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FEASIBILITY OF A SIMPLIFIED FUEL ADDITIVE EVALUATION PROTOCOL

PREPARED FOR

TRANSPORTATION DEVELOPMENT CENTRE

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TP 13215E

Feasibility of a Simplified Fuel Additive Evaluation Protocol

By

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Engine System Development Centre

March 1998

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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16. Abstract

The Simplified Fuel Additive Test (SFAT) project was initiated in conjunction with the Transportation Development Centre (TDC), Transport Canada. The first phase of this project involved the determination of the feasibility of replacing the Association of American Railroads (AAR) Recommended Practice (RP) 503 protocol for testing diesel fuel oil additives with a new procedure, using the Single Cylinder Research Engine (SCRE-251) as the laboratory test engine, which tests for both engine performance as well as emissions compliance.

This report describes the work carried out during the four stages of the first phase of the SFAT project. Following a literature search, a review of the new U.S. Environmental Protection Agency (EPA) regulations is provided, a comparison between the AAR RP-503 test engines and the SCRE-251 is made, and finally, a study of the SCRE-251's ability to represent a multi-cylinder medium-speed diesel engine is conducted.

The report concludes that it is feasible to develop a new Simplified Fuel Additive Test that replaces the AAR RP-503, reflecting the requirements of the EPA locomotive emissions regulations using the medium-speed SCRE-251.

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16. Résumé

Le projet d'étude d'un protocole d'essai simplifié des additifs pour carburants (SFAT pour Simplified Fuel Additive Test) a été lancé en collaboration avec le Centre de développement des transports (CDT), de Transports Canada. La première phase visait à établir la faisabilité d'un nouveau protocole d'essai d'additifs pour carburants diesel qui remplacerait la Pratique recommandée 503 de l'Association of American Railroads (AAR) et qui utiliserait le moteur de recherche monocylindre (SCRE-251) comme banc d'essai en laboratoire servant aussi bien à déterminer les performances qu'à mesurer les émissions polluantes.

Ce rapport documente les travaux réalisés au cours des quatre premières étapes de la phase I de l'étude SFAT. Il présente les résultats d'une recherche documentaire, un examen de la nouvelle réglementation antipollution de la U.S. Environmental Protection Agency (EPA), une étude comparative des moteurs d'essai AAR RP-503 et SCRE-251 et, enfin, une étude de la capacité du SCRE-251 à bien représenter le fonctionnement d'un moteur diesel multi-cylindres à vitesse moyenne.

Les chercheurs ont conclu qu'il est possible de développer un nouveau protocole simplifié d'évaluation des additifs pour carburants en remplacement de la PR 503 de l'AAR, protocole qui intégrerait la réglementation EPA sur les émissions polluantes des locomotives et qui serait réalisé à l'aide du SCRE-251 à vitesse moyenne.

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EXECUTIVE SUMMARY

One significant operating cost railways face today is the cost of fuel; consequently, any reduction in fuel consumption would result in large savings. There are numerous after-market Performance Enhancing Product (PEP) suppliers who wish to sell into the locomotive market; however, they face a financial hurdle in that the railways often stipulate that their product be evaluated by a reputable laboratory before they consider in-service trials. The only procedure existing for testing these after-market products is the Association of American Railroads (AAR) Recommended Practice (RP) 503 that was adopted in 1980 and is currently performed at Southwest Research Institute (SwRI). This procedure does not measure emissions to the recently promulgated U.S. Environmental Protection Agency (EPA) rules for locomotives. These rules affect the entire locomotive community including manufacturers, rebuilders, and the after-market suppliers, with a great deal of the background work having been done at SwRI.

The overall purpose of the first phase of the Simplified Fuel Additive Test (SFAT) project is to assess the feasibility of developing a test protocol that will replace the AAR RP-503, and will reflect the new EPA emission rules for locomotives. The project is divided into four tasks – a literature search, an analysis of the EPA regulations, a comparison of the Single Cylinder Research Engine (SCRE-251) to the Caterpillar 1G2 engine, and a comparison of the SCRE-251 to a multi-cylinder engine.

The literature search produced many informative papers on the topics under consideration and a search of the Internet yielded information on after-market suppliers. In addition, a list of EPA tested after-market products was acquired.

The new EPA emission standards affect locomotive engines that had previously been unregulated and should achieve a significant reduction in emissions. The regulations, which take effect on January 1, 2000, will affect North American manufacturers, re-manufacturers, and importers of locomotives and locomotive engines, and railways and operators. The impact for Canadian railway companies that operate divisions in the U.S. and for Canadian companies that supply the U.S. market – be they manufacturers, re-manufacturers, or parts suppliers – is that they will be required to meet the regulations. To ensure compliance, the EPA will conduct both production line certification testing and in-use verification tests. The in-use tests are meant to ensure that manufacturers and re-manufacturers produce units that continue to meet emission standards beyond the production and certification stages and during actual operation. Upon the determination of a non-compliant unit, the actual repair will apply to all locomotives of that family regardless of whether or not the locomotives have exceeded their useful life. Also, Class I railways will be required to annually test a sample of their locomotive fleet that have surpassed their useful life. The regulations include an anti-tampering provision that calls for severe criminal penalties, not only for the corporation, but for the “responsible corporate officials” as well. Tampering is defined as knowingly altering the emission characteristics of a locomotive and includes removing emission control devices or applying uncertified systems or kits.

It is concluded that a procedure that utilizes a single cylinder research engine derived from a medium-speed diesel engine will not only be more economical, but will be less complex, since two intermediate engines, the 1G2 and EMD 567-twin, used in the AAR RP-503 test sequence, would not be required. The new procedure will require less time to complete and will be more representative of modern locomotive diesel engines. In addition, the upgrading of the exhaust emissions section of the current procedure to reflect the new EPA regulations will produce a comprehensive but simplified fuel additive screening and evaluation procedure.

SOMMAIRE

Les dépenses en carburant représentent une part importante des frais d'exploitation des compagnies ferroviaires. Aussi, toute mesure permettant de réduire la consommation des locomotives entraînera des économies substantielles. De nombreux fournisseurs de produits d'optimisation du rendement sont intéressés par le marché des locomotives, mais ils se butent à un obstacle financier majeur du fait que les compagnies ferroviaires exigent fréquemment qu'un laboratoire reconnu procède à une évaluation indépendante des produits qui leur sont proposés, avant même d'envisager un programme d'essai en service. Il existe un seul protocole d'essai des produits en question, soit la Pratique recommandée 503 de l'Association of American Railroads (AAR) adoptée en 1980 et appliquée à l'heure actuelle par le Southwest Research Institute (SwRI). Ce protocole ne comporte aucune disposition concernant la vérification de la conformité des locomotives aux nouvelles normes antipollution mises en place par la U.S. Environmental Protection Agency (EPA). Ces normes, fondées en majeure partie sur les travaux préparatoires réalisés au SwRI, ont une incidence sur tous les intervenants du marché des locomotives, fabricants, ateliers de reconstruction, fournisseurs de produits d'optimisation du rendement et autres.

