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SIMPLIFIED FUEL ADDITIVE TEST

PHASE II: PROCEDURE DEVELOPMENT AND METHODOLOGY

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BY

AREF TAGHIZADEH, MALCOLM L. PAYNE, FAN SU, AND MANUEL VASQUEZ

ENGINE SYSTEMS DEVELOPMENT CENTER

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16. Abstract

This report describes a preliminary methodology developed for the Simplified Fuel Additive Test (SFAT) protocol. The report discusses proposed test sequences based on available information on tests performed by others on single-cylinder and multi-cylinder research engines. The test consists of preliminary chemical analyses, followed by baseline, conditioning, and performance engine tests. Emissions trending is also incorporated into the test sequence. The validity of the recommended tests will be verified through proof-of-concept, which will follow this phase of the project. Any necessary changes to the test sequences proposed in the report will take place during the proof-of-concept stage.

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16. Résumé

Ce rapport présente un protocole préliminaire mis au point pour l'essai simplifié des additifs pour carburants (SFAT, pour *Simplified Fuel Additive Test*). Les séquences d'essais proposées se fondent sur les résultats d'une étude comparative de moteurs de recherche monocylindre et multi-cylindres réalisée lors d'une phase antérieure du projet. Ces séquences débutent par des analyses chimiques, suivies de trois types d'essais sur moteur (de référence, de rodage et de performances). La mesure des émissions polluantes est également intégrée au protocole. Les essais recommandés seront validés au cours de la prochaine phase du projet, soit celle de la validation de principe. C'est alors que seront apportées les modifications nécessaires aux séquences d'essais proposées.

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EXECUTIVE SUMMARY

Operating cost reduction through fuel economy is a major challenge in the railway industry. Such a reduction can be realized through approved aftermarket performance-enhancing products. Certification of these products requires performance and emissions tests in accordance with the Association of American Railroads Recommended Practice (AAR RP-503) test procedure and Environmental Protection Agency (EPA) emissions regulations. The existing test is lengthy and expensive, preventing small businesses from entering the market. The need for an alternative procedure that could provide similar results with inclusion of emission tests faster and at lower cost resulted in the Simplified Fuel Additive Test (SFAT) project.

The SFAT project (Phase I) examined the feasibility of developing a test procedure that could properly evaluate the claimed benefits of aftermarket products at faster time and lower cost. This study showed that the ALCO 251 single-cylinder research engine (SCRE-251) can be used to develop such a procedure (TP 13215E). It was concluded that using a single-cylinder research engine derived from a medium-speed diesel engine would not only be more economical, but also less complex and more representative of modern locomotive diesel engines.

The current phase of the SFAT project was undertaken to develop a test procedure based on the information gathered in the feasibility report. Existing test procedures such as RP-503, SAE J304, SAE J1423, DIN 51 361, ASTM STP 509A Part I, and CEC L-42-A-92 were reviewed. Based on the information gathered from this review, a tentative test procedure was developed.

The test consists of two steps. The first step determines the fuel properties with and without additive through chemical analyses to ensure its suitability for engine testing. The next step is the engine test, which includes 40 hours baseline with base fuel, 160 hours conditioning, and 40 hours performance test with treated fuel. The emission analyses will be conducted during baseline and performance tests for comparison purposes. This procedure is also suitable for evaluation of lubrication oil additives.

The ESDC test cell and data acquisition system were reconfigured and automated for both low- and high-speed data collection and processing. The fuel and lubrication oil laboratory was upgraded for fuel analyses.

The test sequence must be finalized through the next proof-of-concept phase. For this reason ASTM-2D railroad diesel fuel and lubrication oil SAE 40 railroad oil with a high total base number (TBN 17) were purchased and stored. Nine candidates were acquired, including three fuel additives, three oil additives, and three performance enhancing devices. These materials will be used to complete the SFAT project.

SOMMAIRE

La réduction des dépenses d'exploitation par une économie de carburant représente un défi de taille pour les compagnies ferroviaires. Il est possible d'obtenir une telle réduction en ajoutant au carburant des produits d'optimisation du rendement qui doivent être approuvés. Pour être homologués, ces produits doivent subir des essais de performances selon la Pratique recommandée 503 de l'Association of American Railroads, et satisfaire à la réglementation antipollution de l'Environmental Protection Agency (EPA). Le protocole d'essai actuel est long et coûteux, ce qui limite l'accès des petites entreprises au marché des additifs. D'où le besoin d'un nouveau protocole, plus rapide et moins coûteux, qui serait aussi probant que le protocole actuel et intégrerait en plus la mesure des émissions polluantes. Ce besoin est à l'origine du projet d'essai simplifié des additifs pour carburants (SFAT, pour *Simplified Fuel Additive Test*).

La phase I du projet a consisté à étudier la faisabilité d'un protocole d'essai qui pourrait évaluer correctement les avantages prétendus des produits d'optimisation du rendement, en moins de temps et à moindre coût que le protocole actuel. Cette étude (TP 13215E) a confirmé la possibilité de faire appel à un moteur de recherche monocylindre ALCO 251 (SCRE-251) pour la mise au point du nouveau protocole. Elle a en outre déterminé qu'un protocole faisant appel à un moteur de recherche monocylindre dérivé d'un moteur diesel multi-cylindres à vitesse moyenne serait non seulement plus économique, mais encore plus simple et plus représentatif du fonctionnement des moteurs diesel modernes pour locomotives.

La présente phase du projet SFAT visait à développer un protocole d'essai fondé sur les données du rapport de l'étude de faisabilité. Après examen des protocoles d'essai existants (RP-503, SAE J304, SAE J1423, DIN 51 361, ASTM STP 509A Part I et CEC L-42-A-92), un nouveau protocole a été développé, qui reste à valider.

L'essai se divise en deux étapes. La première consiste en des analyses chimiques destinées à déterminer les propriétés du carburant, avec et sans additifs, afin de s'assurer qu'il soit compatible avec les essais envisagés. La deuxième étape est l'essai sur moteur : 40 heures de marche avec le carburant de référence (sans additif), 160 heures d'essais de rodage et 40 heures d'essais de performance avec le carburant traité (avec additif). Les analyses des émissions seront effectuées au cours des essais de référence et des essais de performances, pour des fins de comparaison. Ce protocole est également valable pour l'évaluation des additifs pour huiles lubrifiantes.

