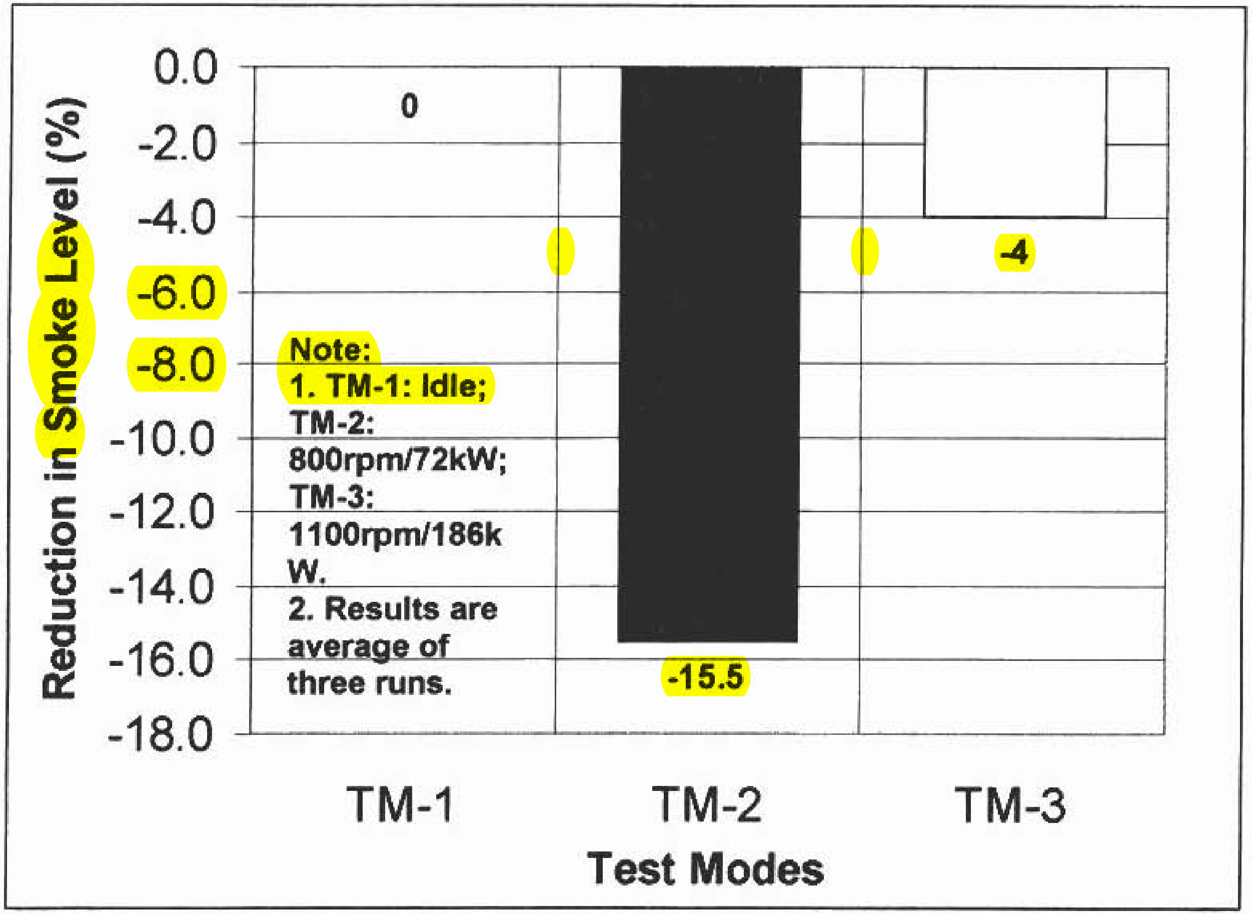
*Note: * - Each value shown in the table is average of three runs.*