La première phase du projet d'étude d'un protocole simplifié d'essai des additifs pour carburants (SFAT pour Simplified Fuel Additive Test) a pour objectif général d'évaluer la faisabilité d'un protocole d'essai qui remplacerait l'actuelle Pratique recommandée 503 de l'AAR et permettrait en même temps de vérifier la conformité des locomotives aux nouvelles normes antipollution de l'EPA. Ce projet comporte quatre étapes : une recherche documentaire, une analyse de la réglementation EPA, une comparaison du moteur de recherche monocylindre (SCRE-251) et du moteur Caterpillar 1G2, et une comparaison du SCRE-251 à un moteur multi-cylindres.

La recherche documentaire a permis de trouver de nombreuses études intéressantes consacrées à l'objet de la présente étude, tandis qu'une recherche sur Internet a livré des informations sur les fournisseurs de produits d'optimisation du rendement. De plus, on a obtenu une liste de produits de cette catégorie testés par l'EPA.

Les nouvelles normes antipollution de l'EPA s'appliqueront à des locomotives qui échappaient jusqu'ici à toute réglementation et devraient donc déboucher sur une réduction appréciable des émissions polluantes par l'industrie ferroviaire. Ces normes, qui doivent entrer en vigueur le 1^er^ janvier 2000, auront une incidence sur tout le secteur ferroviaire nord-américain : constructeurs, importateurs de locomotives et de moteurs de locomotives, ateliers de reconstruction, chemins de fer et exploitants de lignes ferroviaires. Elles toucheront les compagnies ferroviaires canadiennes qui exploitent des divisions en territoire américain et toute entreprise canadienne du secteur ferroviaire ayant des débouchés aux États-Unis, qu'il s'agisse de constructeurs, d'atelier de reconstruction ou de fournisseurs de pièces. Pour faire respecter sa réglementation, l'EPA procédera aussi bien à des essais d'homologation de type en usine qu'à des vérifications de conformité en service. Ces dernières viseront à faire en sorte que les constructeurs et les ateliers de reconstruction mettent sur le marché des locomotives dont les émissions restent à l'intérieur des plages admissibles après les essais d'homologation et en cours d'exploitation. Dans le cas où une locomotive serait trouvée non conforme aux normes, les correctifs devront viser toutes les locomotives de la même famille, qu'elles aient dépassé leur durée de vie utile ou non. Par ailleurs, les chemins de fer de classe I devront contrôler chaque année un échantillon de leur parc de locomotives ayant dépassé leur durée de vie utile. La réglementation prévoit aussi de lourdes sanctions pénales à l'encontre non seulement des sociétés qui auront trafiqué leur matériel, enlevé des dispositifs antipollution ou mis en service des équipements ou accessoires non homologués, mais aussi de leurs «dirigeants responsables».

L’étude a déterminé qu’un protocole faisant appel à un moteur de recherche monocylindre dérivé d’un moteur diesel à vitesse moyenne serait non seulement plus économique, mais également moins compliqué à exécuter que celui de la PR 503 de l’AAR qui suppose l’utilisation successive de deux moteurs intermédiaires, soit un 1G2 et un EMD 567 bi-cylindre. Le nouveau protocole prendra moins de temps et donnera des résultats caractérisant mieux les moteurs diesel ferroviaires modernes. De plus, avec un volet contrôle des émissions polluantes aligné sur la nouvelle réglementation antipollution de l’EPA, ce protocole deviendra un outil à la fois simple et exhaustif d’évaluation et de contrôle des additifs pour carburants.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

AAR	Association of American Railroads
ASME	American Society of Mechanical Engineers
CED	Combustion Enhancing Device
CFR	Code of Federal Regulations (U.S.)
CO	Carbon Monoxide
CRC	Coordinated Research Council (U.S.)
DI	Direct Injection
DIN	Deutsche Industrie Norm
EMD	Electro-Motive Division of General Motors
EPA	Environmental Protection Agency (U.S.)
ESDC	Engine System Development Centre
FOA	Fuel Oil Additive
FTP	Federal Test Protocol (U.S.)
GE	General Electric
THC	Total Hydrocarbons
IDI	Indirect Injection
IMEP	Indicated Mean Effective Pressure
LOA	Lube Oil Additive
NO_X	Oxides of Nitrogen
PEP	Performance Enhancing Products
PM	Particulate Matter
RAC	The Railway Association of Canada
RP	Recommended Practice
SAE	SAE International
SCRE-251	ALCO 251 Single-Cylinder Research Engine
SFAT	Simplified Fuel Additive Test
SwRI	Southwest Research Institute

1.0 INTRODUCTION

One of the major operating costs incurred by the railways today is the cost of diesel fuel; therefore, companies are constantly examining the possibility of increasing fuel efficiency with fuel oil additives (FOA), lubricating oil additives (LOA) and combustion enhancing devices (CED). However, products which increase fuel efficiency generally tend to affect engine components as well as emissions. The presently accepted standard of evaluating these performance enhancing products (PEP) is the Association of American Railroads (AAR) Recommended Practice (RP) 503, entitled, "Locomotive Diesel Fuel Additive Evaluation Procedure". This procedure was adopted in 1980, and consists of four different stages. It compares the effects of FOAs on fuel chemical properties, engine wear and deposits, as well as engine performance characteristics (1). Presently, the only organization that can carry out the AAR RP-503 test is Southwest Research Institute (SwRI). Each test requires over 1000 hours for completion and costs more than $240,000 US. Furthermore, it does not evaluate the effect of PEPs on engine emissions on a level representative of EPA's new emission standard known as 40 CFR 92 (2). Modification of the AAR RP-503 procedure to include testing to the 40 CFR 92 emission standard requirements would make this evaluation method even more expensive. The costly and time consuming test procedure imposes a financial burden for anyone who wishes to develop and market certified additive products.

The Simplified Fuel Additive Test (SFAT) project proposed by the Engine Systems Development Centre (ESDC) was initiated to develop a procedure that would address both the engine performance and wear effects as well as the emissions trend exhibited by the PEP. The proposed procedure would offer a lower analysis cost and would require less time for completion.

Hence, the purpose of the first phase of the SFAT project is to assess the feasibility of developing a PEP evaluation protocol that replaces the AAR RP-503 and includes emissions testing representative of the EPA 40 CFR 92 regulations while offering a lower overall evaluation cost to the PEP manufacturer. The following is a list of the objectives of this study:

- Literature search - conduct a comprehensive literature search of all documentation relating to fuel and lubricant additives and combustion enhancers as well as pertinent information on test engines.