Le banc d'essai ESDC, qui permet aussi l'acquisition de données, a été reconfiguré et automatisé pour la collecte et le traitement de données aussi bien à faible qu'à grande vitesse. Le laboratoire des carburants et lubrifiants a été modifié pour permettre les analyses de carburants.

La séquence d'essai sera finalisée lors de la validation de principe qui fera suite à la présente phase. Du carburant diesel pour locomotives ASTM-2D et de l'huile lubrifiante

SAE 40 à indice élevé d’alcalinité (TBN de 17) ont été achetés et stockés à cette fin. En tout, neuf produits candidats ont été achetés, soit trois additifs pour carburants, trois additifs pour huiles et trois dispositifs optimiseurs de rendement. Ils seront utilisés pour mener à bien le projet SFAT.

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GLOSSARY

AAR	Association of American Railroads
ASTM	American Society for Testing Materials
BMEP	Brake Mean Effective Pressure
BMHP	Brake Mean Horsepower
BSFC	Brake Specific Fuel Consumption
CEC	Coordinating European Council
CFH	Cubic Feet per Hour
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CRC	Coordinated Research Council (U.S.)
DAECS	Data Acquisition and Engine Control System
DIN	Deutsche Industrie Norm
EPA	Environmental Protection Agency (U.S.)
ESDC	Engine Systems Development Center
FC	Fuel Consumption
NHR	Net Heat Release
NO_x	Oxides of Nitrogen
PED	Performance Enhancing Devices
PEP	Performance Enhancing Product
RP	Recommended Practice
SAE	SAE International (U.S.)
SCRE-251	ALCO 251 Single-Cylinder Research Engine
SFAT	Simplified Fuel Additive Test
SO_2	Sulfur Dioxide
SwRI	Southwest Research Institute
TBN	Total Base Number
THC	Total Hydrocarbons

1.0 INTRODUCTION

Introduction of an approved after-market performance-enhancing product (PEP) to the North American locomotive market is an extremely difficult task with respect to the associated testing and evaluation cost. The only approved test procedure available is the AAR RP-503 that was adopted in 1980. This procedure consists of four stages and is designed to compare the effects of fuel oil additives on fuel chemical properties, engine wear and deposits, as well as engine performance characteristics. Presently, the only organization that can carry out the AAR RP-503 test is Southwest Research Institute (SwRI). Each test requires more than 1000 hours for completion and costs over $240,000 US. Furthermore, it does not address engine emissions measurements required by the EPA, which take effect on January 1, 2000. Inclusion of emission testing into the AAR RP-503 to the level representative of the EPA emissions standard requirements makes this procedure even more expensive.

The first phase of the SFAT project was initiated by Engine Systems Development Center (ESDC) to study the feasibility of developing an alternative test procedure. This test procedure would address both the engine performance and power assembly deposits as well as the emissions trend exhibited by the PEP at lower cost and reduced analysis time. According to the findings in phase I, it is feasible to develop a new test procedure to replace the AAR RP-503 protocol to test PEPs' effects on engine performance while concurrently collecting emissions trending representative of the EPA 40 CFR 92 emissions standards for locomotive engines. Based on SFAT phase I recommendations, a SCRE-251 representative of multi-cylinder medium-speed diesel engine (EMD or GE) would be used instead of the 1G2 Caterpillar engine and the multi-cylinder locomotive engines, resulting in time and cost reduction associated with this test protocol.

The positive outcome from the feasibility study conducted in the first phase of SFAT project has resulted in the initiation of a second phase. The aim of this phase is to develop a detailed methodology for engine and emissions testing comparable to that of the RP-503 test procedure. The following are the objectives of the second phase of the SFAT project:

i) *Procedure Development*
To complete the definition of the preliminary simplified test procedure outlined in the ESDC feasibility study in order to define the required configuration of the SCRE-251 test cell and the fuels and lubricants laboratory.

ii) *Test Cell Configuration*
To determine the instrumentation requirements of the engine test cell and fuels and lubricants laboratory to meet the performance and emissions measurement capabilities for the SFAT test procedure, and to reconfigure the test cell accordingly, including data processing capability.

iii) *Test Material Acquisition*

To acquire the required consumable material including specification fuel and test additives, and reference documentations on ASTM, DIN, and CRC testing and evaluation methods.

The following sections detail the content and outcome of this work after which a conclusion is presented along with the recommendations.

2.0 PROCEDURE DEVELOPMENT

This section describes the steps taken to develop a simplified methodology for engine and emissions testing analogous to that of the RP-503 test procedure. The following test sequence is based on a review of several accepted test methods used for evaluation of aftermarket fuel and lubricants additives. These test procedures included: SAE J304, SAE J1423, DIN 51 361, guide for evaluating aftermarket fuel and lubricant additives (U.S. Army), AAR RP-503, ASTM STP 509A Part I, and Coordinating European Council Test Method CEC L-42-A-92.

The procedure is initiated by issuing a questionnaire to the PEPs manufacturer. The purpose is to identify the claim made by the manufacturer and to recognize any additive's ingredient that may have an adverse effect on the engine components and performance (appendix A). Following this step, preliminary chemical analyses will be performed on the treated fuel or treated lubricating oil. These tests would be used to evaluate the quality of treated fuel/oil relative to that of untreated fuel/oil and its suitability for engine testing. The required tests should evaluate the fuel/oil for its ignition quality and combustion roughness, storability, contribution to engine deposits, and finally, its corrosiveness. The gathered information from these tests will allow ESDC to approve or reject an engine test.

The engine test is divided into two parts; baseline on base fuel/oil and performance test on a treated fuel/oil. The baseline takes forty hours. During this period, the performance and exhaust emissions are measured at various speeds and loads on untreated fuel/oil. The baseline test is followed by one hundred and sixty hours conditioning period with the candidate PEP. The conditioning duration may vary depending on the treated fuel/oil properties. Finally, the performance and emissions data are collected on treated fuel/oil during forty hours performance test and compared to those collected for baseline to evaluate the claimed benefits. The flow chart Figure 1 summarizes the procedure sequence. Detailed descriptions of these steps are given in the following sub-sections.

2.1 Chemical Tests for Fuel/Oil Additives and Performance Enhancing Devices

Prior to the engine test performed on the SCRE-251, preliminary chemical analyses have to be executed on both untreated fuel or oil, and the treated fuel or treated lubricating oil. The information will be used to compare the properties of treated fuel or oil to that of base fuel or oil. These results will allow ESDC to approve or reject an engine testing on the SCRE-251. The following ASTM test methods were selected for this purpose.

