Draft of Standard Test Method for
Cummins ISB Test[1]

1. Scope

1.1 This test method is commonly referred to as the Cummins ISB Test. The test method utilizes a modern medium-duty diesel engine equipped with exhaust gas re-circulation used to evaluate oil performance with regard to valve train wear.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parenthesis are for information only.

1.3 <u>This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use</u>. See A1 for general safety precautions.

2. Referenced Documents

2.1 <u>ASTM Standards:</u>

D 86 Standard Test Method for Distillation of Petroleum Products[4]

D 92 Standard Test Method for Flash and Fire Points by Cleveland Open Cup[4]

D 97 Standard Test Method for Pour Point of Petroleum Products[4]

D 130 Standard Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[4]

D 287 Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)[4]

D 445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[4]

D 482 Standard Test Method for Ash from Petroleum Products[4]

D 524 Standard Test Method for Ramsbottom Carbon Residue of Petroleum Products[4]

D 613 Standard Test Method for Cetane Number of Diesel Fuel Oil[5]

D 664 Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration[4]

D 1319 Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption[4]

D 2500 Standard Test Method for Cloud Point of Petroleum Products[4]

D 2622 Standard Test Method for Sulfur in Petroleum Products by x-ray Spectrometry[6]

D 2709 Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge[6]

D 2896 Standard Test method for Base Number of Petroleum Products by Potentionmetric Perchloric Acid Titration[6]

D 4485 Specification for Performance of Engine Oils[6]

D 4737 Standard Test Method for Calculated Cetane Index by Four Variable Equation[7]

D4739 Standard Test method for Base Number Determination by Potentiometric Titration[7]

D 5185 Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)[7]

D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light Duty Conditions[7]

D 5967 Standard Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine[7]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[8]

E 344 Terminology Relating to Thermometry in Hydromometry[9]

3. Terminology

3.1 Definitions:

blind reference oil, n - a reference oil, the identity of which is unknown by the test facility. D 5844

blow-by, n — in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. D 5302

calibrate, v - to determine the indication or output of a measuring device with respect to that of a standard. E 344

heavy-duty, adj. – in internal combustion engine operation, characterized by average speeds, power output, and internal temperatures that are close to the potential maximum. D 4485

lug, v - to cause the engine to run in a burdened condition with the potential to cause hesitation.

medium-duty engine, adj. – an internal combustion engine,??. D 4485

non-reference oil, n — any oil other than a reference oil, such as a research formulation, commercial oil or candidate oil. D 5844

non-standard test, n – a test that is not conducted in conformance with the requirements in the standard test method; such as running in an non-calibrated test stand or using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. D 5844

reference oil, n – an oil of known performance characteristics, used as a basis for comparison. D 4485

sludge, n — in internal combustion engines, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and the lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. D 5302

wear, n — the loss of material from, or relocation of material on, a surface. D 5302

Discussion – Wear generally occurs between two surfaces moving relative to each other, and is the result of mechanical or chemical action or by a combination of mechanical and chemical actions.

3.2 Descriptions of Terms Specific to This Standard:

3.2.1 crosshead, n — an overhead component, located between the rocker arm and each intake valve and exhaust valve pair, that transfers rocker arm travel to the opening and closing of each valve pair.

3.2.1.1 Discussion -- Each cylinder has two crossheads, one for each pair of intake valves and exhaust valves.

3.2.2 exhaust gas re-circulation (EGR), n - a method by which a portion of engine's exhaust is returned to its combustion chambers via its inlet system.

3.2.3 overhead, n – in internal combustion engines, the components of the valve train located in or above the cylinder head.

3.2.4 tappet, n - in internal combustion engines, a valvetrain component, located between the camshaft and push rod, that transfers cam lobe travel to the rocker arm, opening and closing a pair of intake or exhaust valves.

3.2.5 valve train, n – in internal combustion engines, the series of components such as valves, crossheads, rocker arms, push rods, tappets and camshaft, which open and close the intake and exhaust valves.

4. Summary of Test Method

4.1 This test method uses a 2004 EPA emission compliant Cummins 5.9L ISB diesel engine. Test operation includes a 17-min. warm-up, an 80-h break-in, and 350 h in two stages. During stage A the engine is operated with retarded fuel injection timing to generate excess soot. During stage B the engine is operated at cyclic conditions to induce valve train wear.

4.2 Prior to each test, the engine is cleaned and assembled with overhead valve train components. All aspects of the assembly are specified.