- Review of the EPA regulations - identify and review the pertinent EPA emissions regulations and definition of test facility equipment requirements to carry out emission tests in accordance with the regulatory requirements.

- Review of the Caterpillar 1G2 Engine and comparison with the Single-Cylinder Research Engine (SCRE-251). Review the role and characteristics of the Caterpillar 1G2 engine used in the AAR RP-503 to measure the effect that additives may have on engine components and assess how the ESDC SCRE-251 can be used in its place. Compare the dimensions of the SCRE-251 and 1G2 and determine whether the existing 1G2 charts relating to the effects of the additive on deposits and wear will be applicable to the SCRE-251 or a new correlation has to be developed

- Performance correlation to current multi-cylinder engines - evaluate the use of the unique capability of the SCRE-251 to represent various engine configurations of current medium-speed locomotive diesel engines, and its use in place of the multi-cylinder engines.

The results of studying these objectives are detailed in the following sections after which a conclusion is presented along with the recommendations offered by the project team members.

2.0 LITERATURE SEARCH

As part of the evaluation of the feasibility of developing a Simplified Fuel Additive Test procedure that would be more affordable and accessible to aftermarket suppliers when compared to the current AAR RP-503, a comprehensive literature search was conducted. A large number of references were cited, including SAE technical papers and EPA reports. Furthermore, relevant information was obtained from suppliers of additives, bolt-on devices, and Internet web sites. Only those references that are relevant to this study are presented in the reference section.

The database and information sources used in this work are provided in Appendix A. Appendix B depicts relevant test procedures being used to test PEPs. Appendix C specifies the internet web sites employed to gather information in addition to sources previously mentioned in Appendix A. Appendix D includes reports and articles illustrating the different types of products being marketed as well as test results on these products being offered by the manufacturers or a third party. In addition, this section provides a list of devices and additives that were previously tested.

The review of the gathered data focused on; (a) the current state-of-the-art technology of screening and evaluating the effects of additives on engine performance, (b) the type of test engine mostly used, (c) understanding the mechanisms and controlling factors of the AAR RP-503 and, (d) the potential of using the ESDC single-cylinder engine as the screening and evaluation tool.

Numerous claims are being made by manufacturers of PEPs with respect to fuel saving, improved performance and reduced emissions (Appendix D) examples of which are provided below.

> "Laboratory and field tests of diesel engines using Ion Collider technology demonstrate the following benefits: reduces fuel consumption 5%-20%, increases power output 5%-15%, reduces heat production 5%-10%, reduces hydrocarbon emissions, reduces exhaust opacity, eliminates carbon deposits."
>
> - Advanced Catalytic Technologies, Fuel Refinement Products for Diesel Engines, Brochure (see Appendix D)

> "The COMTEC combustion enhancement technology reforms the molecular structure of diesel, gasoline and other liquid fossil fuels. This will improve the combustion process resulting in: reduced fuel consumption, increased power, reduced smoke, reduced emissions, reduced exhaust gas temperatures, cleaner combustion chamber"
>
> - COMTEC Combustion Technologies Inc. Brochure (see Appendix D)

> "ADERCO maintains a higher performance (for a longer period of time) for maximum fuel savings. By treating diesel fuel with ADERCO additives, you will obtain better atomization and more complete combustion which will translate into: fuel savings (brochure indicates 4% on locomotive engines), reduced emissions, reduced maintenance."
>
> - ADERCO Additives Brochure (see Appendix D)

These claims that are being made by the PEP suppliers could be substantiated using the SFAT protocol.

The obtained information tends to indicate that a single-cylinder research engine can be conveniently used to provide an alternative to the existing AAR RP-503 test procedure. These types of engines can be utilized to investigate the effect of fuel and lubricant additives on emission, engine wear, and deposits. Various methods have been found in the literature that are currently used for in-house research that examine the effect of fuel additives on emissions (3-9). These test procedures can be used as background information when developing a standard test protocol to replace the AAR RP-503. The trend observed in literature shows that the use of single-cylinder research engines in laboratories is rapidly increasing due to the advantages offered by this type of engine.

The results of this extensive survey are sufficient to assess the feasibility of developing a test protocol that will be an alternative to, or replace the AAR RP-503. Complete descriptions of these findings are covered in the following sections.

3.0 REVIEW OF THE EPA REGULATIONS

The promulgated emission standards published in the Federal Register on April 16, 1998, regulating locomotive diesel engine emissions of oxides of nitrogen (NO_x), total hydrocarbons (THC), carbon monoxide (CO), particulate matter (PM), and smoke are given in Tables 1 and 2. The three tier levels refer to date of manufacture of the diesel engine. After Tier 2 is enforced, the new standards will achieve approximately a two-thirds reduction in NO_x emissions while THC and PM emissions will be halved. The standards are effective January 1, 2000, and will affect locomotive manufacturers, re-manufacturers and importers, as well as locomotive diesel engine component suppliers and railroads.

Table 1 - Gaseous and Particulate Emissions For
Locomotives Under EPA (g/bhp.h)

	THC	CO	NO_x	PM
Tier 0 Locomotives - Manufactured from 1973- 2001				
Line Haul	1.0	5.0	9.5	0.60
Switch	2.1	8.0	14.0	0.72
Tier 1 Locomotives - Manufactured from 2002-2004				
Line Haul	0.55	2.2	7.4	0.45
Switch	1.2	2.5	11.0	0.54
Tier 2 Locomotives - Manufactured from 2005 and beyond				
Line Haul	0.3	1.5	5.5	0.20
Switch	0.6	2.4	8.1	0.24
Estimated Emissions 1997				
Line Haul	0.5	1.5	13.5	0.34
Switch	1.1	2.4	19.8	0.41

These new regulations pose a significant impact for the Canadian locomotive industry being that any U.S.-bound locomotive or engine component must comply with the new EPA regulations. Presently, Canadian locomotives are exempted from EPA regulations if their use in the U.S. is negligible. However, Canadian locomotives that operate extensively in the U.S. must conform to the EPA regulations (2). This requires frequent and extensive testing and certification of those affected Canadian locomotives.

Table 2 – Smoke Standards For Locomotives Under EPA
(% Opacity – Normalized)

	Steady State	30 sec Peak	3 sec Peak
Tier 0 Locomotives	30	40	50
Tier 1 Locomotives	25	40	50
Tier 2 Locomotives	20	40	50

The EPA regulation contains an anti-tampering provision, which provides for severe criminal penalties for corporations and responsible corporate officials (2). Tampering, in the current context, includes knowingly changing the emissions characteristics of a regulated diesel engine by installing a non-EPA-approved component or removing an engine component. Therefore, the use of any non-EPA-approved PEP will be considered tampering.