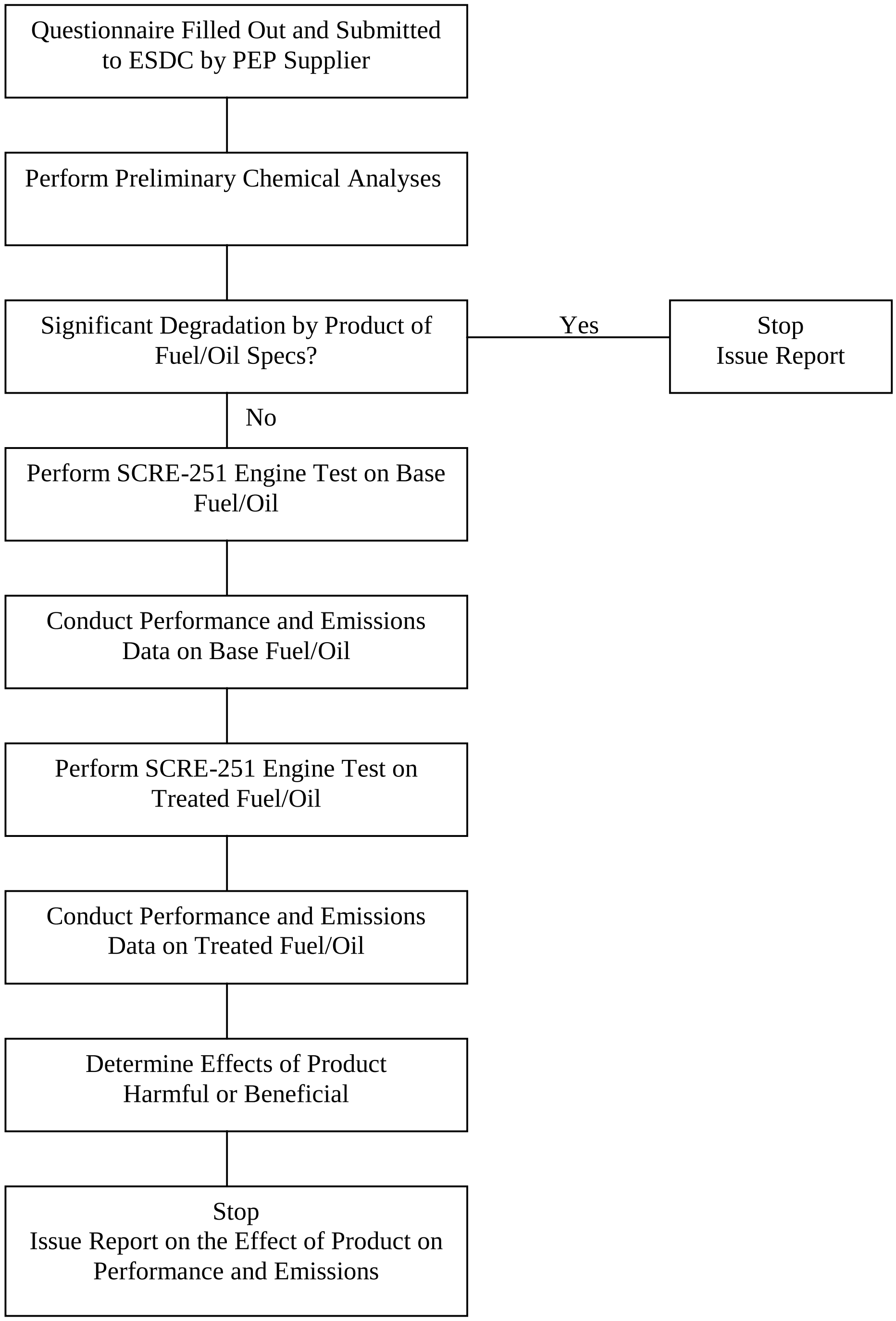


Figure1: Test Sequence for SFAT Procedure

2.1.1 *Fuel Property Tests*

These ASTM tests should be performed on both a sample of diesel fuel and a sample of the same fuel treated with fuel additives or performance enhancing devices (PED). Diesel fuel conforming to ASTM specification grade 2D shall be used unless otherwise specified. The purpose of these tests is to evaluate effects of the additives or PED on limiting fuel specification requirements. This set of tests (Table 1) is used as a general guideline and may be modified to include additional tests if necessary due to the nature of the additives or PED being tested.

Table 1: ASTM Tests for Fuel Analysis

Property	ASTM Test Method No.
Gravity, API	D 287
Flash Point	D 93
Cloud Point	D 2500
Pour Point	D 97
Kinematic Viscosity	D 445
Distillation, 50%, 90%, and End-Point	D 86
Carbon Residue	D 524
Sulfur	D 1552, D 129, or D 2622
Copper Strip Corrosion	D 130
Ash	D 482
Water and Sediment	D 2709
Accelerated Stability	D 2274
Neutralization	D 974
Particle Contamination	D 2276
Cetane Number	D 613 or D 976
Heat of Combustion	D 240

Significance of Tests Required for Diesel Fuel Aadditives and PEDs

Test Parameter	**Test Method**	**Significance**
Gravity, API	D 287	Approximate indication of fuel quality.
Flash Point	D 93	Required for safety precautions involved in fuel handling and storage.
Cloud Point	D 2500	Indicates tendency of filter plugging due to wax formation.
Pour Point	D 97	Determine lowest temperature at which the product can be pumped.
Kinematic Viscosity	D 445	Measure of resistance to flow.
Distillation	D 86	Determines the volatility which effects power output, fuel economy viscosity, and starting.
Carbon Residue	D 524	Indicates relative coke or carbon forming tendency.
Sulfur	D 1552, D 129, or D 2622	Measure sulfur content.
Copper Strip Corrosion	D 130	Measures the relative degree of copper corrosion due to sulfur content.
Ash	D 482	Measure the non-combustible residue.
Water and Sediment	D 2709	Indicative of emulsification and filter plugging of fuel.
Accelerated Stability	D 2274	Measures the stability under accelerated oxidizing conditions.
Neutralization	D 974	Measures the acidity or alkalinity of fuel.
Particulate Contamination	D 2276	Indicates tendency of filter plugging.

Test Parameter	Test Method	Significance
Cetane Number	D 613 or D 976	Indication of fuel quality as a function of ignition delay.
Heat of Combustion	D 240	Measures the energy available from a fuel.