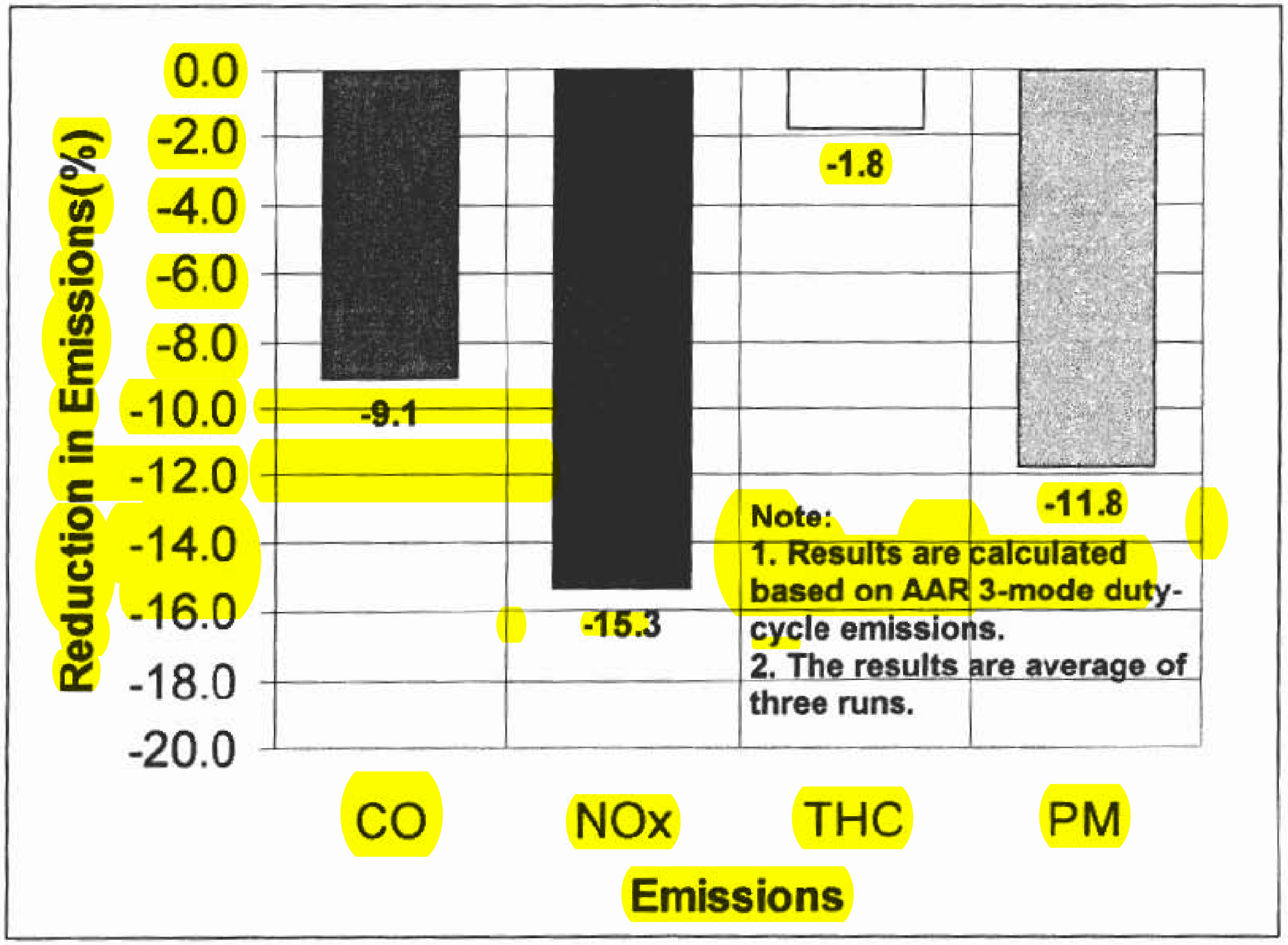
Some unregulated emissions were also obtained at TM-3. They are shown in Table 6.

Table 6: Comparison of Unregulated Emissions

Unregulated Emissions	Baseline (mg/ml)	RIFC (mg/ml)	Changes (%)
ACETONE	0.0115	0.0099	-13.9
BENZENE	1.344	0.963	-28.3
TOLUENE	40.41	25.80	-36.2
ETHYLBENZENE	5.63	7.61	+35.2
M-XYLENE	4.80	7.31	+52.1
O-XYLENE	12.90	16.80	+30.0
P-XYLENE	4.68	6.60	+41.0


Reduction in BSFC (%)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-7
-1.5
-1.5
Note:
1. TM-1: Idle; TM-2: 800rpm/72kW;
TM-3: 1100rpm/186kW.
2. Results are average of three runs.
TM-1
TM-2
TM-3
Test Modes


Reduction in Smoke Level (%)
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
0
-15.5
-4
Note:
1. TM-1: Idle;
TM-2:
800rpm/72kW;
TM-3:
1100rpm/186k
W.
2. Results are
average of
three runs.
TM-1
TM-2
TM-3
Test Modes



Reduction in Emissions(%)
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
-9.1
-15.3
-1.8
-11.8
Note:
1. Results are calculated based on AAR 3-mode duty-cycle emissions.
2. The results are average of three runs.
CO
NOx
THC
PM
Emissions

4.0 CONCLUSIONS

The following conclusions were made from the investigations:

1. The Rentar in-line fuel catalyst improves fuel consumption depending on engine operating mode. The improvement at full-load is about 1.5% of baseline value.
2. With application of the Rentar, engine CO, NOx, THC and PM emissions were reduced by 9.1%, 15.3%, 1.8% and 11.8% respectively. Smoke (BOSCH) decreases about 4% of baseline value at engine full-load.

5.0 RECOMMENDATION

The following additional work is recommended in phases:

Phase 1: Review the catalyst formulation and optimize the device through a series of tests with different formulations (either quantity, concentration or flow rates).

Phase 2: From the best selection of Phase I perform the SFAT test.

Phase 3: Apply a set of RIFC to a multi-cylinder engine (ALCO or GE) locomotive, marine or power station.

REFERENCES

1. "Fuel Additive Evaluation Procedure – Recommended Practice RP-503", Association of American Railroads Technical Services Division – Mechanical Section Manual of Standards and Recommended Practices, 1994.

2. M. Payne, "Simplified Additive Test Phase I, II and III", Transportation Development Centre, Transport Canada.