To ensure that all diesel engine locomotives meet the new EPA standards as they roll off the production line, the EPA will conduct production line testing of new and re-manufactured locomotives. An in-use testing program will evaluate the ability of locomotives to continue to comply with the new standards by requiring the locomotives be tested at 50%-75% of useful life and that Class 1 railroads annually test 0.15% of their locomotives that have met or exceeded their useful life.

The exhaust gas sampling and analytical system shown in Figure 1 was developed for the EPA at SwRI and no variation is allowed from the equipment indicated unless permitted by the administrator as a result of a proponent proving functional equivalence. The actual equipment required is: NO_x detection - chemiluminescence detector, CO and CO_2 non-dispersive infrared analyzer, and a heated flame ionization detector is used for the hydrocarbon detection. Particulate matter measurement requires the use of a dilution tunnel that is built to SAE specifications. Portable mini-dilution tunnels are available; however, EPA has not yet approved them for regulatory purposes. The remainder of the equipment required is mainly gas tubing and instrumentation. A significant item that is not on the flow sheet is a temperature and humidity controlled weighing room used in the particulate matter determination.

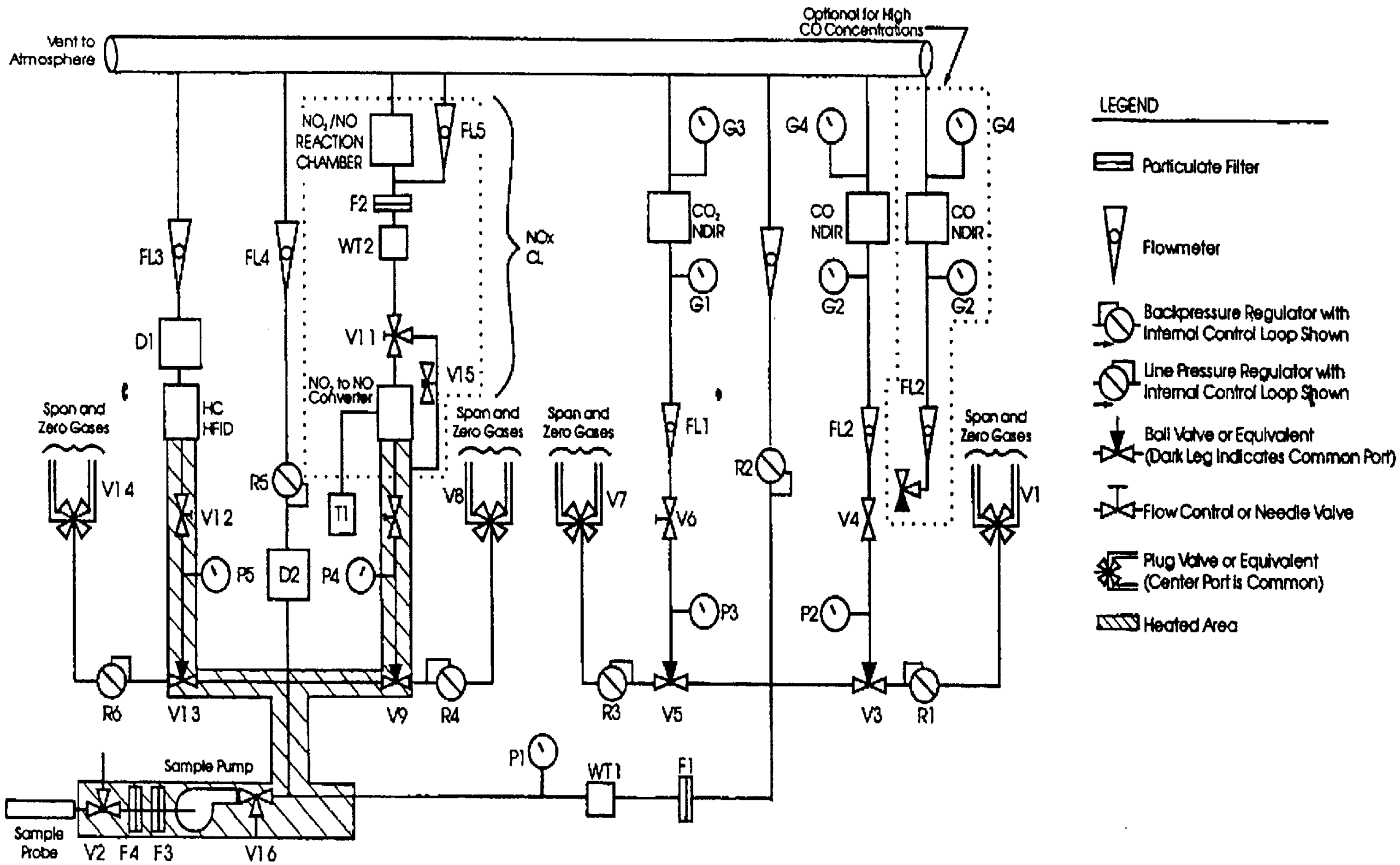


Figure 1 – Exhaust Gas Sampling and Analytical Train

4.0 REVIEW OF THE AAR RP-503 AND PROPOSED SFAT PROCEDURE

The currently accepted method of testing fuel oil additives for use in locomotive engines is the AAR RP-503 procedure entitled "Locomotive Diesel Fuel Additive Evaluation Procedure" which was adopted in 1980. This procedure consists of four individual phases of evaluation; a chemical analysis of the treated diesel fuel, a wear and deposit evaluation conducted on a Caterpillar 1G2 test engine, a performance evaluation conducted on an EMD twin-cylinder test engine, and a final performance evaluation on a multi-cylinder GE or EMD locomotive engine. The AAR RP-503 procedure does not address lube oil additives nor combustion enhancing devices. The results of conducting multiple engine tests are that the RP-503 procedure requires in excess of 1000 hours of testing and may cost upwards of $240,000 US. Furthermore, the only institution currently equipped to carry out this procedure is SwRI in San Antonio, Texas. The flow chart displayed on pages F-234 and F-235 of the AAR Mechanical Division Manual of Standards and Recommended Practices outlines the activities involved in the AAR RP-503 procedure and is summarized for comparison in Figure 2.

The "Feasibility of a Simplified Fuel Additive Evaluation Protocol" project was initiated in order to assess the feasibility of developing a new test procedure that provided to the aftermarket performance enhancing product suppliers a simplified, less costly alternative to the existing AAR RP-503 protocol. In addition to fuel oil additive evaluation, this proposed protocol would provide a means for testing lube oil additives and combustion enhancing devices, for both performance and engine wear characteristics while also examining the effects on the exhaust emissions. A study of the recently published EPA regulations was included in the project scope in order to establish a target for the emissions segment of the proposed protocol and to create an awareness of the ever increasingly stringent emission regulations, thereby showing the importance of putting in service the available products. The proposed SFAT procedure would require less time and money than the existing AAR RP-503 while conducting an analysis of the effects of aftermarket products on performance, wear, and emissions with results more representative of today's locomotive engines.