2.1.2 Lubricating Oil Property Tests

The necessity for properly lubricating the dynamic components of any engine is readily apparent. It should be recognized that the only real measure of quality in a lubricating oil is its actual performance in the diesel engine. This is apparent because of the impossibility of establishing limits on all physical and chemical properties of lubricating oils, which can affect their performance in the engine over a broad range of environmental influences. However, the quality and performance of lubricating oils and additives may be judged through a set of laboratory tests, which would identify their suitability for engine testing. For this reason, the following tests are being recommended by ESDC as an initial step in the SFAT program for evaluation of oil additives and lube oil PED (Table 2).

Table 2: ASTM Tests for Lube Oil Analysis

Property	ASTM Test Method No.
Viscosity	D 88 or D 445
Viscosity Index	D 567
Flash Point	D 92
Pour Point	D 97
Zinc Content	(10 ppm max.)
Total Base Number	D 664 or D 2896
Evaporative loss	D 2887
Carbon Residue	D 524
Sulfated Residue	D 874

2.2 Engine Test Procedure for Performance and Emissions Evaluations

This test is intended to evaluate the effects of fuel/oil additives or PEDs on the engine performance and emissions. For each test, a set of new power assembly (piston, liner, rings, and cylinder head) is employed. The engine is filled with fresh oil (SAE 40 Railway lube oil) for each set of the test. Fresh oil is added to the engine at 10-hour intervals to compensate for oil consumption. The following sub-sections describe the proposed test sequence.

2.2.1 Baseline Test

The baseline test is performed at a speed of 1050 rpm and a load of 1696 Nm. Results are collected every 30 minutes for 17 hours. From collected data the following parameters are determined: brake specific fuel consumption (BSFC), fuel consumption (FC), brake mean effective pressure (BMEP), brake mean horsepower (BMHP), oil consumption, and net heat release (NHR).

At the end of the 17-hour performance measurement, an exhaust emissions test is conducted according to the sequence given in Table 1. The performance measurements are repeated for another seventeen hours and again the emissions information is collected.

Table 3: Emissions Test Sequence for the SCRE-251 Test Engine

Mode no	Notch setting	Speed/load (rpm/N.m)	Time in notch
1	Idle	400/-	6 min minimum
2	Notch 1	480/213	6 min minimum
3	Notch 2	560/425	6 min minimum
4	Notch 3	643/638	6 min minimum
5	Notch 4	725/850	6 min minimum
6	Notch 5	805/1063	6 min minimum
7	Notch 6	885/1275	6 min minimum
8	Notch 7	968/1486	6 min minimum
9	Notch 8	1050/1696	15 min minimum

2.2.2 Engine Conditioning

At this point, the additive is added to the fuel/oil (in the case of performance enhancing devices, the device will be added to the system) and the engine is operated for 160 hours conditioning period at full load. The conditioning period may vary from one additive to another. For this reason, the BSFC is measured during this stage at 5-hour intervals until a steady level is reached.

2.2.3 Treated Fuel/Oil Performance Test

Following the conditioning stage, a 40-hour performance and exhaust emissions test will be completed on the treated fuel/oil. These tests will be identical to those acquired during baseline test. Upon completion of these tests, the acquired results for base fuel and treated fuel will be compared to determine the validity of claims made by the additive manufacturer.

2.2.4 Exhaust Emissions Test

As mentioned previously, the exhaust emissions are measured twice during the baseline test and twice during the performance test. The emissions test follows the sequence given in Table 3 and measures the smoke, NO_X, CO, CO_2, SO_2, and THC under various loads and speeds.

3.0 TEST CELL CONFIGURATION AND LABORATORY UPGRADES

This section is intended to describe the capability of fuel and lubricants laboratory with respect to the required fuel and oil analyses for the SFAT project. In addition, the test cell configuration, its individual components, data acquisition system, and emissions measuring system are described in detail.

3.1 Fuel and Lubricants Laboratory's Capability

The chemical laboratory was initially equipped to perform chemical analyses on lubricating oil with limited ability to do fuel analyses. Due to the extensive need for detailed fuel analyses during the SFAT project, the laboratory was upgraded to meet the requirements. Following the upgrade, the laboratory is now able to perform the majority of the required tests in accordance to ASTM standards. There are several tests such as heat of combustion and cetane number, which require special equipment and setup. These tests will have to be performed by external qualified laboratories that can carry out these tests according to the conditions set by ASTM. Appendix B provides a general view of the fuel and lubricants laboratory.

3.2 Test Engine System

The test engine is a single-cylinder, direct fuel injection, four-stroke diesel engine. Its specifications are listed in Table 2. The features of engine subsystems are summarized in the following sections. The test sequence and cell configuration are illustrated in Figure 2. The test cell and control room are shown in Appendix C.

Table 4: SCRE-251 Engine Specifications

SCRE-251 SPECIFICATIONS	
Type	**BSCRE-251-002 ALCO**
Bore and Stroke	9.0 in × 10.5 in
Injector	9 holes x 0.40 mm x 145°
Displacement	668 in^3
Rated speed /Rated power	1050 rpm/250 H.P
IMEP max	334 psi
P_{max}	2300 psi
Fuel injection	1530 mm^3/inj
Idle Speed	400 rpm
Compression Ratio	12.5:1
Fuel Injection Time	27.5° BTDC
Piston	251 Mexican hat
Mean Piston Speed (@1200 rpm)	35 ft/s