As shown in Figure 3, the preliminary activities of the proposed SFAT procedure would be identical to those of the existing AAR RP-503, involving mainly the initial information gathering and contracting between the supplier and the testing facility, and the chemical analysis of the treated fuel or oil. However, the three phases of engine testing called for by the RP-503 would be replaced in the SFAT procedure through the conducting of performance and engine wear testing on a sole medium-speed single-cylinder diesel engine, the SCRE-251. In order to validate the replacement of the Caterpillar 1G2, EMD twin-cylinder, and GE or EMD multi-cylinder test engines with the SCRE-251, a comparison of these engines must be made. As shown in the following sections, the ability of this single-cylinder engine to represent current high horsepower multi-cylinder engines eliminates the need for testing on full size locomotive engines, provides a more representative engine wear analysis tool, and consequently dramatically reduces the overall time and cost involved with the test procedure. The battery of tests performed in the RP-503 includes the option to evaluate the emission effects of an additive, while the proposed SFAT protocol would include an emphasized emissions trending analysis based on the EPA regulations and federal testing procedures.

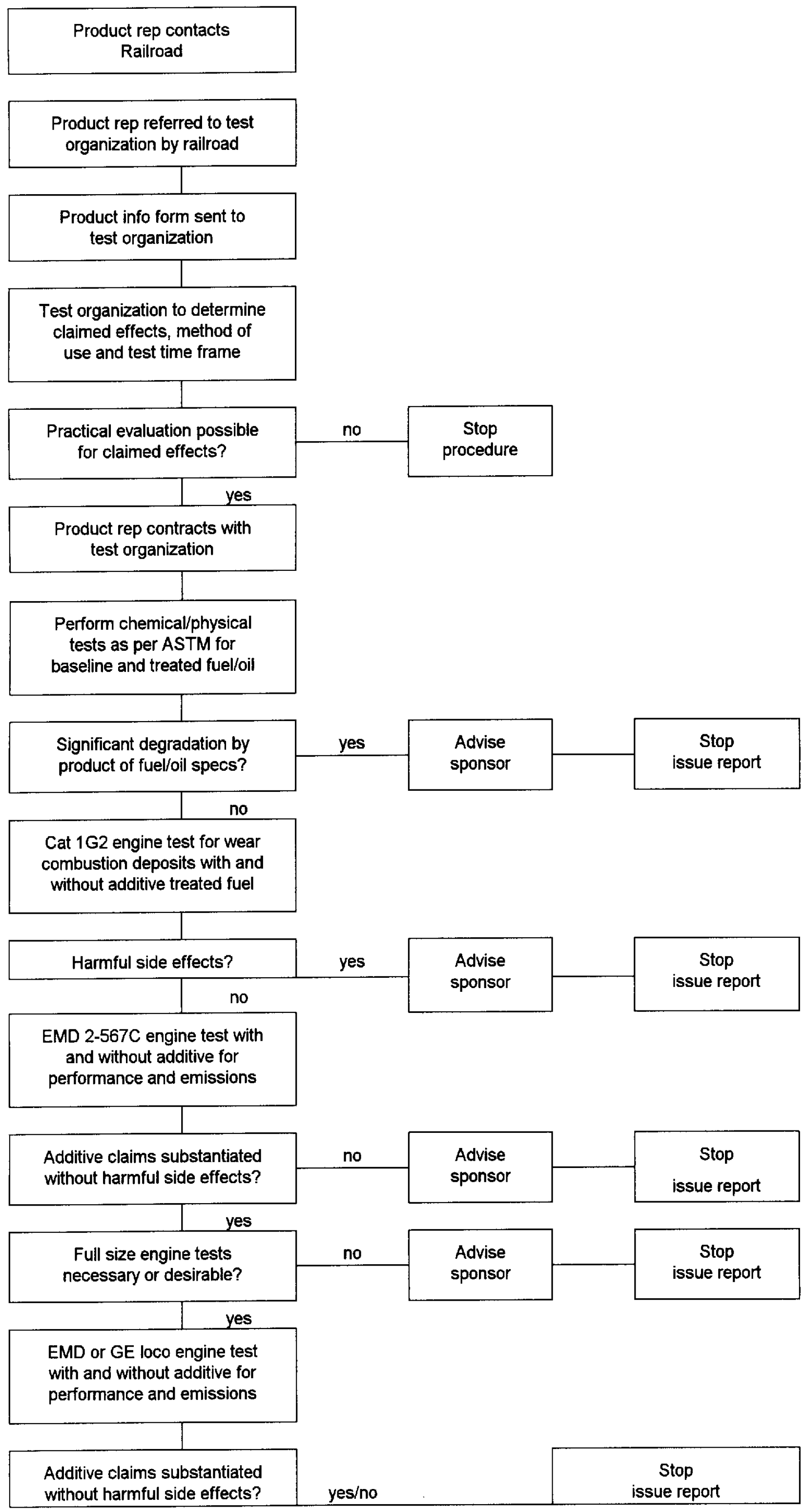


Figure 2 - Existing AAR RP-503 Procedure

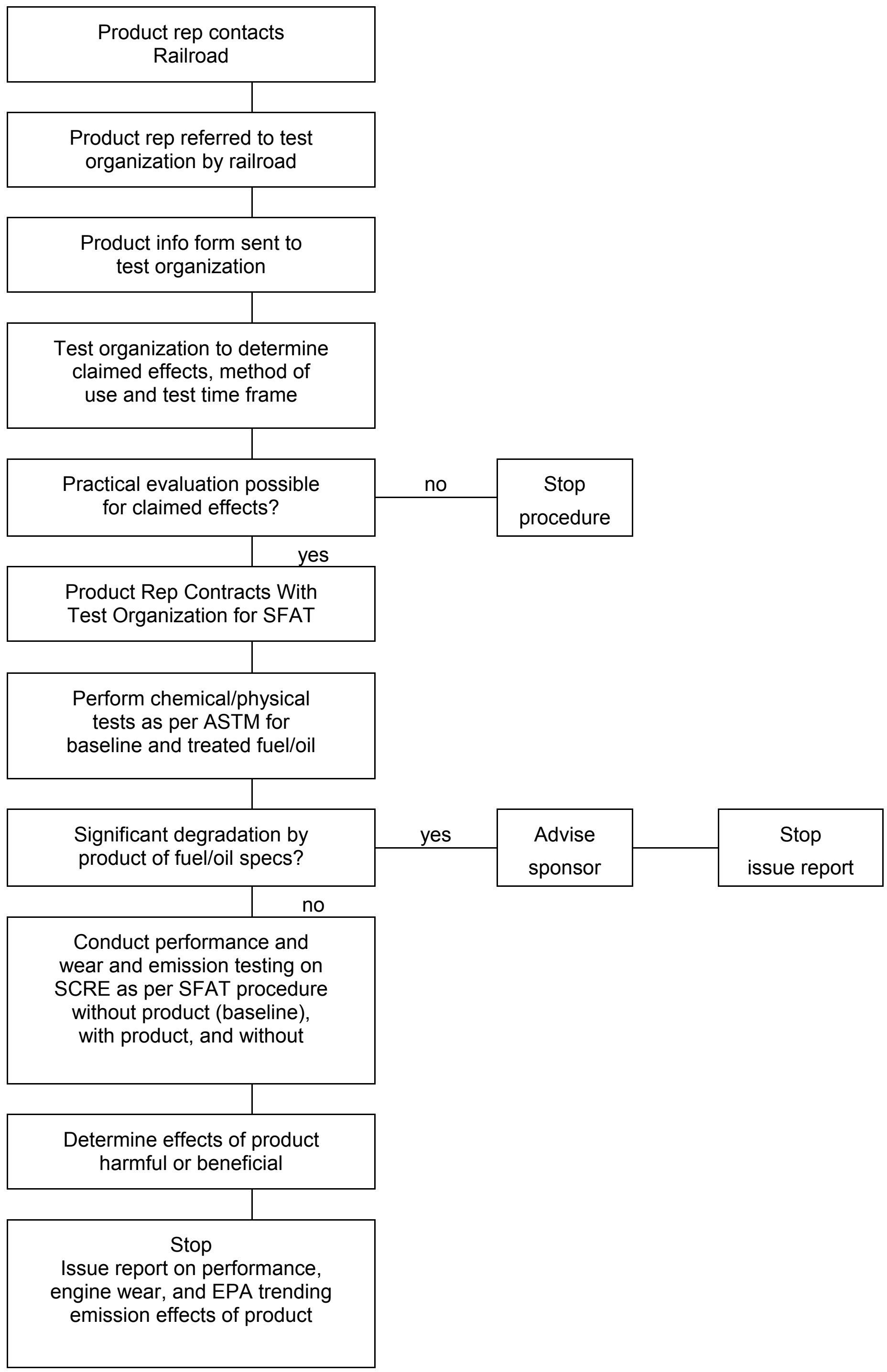


Figure 3 - Proposed SFAT Procedure

5.0 REVIEW OF THE CATERPILLAR 1G2 AND COMPARISON WITH THE SCRE-251

The main objective of this task is to determine the feasibility of utilizing the ESDC SCRE-251 in the proposed SFAT procedure in place of the Caterpillar 1G2 test engine used in Phase II of the AAR RP-503 procedure. This includes reviewing the role and characteristics of the Caterpillar 1G2 engine and determining whether the existing Caterpillar 1G2 demerit charts are applicable to the SCRE-251 for deposit and wear analysis.

The 1G2 is an indirect-injection (IDI), aluminum piston engine with a rated speed of 1800 RPM and a rated power of 33 kW that is nearly fifty years old. It was replaced first by the Caterpillar 1K test engine and most recently by the Caterpillar 1P test engine, both of which are direct injection (DI), steel cap-aluminum body piston engines with rated speeds of 1800 RPM, rendering the 1G series engines obsolete. The 1G2 is no longer manufactured and the replacement parts supply for this engine is severely limited.

The main role of the Caterpillar 1G2 engine in the AAR RP-503 procedure is to provide a preliminary evaluation of the fuel additive with respect to engine performance, wear and deposits (1). The results obtained from the 1G2 test will determine the merit of continuing the AAR RP-503 test procedure. The 1G2 was selected for use in the AAR RP-503 procedure because it was the standard tool for lubricant and fuel testing at the time. The 1G2 is not capable of simulating conditions expected on a medium-speed diesel engine; however, it was used to eliminate the financial burden of conducting preliminary testing on a full-size locomotive engine (1).

The Caterpillar 1G2 test involves comparison of the piston with demerit charts to determine the wear and deposit conditions of the 1G2 after burning the test fuel. The demerit charts deal only with the piston condition and are specific for the Caterpillar 1G2 test engine. Therefore, these demerit charts are not applicable to the ESDC SCRE-251 and new charts would have to be developed for the SCRE-251 piston. In addition, demerit charts should be developed for the other power assembly components of the SCRE-251. There are several standard rating methods including the Coordinating Research Council (CRC) rating method and the Deutsche Industrie Norm (DIN) 51361 rating method (10). Whether a completely new method is developed for the SCRE-251 or a standard rating method is adopted, the important issue is consistency of method usage when comparing results.

As shown in Table 3 and Figure 2, the Caterpillar 1G2 engine does not represent the characteristics of a medium-speed diesel engine. From the research done during Task IV of this project, it is evident that using the SCRE-251 in place of the Caterpillar 1G2 test engine would result in a wear and deposit analysis much more representative of medium-speed locomotive diesel engines without the financial burden involved with testing on a multi-cylinder locomotive engine. The added benefit of utilizing the SCRE-251 as a test engine for the SFAT is that the first stage of fuel additive testing could incorporate both a preliminary wear/deposit analysis similar to the 1G2 test simultaneous with performance testing similar to the Phase III and IV testing of the AAR RP-503 procedure.

It should be noted that the trend apparent in the literature (11-13,17) is towards conducting research and development testing on single-cylinder engines that are representative of the fleet for which testing is being done.

Table 3 - 1G2, SCRE-251, and SCRE-B2400 Specifications

	Caterpillar 1G2	SCRE-251	SCRE-B2400
Bore x Stroke (mm)	13 x 16.5	229 x 267	240 x 270
Displacement (L)	2.2	11.0	12.2
Rated Speed (RPM)	1800	1200	1200
Rated Power (kW)	33	253	305
IMEP (Bar)	n/a	23.0	25.0
P_{max} (Bar)	n/a	145.0	175.0
Injection	IDI	DI	DI