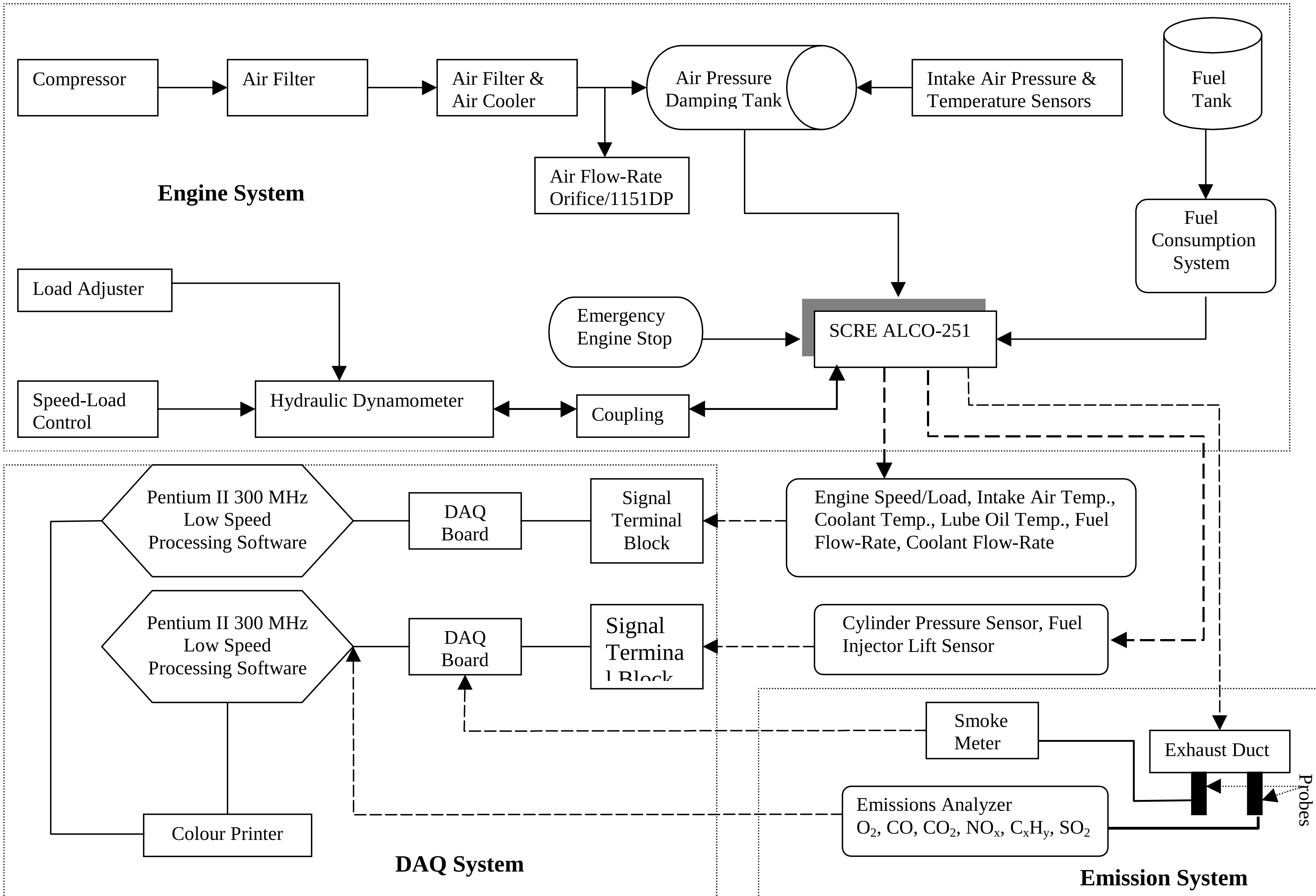


Figure 2: Test Cell Set up and Configuration

3.2.1 Cooling System

The engine is equipped with a circulating cooling system with an electric motor driven water pump that circulates water through the engine jacket and heat exchanger. The flow through the engine jacket is measured by an electromagnetic flow meter with an accuracy of ±0.25%/full scale. The temperature of the jacket water system is controlled to any desired set-point by a temperature control valve on the process cooling water side (shell side) of the heat exchanger.

The system header tank (expansion tank) maintains the system filled and vented during operation. This tank will also compensate for the expansion of water during operation.

The system includes a pre-warmer (thermostatically controlled) in the recovery tank that heats and circulates the jacket water to aid cold starting. This recovery tank is also used for water treatment of the engine jacket water system.

To simulate the water flow variation proportional to the engine speed in comparison with a multi-cylinder engine, a remote controlled throttling valve is installed on the jacket water system.

3.2.2 Lubricating Oil System

The test cell is equipped with an electric motor driven pump, which draws oil from the sump and passes it through a magnetic filter, heat exchanger, and filter then into the engine main bearing.

A thermostatic controlled oil-warmer is installed in the sump of the engine, for heating the lube oil to aid cold starting.

To simulate multi-cylinder engine oil flow variation proportional to the engine speed of an engine driven pump, a motorized valve with bypass pipe-work is installed on the lube oil system. The lube oil flow is measured using an orifice with an accuracy of ±1.5%.

3.2.3 Fuel System

Diesel fuel is pumped to the day-tank from the main storage tank; a level switch controls the level of the day-tank.

Fuel flows by gravity into a small weighing tank within the fuel flow measuring device, when the solenoid valve is energized by the fuel. The fuel measuring device consists of a single channel microprocessor based process monitor (Visipak VIP 524 W) connected to a load cell, which carries the weighing tank. The accuracy of the device is ±0.03%/full scale.

The fuel is drawn from the fuel consumption device by the engine booster pump, which then passes it through a filter to the engine fuel pump. This pump incorporates a pressure relief valve that returns excess fuel.

3.2.4 Intake Air System

The engine is equipped with a compressor and a surge tank to simulate turbocharging. The air passes through a control valve into the pressure reducer (from 100 psi to 2 psi) ,which is remotely controlled from the console for desired testing pressure ratios. The air temperature is regulated by electric heaters that are positioned after the surge tank. Using this setup, the inlet air temperature can be raised to preset points as required. The inlet airflow is measured with an accuracy of ±1.5% and a range of 72,000 cubic feet per hour (CFH).

3.2.5 Exhaust System

The exhaust surge tank and silencer in the system are installed close to the engine. A restricting orifice and butterfly valve are installed in the exhaust ducting to simulate multi-cylinder exhaust pulsation and back-pressure.

3.2.6 Start System

An air start-system connected to the main air supply header is used to start the engine. The air passes through a shut-off valve into a pressure reducer. The air pressure, 150 psi is required to start the engine. The air passes through a filter and a lubricator before reaching the start motor. The actuation of the starter is by a solenoid valve, controlled by a starter switch at the console.

3.2.7 Load/Speed Control System

The speed of the engine is controlled by an electronic engine governor, the set-point for which is adjusted by a servo motor. The governor adjusts the fuel pump rack to suit the load on the engine and to maintain a constant engine speed.

The load on the engine is controlled and measured by the Schenk D 1100 hydraulic dynamometer. The required load is maintained by controlling the amount of water in the casing, which is determined by the position of the outlet valve. The load is measured by a strain-gauged cell fixed between the casing and dynamometer bed-plate.

3.3 Data Acquisition System

The test cell control and data collection is accomplished by a computerized and fully automated Data Acquisition and Engine Control System (DAECS) developed by ESDC. The system is designed to readily acquire data on a crank-angle time base (high speed) and on a seconds time base (low speed). The engine and auxiliaries are also controlled by this system.