6.0 SCRE-251 TO MULTI-CYLINDER COMPARISON

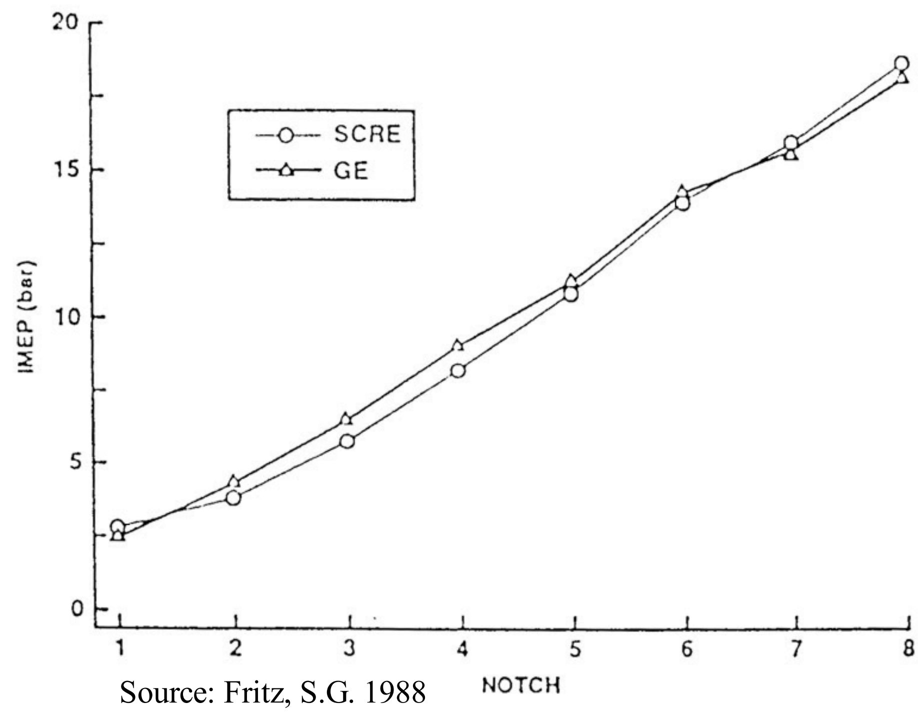
The SCRE-251 is a four-stroke, high Indicated Mean Effective Pressure (IMEP) diesel engine with a 1200 RPM rated speed, originally designed by Bombardier as a joint project with Transport Canada - Transportation Development Centre, as a development tool for the ALCO-251 medium-speed diesel engine, as a research tool for off-spec and alternative fuels in medium-speed diesel engine use, and as a lubricating oil research and classification tool (14). The most obvious benefits gained through use of a single-cylinder engine include lower operating costs, reduced maintenance time, expanded flexibility, minimized instrumentation requirements, and precise investigations with minimum components to adjust.

The conditions required by a single-cylinder engine to represent the performance of a multi-cylinder engine are quoted below, as published by E.M.J. McKenzie and S.G. Dexter in the Ricardo paper number DP82/1667 entitled "The Use of a Single-Cylinder Test Engine for Research and Development of Medium Speed Diesels" (15).

> "There are five main conditions which a single-cylinder engine should fulfill if the measured fuel consumption and other performance parameters are to be directly related to a multi-cylinder engine. It is also advisable to attempt to fulfill these conditions if fully representative conditions for component testing are to be supplied. These conditions are:
>
> (i) The in-cylinder components of the single should be identical to those of the multi-cylinder engine;
>
> (ii) The single should operate at the same IMEP as the multi-cylinder engine;
>
> (iii) Coolant and lubricant flows and temperatures should be identical to those on the multi- cylinder engine;
>
> (iv) The conditions before the intake ports on the cylinder head should be identical to those on the multi-cylinder engine;
>
> (v) The conditions after the exhaust ports on the cylinder head should be identical to those on the multi-cylinder engine."

The SCRE-251 was designed specifically to meet these requirements (16) using a standard power assembly, fuel pump, fuel pump support and main bearings, and incorporating the necessary flexibility required to represent future medium-speed diesel engines of higher IMEPs and rated RPMs. Because of the incorporation of many standard components, the availability of replacement parts for the SCRE-251 is not a significant concern. Simulation of modern turbo-charging boost pressures on the SCRE-251 is accomplished with a variable compressor and air-heater system. Exhaust back pressure can be varied through a butterfly valve, while blow-down pressures may be simulated with an orifice plate. Through use of an electronic governor, either gen-set type or locomotive type loading characteristics may be adopted.

To show that the SCRE-251 can accurately represent multi-cylinder engines, SwRI's Bombardier SCRE-251 was configured to represent a General Electric (GE) 7FDL 12-cylinder engine with excellent results (17). Figure 4 shows the relationship in IMEP of the SCRE-251 and the GE-7FDL after the SwRI experiment. Note that the SCRE-251 employs the same bore and stroke (229 mm x 267 mm) as the GE-7FDL. The close correlation between the IMEP of the configured SCRE-251 and GE-7FDL indicates a direct agreement between the performance characteristics witnessed on the SCRE-251 and those expected on the GE-7FDL.



Source: Fritz, S.G. 1988

Figure 4 - SCRE-251 to GE 7FDL Emulation

The ability of ESDCs SCRE-251 to represent wear and deposit tests representative of medium-speed locomotive diesel engine has been demonstrated in this section. Its unique design features, allows easy modification and reconfiguration of the engine to perform various tests. Furthermore, the engine can be easily equipped with instruments required to evaluate the emissions. Based on these findings, it is feasible to use ESDCs SCRE-251 to develop a new Simplified Fuel Additive Test, which may replace the AAR RP-503 test procedure.

7.0 THE FEASIBILITY ASSESSMENT

The feasibility of developing a simplified fuel additive evaluation test has been explored extensively. A literature search was conducted to obtain relevant information relating to PEPs and test procedures. According to these findings a simple fuel additive evaluation test can be devised to replace the AAR RP-503 which will utilize the SCRE-251 to examine the effect of PEPs on engine wear and deposits while also trending the emissions effects.

The utilization of the SCRE-251 for the SFAT stems from the unique advantages offered by its design. The engine is mechanically similar to the multi-cylinder GE-7FDL engine presently used by SwRI for the AAR RP-503 evaluation procedure. Therefore, data generated with the SCRE-251 will correlate well with today's full-size high power locomotive engines. The mechanical simplicity of the engine allows for very precise in-engine instrumentation. This system can be used to carry out engine wear and lubricating oil analysis at a much lower cost, since a single locomotive cylinder is being used instead of a multi-cylinder locomotive engine.

Unlike the AAR RP-503, where the wear and deposit evaluation test is conducted in three different phases, the simplified fuel additive test would require only a single step for engine wear and deposit evaluation due to the use of the SCRE-251. However, demerit charts used for AAR RP-503 cannot be utilized and new demerit charts have to be developed for this procedure. According to the gathered information, establishing a correlation between a single-cylinder engine and a multi-cylinder engine with respect to emission would be a very complicated project in itself. However, a test procedure can be developed to determine the emissions trend exhibited by PEPs.

Based on the above explanations, developing a simplified fuel additive test that can be used to evaluate the engine wear and deposits effects as well as the emissions trend for PEPs is feasible and would be a cost effective alternative to the existing AAR RP-503.

8.0 CONCLUSIONS

The literature search produced sufficient information to determine the diverse types of fuel oil and lube oil additives and combustion enhancing devices that are presently available and/or have been tested in the recent past. Also examined were the methods utilized during testing of these above-mentioned products from which a trend was observed towards testing with single-cylinder engines representative of the fleet in question (11,12,18-20). Information was also gathered concerning the Caterpillar 1G2 Test Engine, the ESDC SCRE-251 and the EPA regulations pertinent to future emissions requirements.