Low-speed and high-speed data acquisitions are accomplished simultaneously by two separate computers. Signals such as those from temperature sensors, flow-rate transducers, and speed transducer are measured by the low-speed system, while parameters such as crank-angle, fuel injector needle lift, and fuel injection pressure are collected by the high-speed data acquisition system. Data acquisition and control system schematic is shown in Figure 3.

3.4 Emissions Measurement System

A portable emissions analyzer (ECOM) is used for exhaust emissions measurements. The exhaust sample is drawn via a high flow pump assembly with an in-line water trap and particulate filter for proper conditioning prior to the gas sensors. An internal reservoir separates the gas samples to the individual sensors. Integrated software provides dampening for any background interference allowing for accurate analysis. Collected data are processed and viewed through a software program supplied by the analyzer’s manufacturer. Smoke is measured with a smoke opacity meter mounted on the top of the exhaust stack extension, or a Bosch smoke meter.

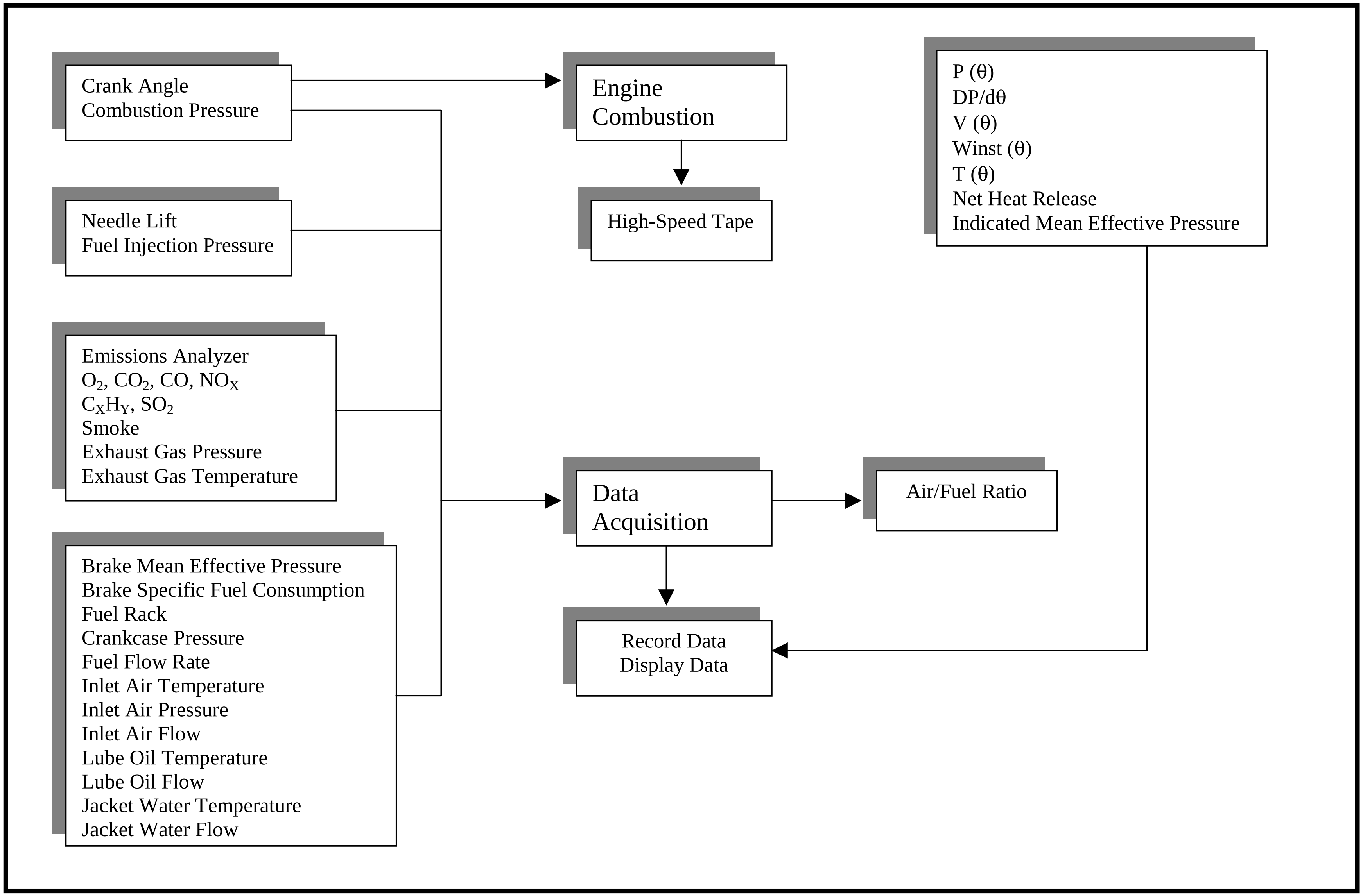


Figure 3: Data Acquisition System

4.0 TEST MATERIALS

Validation of the methodology developed for the SFAT protocol will require experimental engine testing. Such an engine testing would provide the necessary proofs that the SCRE-251 can produce adequate results within 90 percent confidence level and can replace the multi engine test, used in AAR RP-503 test procedure. Furthermore, the suitability of the SFAT test procedure for evaluation of fuel efficiency and emissions reduction claimed by PEPs suppliers can be demonstrated. Any necessary modification to the test procedure will take place during this stage. For this reason, standard fuel and lubrication oil used by railway industry were acquired. The fuel oil is ASTM-2D railroad diesel fuel. The lubrication oil is high total base number (TBN 17) SAE 40 railroad oil.

In addition to the standard fuel and lubrication oil, nine candidate samples were gathered. These samples include three fuel additives, three oil additives, and three performance enhancing devices. The claimed benefits made by individual manufacturers include lower emissions, improved performance, and better fuel economy. These additives will be used to validate the developed methodology for SFAT, through experimental engine testing, which will follow the current stage of the project.

5.0 CONCLUSIONS

This project was undertaken to develop the required methodology for a simplified test procedure that could verify both the performance and emissions benefits claimed by aftermarket suppliers. A tentative test procedure was developed based on the review of existing test procedures such as AAR RP-503, SAE J304, SAEJ1423, DIN 51 361, ASTM STP 509A Part I, CEC L-42-A-92, and U.S. Army guide for evaluating aftermarket fuel and lubricant additives.