Following a review of the new EPA regulations, the testing equipment required to perform EPA emissions testing was determined. A review of the regulations was provided and the most important aspects highlighted.

It was determined that the SCRE-251 could certainly replace the Caterpillar 1G2 test engine and would consequently produce test results much more representative of those expected from a multi-cylinder medium-speed diesel engine while remaining cost efficient. In addition, wear and deposit demerit charts would need to be developed specifically for the ESDC SCRE-251 based on the current standard rating methods such as DIN 51361 and the CRC method.

From the documentation obtained during the literature search concerning the design of the SCRE-251, it is evident that not only was this research engine designed and built to simulate multi-cylinder medium-speed diesel engines with major cost and time advantages, but, also, there exists the flexibility to configure the SCRE-251 to simulate performance conditions representative of current high IMEP multi-cylinder diesel engines.

In conclusion, it was determined that it is definitely feasible to develop a new test procedure to replace the AAR RP-503 protocol to test FOA, LOA, and CED effects on engine performance while simultaneously incorporating emissions trending representative of the EPA 40 CFR Part 92 Emissions Standards for Locomotive Engines. It was also determined that it is feasible to specify the ESDC SCRE-251 as replacements for the Caterpillar 1G2 and other test engines used in the AAR RP-503 protocol while obtaining performance results indicative of those expected from modern multi-cylinder medium-speed diesel engines as used in today’s locomotives.

9.0 RECOMMENDATIONS

The results pertaining to the work carried out during the course of this feasibility study emphasize the limitations imposed by the current standard AAR RP-503 test procedure, rendering it unsuitable for testing representative of today's high-output locomotive engines. It is therefore imperative that a new more representative protocol be developed so that North American railways may realize the lucrative benefits of the products available from PEP suppliers. In addition to the conclusions stated from this work, it is recommended to proceed in the following manner to develop the Simplified Fuel Additive Test Procedure.

Considerable time will be required to gather the necessary information and equipment required to continue this project. Suppliers of PEPs should be contacted and samples of their products, along with all the information and specifications relating to them, obtained. Emphasis should be placed on acquiring products that have already been tested and documented according to other protocols. A baseline fuel will need to be acquired in order to conduct trending tests representative of the EPA regulations. With the PEPs and baseline fuel in hand, the test cell instrumentation should be designed to enable performance testing of the PEPs. This will include designing both low-speed and crank-angle based instrumentation as well as determining the equipment required to examine emission trends. The final step before commencing testing is to develop a test sequence for determining the demerit charts that will be utilized during the SFAT.

With completion of the above-mentioned steps, testing of the PEPs may commence. This testing will produce the demerit charts to be used later on during the SFAT. During the testing, the SCRE-251 test engine will be run and disassembled multiple times in order to determine the extent of the effects which each PEP caused. These effects will be correlated to the known effects of the respective PEP when compiling the demerit charts. Upon completion of the required charts, the SFAT protocol can be designed and test cell instrumentation configured. The final step will require proof of concept testing of the SFAT procedure in order to acquire certification and third party approvals.

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APPENDIX A

INFORMATION SOURCES AND DATABASES

MAGAZINES

A-1. Diesel Fuel News

A-2. Octane Week

A-3. 21st Century Fuels

A-4. Diesel Progress

A-5. Lubricants World

A-6. Lubes-n-Greases

A-7. Diesel & Gas Turbine Worldwide

A-8. Lubrication Engineering

A-9. Automotive Engineering

DATABASES

A-10 SAE WEBDEX

A-11 SAE FUELS AND LUBRICANTS CONFERENCE PAPERS ON CD-ROM

APPENDIX B

TECHNICAL PAPERS THAT ADDRESS DIFFERENT TYPES OF TEST PROCEDURES USED FOR EMISSION EVALUATIONS AND ENGINE PERFORMANCE

B-1. Fritz, S.G., McNett, B., and Schandelmeier, R., "Exhaust Emissions from Heavy-Duty Diesel Engines Operating on JP-8 Blended with Used Engine Oil", ASME Paper No. 98-ICE-76, Vol. 30-1, pp. 1-7, 1998.

B-2. Akasaka, Y., Suzuki, T., and Sakurai, Y., "Exhaust Emissions of a DI Diesel Engine Fueled with Blends of Biodiesel and Low Sulfur Diesel Fuel", SAE Paper No. 972998.

B-3. Knothe, G., Bagby, M.O., and Ryan, T.W., "Cetane Numbers of Fatty Compounds: Influence of Compound Structure and Various Potential Cetane Improvers", SAE Paper No. 971681.

B-4. Mainwaring, R., "Soot and Wear in Heavy Duty Diesel Engines", ASE Paper No. 971631.

B-5. Huchings, M., Chasan, D., Bruke, R., Odorisio, P., Rovani, M., and Wang, W., "Heavy Duty Diesel Deposit Control; Prevention as a Cure", SAE Paper No. 972954.

B-6. Tanaka, S., Morinaga, M., Yoshida, H., Takizawa, H., Sanse, K., and Ikebe, H., "Effects of Fuel Properties on Exhaust Emissions From DI Diesel Engines", SAE Paper No. 962114.

B-7. Logan, M.R., Middleton, W.A., and Palazzotto, J.D., "Railroad Diesel Engine Cleanliness: The Impact of the Engine Oil Additive Formulation", ASE Paper No. 961094.

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B-9. Rogerson, J.S., Reynolds, E.G., Marsh, P., and Fredholm, S., "The Influence of Fuel Parameters and Catalyst Formulation on Catalyst Performance over the European R49 Heavy Duty Diesel Emissions Cycle", ASE Paper No. 952390.

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B-11. Kennedy, S., Ragomo, M.A., Lohuis, J.R., and Richman, W.H., "A synthetic Diesel Engine Oil with Extended Laboratory Test and Field Service Performance", SAE Paper No. 952553.

B-12. Mather, D.K. and Reitz, R.D., "Modeling the Use of Air-Injection for Emissions Reduction in a Direct-Injected Diesel Engine", SAE Paper No. 952359.

B-13. Youdan, G.H. and Wharton, M.H., "IDI Lubrication and Wear", SAE Paper No. 810500.

APPENDIX C

INTERNET WEB SITES USED TO ACQUIRE RELEVANT INFORMATION

C-1. WWW.jenbacher.com

C-2. WWW.drdiesel.com

C-3. WWW.designinfo.com/sierra/ref/appnote2.htm

C-4. WWW.montana.com/sfr/sfr2000.htm

C-5. WWW.cat.com

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APPENDIX D

PEP PRODUCTS AND CLAIMS MADE BY MANUFACTURERS

(Not available in electronic format/
Non disponible en format électronique)