The test sequence includes preliminary chemical analyses followed by baseline, conditioning, and performance engine test. Emission analyses are conducted during baseline and performance tests for comparison purposes. The test cell and fuel and lube laboratory were upgraded to meet the performance and emissions measurements capabilities. The necessary equipment and glassware were purchased for fuel analyses. The emission analyzer was set up, calibrated, and connected to the main PC for automatic detection and data collections during the engine testing period. The engine control and data collection at low and high speed were automated using DAECS software, developed by ESDC.

The test cell upgrades allow low-speed and high-speed data acquisitions and emissions measurement under various loads and speeds. Data are collected and processed by PC-based software.

Standard railroad fuel and lubrication oil, as well as candidate additives, were acquired and stored for the engine test that will precede this phase of the project.

6.0 RECOMMENDATIONS

To validate the methodology developed in this stage of the SFAT project, the experimental SFAT engine testing is strongly recommended. During the actual engine test, the necessary modifications and improvements can be made in terms of test procedure and required cell configurations. For this reason, nine candidates were chosen: three fuel additives, three oil additives, and three add-on devices. Tentatively, 40/160/40 time intervals were recommended for baseline, conditioning, and the performance test, including emissions measurements. This timetable can be verified and, if necessary, modified to provide optimum time required for an adequate sequence of engine test.

In addition to the primary objective, phase III will attempt to determine time intervals and the number of data points needed for performance and emission measurements that would satisfy the 90 percent confidence level.

Upon completion of the experimental engine testing on the above-mentioned candidates, the procedure will be finalized and documented. The finalized version of the SFAT procedure will be presented to the AAR as an alternative, economic evaluation tool for aftermarket products, and recommended to the Railway Association of Canada (RAC) as a standard method for the evaluation of railway aftermarket products in Canada.

APPENDIX A: QUESTIONNAIRE FOR DIESEL FUEL AND OIL ADDITIVE EVALUATION PROCEDURE

DIESEL FUEL ADDITIVE EVALUATION PROCEDURE

QUESTIONNAIRE

Complete and send the questionnaire, along with existing data pertinent to the additive's effects, to a laboratory capable of performing the SFAT procedure described herein.

COMPANY NAME: ______________________________

ADDRESS & PHONE NO.: ______________________________

____

____

PERSON TO CONTACT: ______________________________

ADDITIVE NAME OR CODE: ______________________________

What are the additive's effects on the following engine characteristics, and how long does it take to observe these effects?

(1) PERFORMANCE (Fuel Consumption, Exhaust Temperature, etc.)

____

____

____

(2) EXHAUST EMISSIONS (Including Smoke)

____

____

____

(3) COMBUSTION DEPOSITS (Including Sparking)

____

____

____

(4) LUBE OIL

____

____

____

(5) WEAR

____

____

____

(6) FUEL SYSTEM

____

____

____

What are the effects of the additive on the following diesel fuel properties.

(1) Cetane Number: ______________________________

(2) Viscosity: ______________________________

(3) API Gravity: ______________________________

(4) Distillation Range: ______________________________

(5) Sulfur Content: ______________________________

(6) Carbon Residue: ______________________________

(7) Flash Point: ______________________________

(8) Cloud Point: ______________________________

(9) Pour Point: ______________________________

(10) Ash Content: ______________________________

(11) Corrosiveness: ______________________________

(12) Filterability: ______________________________

(13) Water Absorption: ______________________________

(14) Stability: ______________________________

(15) Foaming: ____

(16) Bacterial Resistance: ____

(17) Vapor Pressure: ____

(18) Miscibility Limits: ____

How is this additive used?

(1) How is it mixed with diesel fuel? ________________________________
____

(2) In what proportions? ____
____

(3) How stable is the mixture? _____________________________________
____

(4) How long is the mixture storable? ________________________________
____

Does the additive contain any zinc? ____________________________________

Are there any chemicals, elements, or physical conditions, which can neutralize or otherwise influence the effectiveness of the additive? If so, describe in detail on a separate sheet.

What are the claimed effects of the additive? (Attach any pertinent material.) _________
____
____

What tests have been conducted to substantiate these claims? (Attach any pertinent material.) ____
____
____

What were the results of these tests? (Include data) ___________________________
____
____

Where were these tests performed? ______________________________________

____

____

Depending on the information supplied above, the testing laboratory selected will conduct the appropriate tests in accordance with the SFAT evaluation procedure.

LUBRICATING OIL ADDITIVE EVALUATION PROCEDURE

QUESTIONNAIRE

Complete and send the questionnaire, along with existing data pertinent to the additive's effects, to a laboratory capable of performing the SFAT procedure described herein.

COMPANY NAME: ____________________

ADDRESS & PHONE NO.: ____________________

____

____

PERSON TO CONTACT: ____________________

ADDITIVE NAME OR CODE: ____________________

What are the additive's effects on the following engine characteristics, and how long does it take to observe these effects?

(1) PERFORMANCE (Fuel Consumption, Exhaust Temperature, etc.)

____

____

____

(2) EXHAUST EMISSIONS (Including Smoke)

____

____

____

(3) COMBUSTION DEPOSITS (Including Sparking)

____

____

____

(4) LUBE OIL

____

____

____

(5) WEAR

____

____

____

(6) FUEL SYSTEM

____

____

____

What are the effects of the additive on the following lubricant oil properties.

(1) Viscosity: ____

(2) Viscosity Index: ____

(3) API Gravity: ____

(4) Flash Point: ____

(5) Fire Point: ____

(6) Pour Point: ____

(7) Zinc Content: ____

(8) Total Base Number: ______________________________________

(9) Corrosiveness: ____

(10) Anti-Foaming: ____

How is this additive used?

(5) How is it mixed with lubricant oil? ____________________________________

____

(6) In what proportions? ____

____

(7) How stable is the mixture? ____

____

(8) How long is the mixture storable? ____________________________________

____

Does the additive contain any zinc? ____

Are there any chemicals, elements, or physical conditions, which can neutralize or otherwise influence the effectiveness of the additive? If so, describe in detail on a separate sheet.

What are the claimed effects of the additive? (Attach any pertinent material.) __________

____

____

What tests have been conducted to substantiate these claims? (Attach any pertinent material.) ____

____

____

What were the results of these tests? (Include data) ______________________________

____

____

Where were these tests performed? ____

____

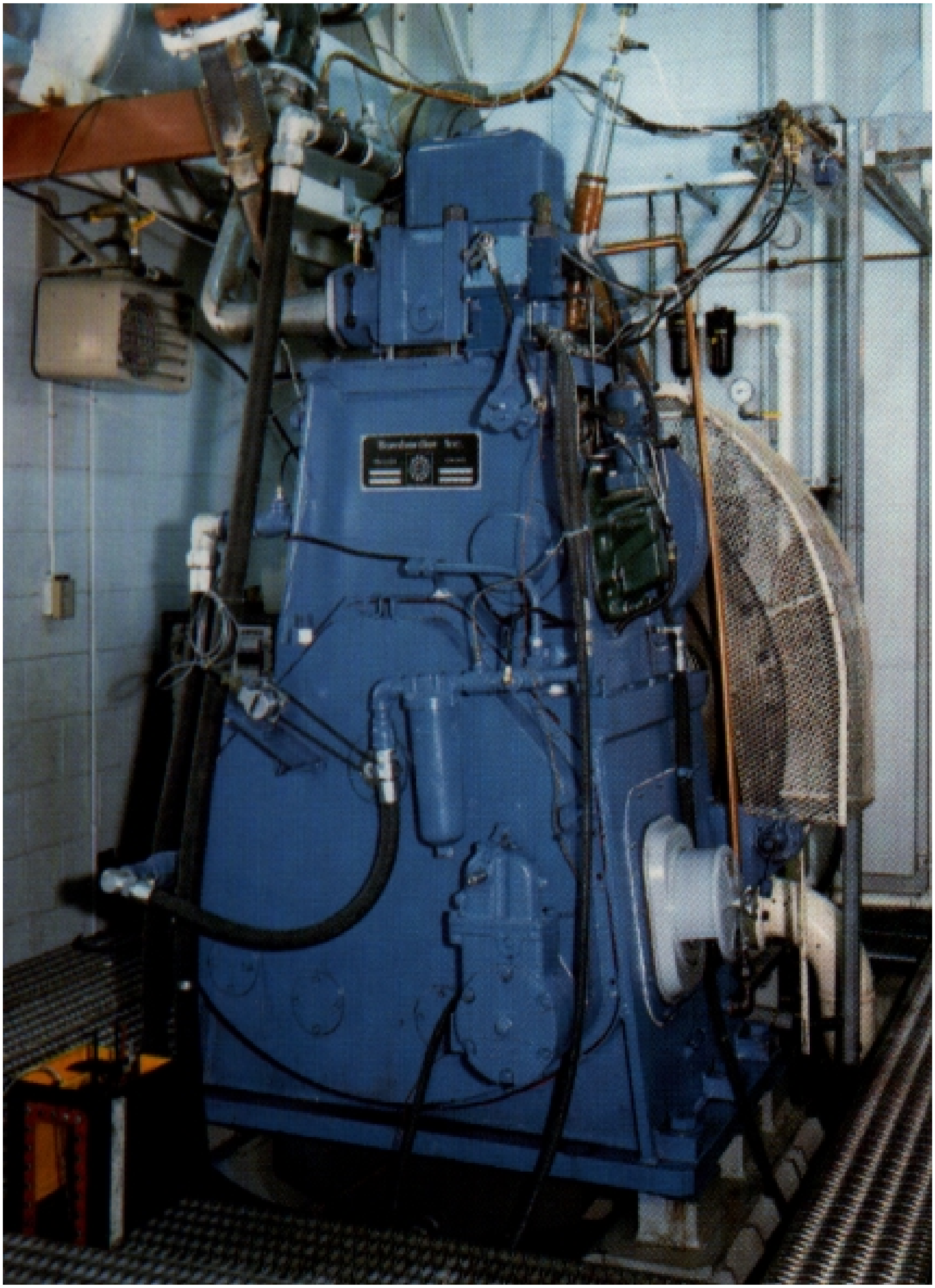
____

Depending on the information supplied above, the testing laboratory selected will conduct the appropriate tests in accordance with the SFAT evaluation procedure.

APPENDIX B: GENERAL VIEW OF FUEL AND LUBRICANTS LABORATORY

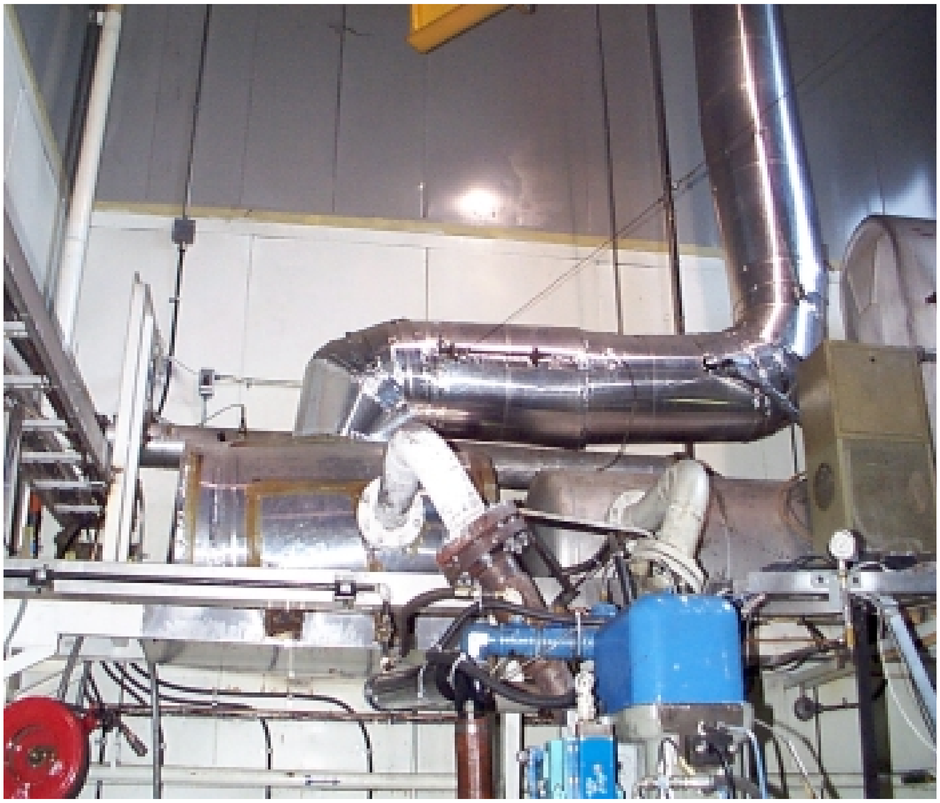

ACID

APPENDIX C: GENERAL VIEW OF TEST CELL AND CONTROL UNIT



C-1: SCRE-251

C-2: Control Unit


C-3: SCRE-251 Exhaust System