4.3 A forced oil drain, an oil sample and an oil addition, are performed at the end of each 25-h period for the first 100-h of the test. Thereafter, oil samples shall be taken every 50-h. Oil additions are not made during the last 250-h of the test cycle.

4.4 The test stand is equipped with the appropriate instrumentation to control engine speed, fuel flow, and other operating parameters.

4.5 Oil performance is determined by assessing crosshead wear, tappet weight loss, and camshaft wear.

5. Significance and Use

5.1 This test method was developed to assess the performance of a heavy-duty engine oil to control engine wear under operating conditions selected to accelerate soot production and valve train wear in a turbo-charged and inter-cooled four-cycle diesel engine with sliding tappet followers equipped with exhaust gas re-circulation hardware.

5.2 The design of the engine used in this test method is representative of many, but not all, modern diesel engines. This factor, along with the accelerated operating conditions shall be considered when extrapolating test results.

6. Apparatus

6.1 <u>Test Engine Configuration:</u>

6.1.1 <u>Test Engine</u> -- The Cummins ISB is an in-line six-cylinder medium-duty diesel engine with 5.9 L of displacement and is turbocharged, after-cooled, and has an overhead valve configuration (Cummins CPL #8123). It features a 2004 emissions configuration with electronic control of fuel metering and common rail fuel injection. Obtain the test engine and the engine build parts kit from the supplier listed in A2.2. The components of the engine build parts kit are shown in Table A3.1.

6.1.2 <u>Remote Oil Heat Exchanger and Adapter Plate</u> — The stock oil heat exchanger is removed from the engine and replaced with an adapter plate (Fig A4.1). A remote adapter is attached to the filter head as shown in Fig A4.2 to allow control of the oil temperature by directing the oil to flow thru a remote oil heat exchanger as shown in Fig. A4.3a. The remote oil heat exchanger is a Kinetic Engineering P/N SN516-003-014-004 available from the supplier shown in A2.3. The oil lines to and from the remote oil heat exchanger and filter head can not be greater than one 1 meter in length. The lines to and from the remote oil heat exchanger and filter head are to be -12 nominal outer diameter tubing. The adapter plate (P/N ISB-OCBP) can be obtained from the supplier shown in A2.2; the remote filter head adapter (P/N 149-0118-00) can be obtained from the suppliers listed in A2.5.

6.1.3 <u>Oil Pan Modification</u> — Modify the oil pan as shown in Fig. A4.4. A modified oil pan can be obtained from the supplier listed in A2.2.

6.1.4 Engine Control Module (ECM) — Obtain the ECM from the supplier listed in A2.2. Use the latest Cummins engineering tools to retard injection timing to increase soot generation and overhead wear. Verify that the 2004 EPA calibration is used. Some engine protection protocols have been disabled to insure that the test be run per the procedure. Instructions on how to disable the engine protection protocols, as well as the use of Cummins engineering tools requires prior authorization by Cummins Inc.

6.1.5 Air Compressor - The engine-mounted air compressor is not used for this test method. The air compressor is removed and the opening is covered by a plate, Cummins part number 3954567 which can be obtained from local Cummins dealers.

6.1.6 Engine Inlet Air Heater – Remove the internal heating elements from the housing of the engine inlet air heater. Remove the lower factory installed electrical terminal. Drill and tap this hole (1/8 NPT) for the inlet manifold pressure fitting.

6.2 Test Stand Configuration:

6.2.1 Engine Mounting — Install the engine so that it is upright and the crankshaft is horizontal. A Vulkan Driveline Coupling part number VKL3415 has shown to be sufficient for this application; it is available from the supplier listed in A2.7.

Note 1: Caution -- The engine mounting hardware should be configured to minimize block distortion when the engine is fastened to the mounts. Excessive block distortion can influence test results.

6.2.2 Intake Air System – The configuration is shown in Fig. A4.6. Use cobra elbow P/N 3037625, available from local Cummins dealers or the supplier listed in A2.2. Use 12” minimum length of straight 4” diameter tubing to connect to the cobra elbow. The air filter should be typical of filters used in diesel engine testing applications. Install the intake air tube (Fig A4.6) at the intake of the turbocharger compressor. Construct the system to minimize airflow restriction. Methods to control the intake air temperature and pressure are required.

Note 2: Difficulty in achieving or maintaining intake manifold pressure or intake manifold temperature, or both, could be indicative of insufficient or excessive restriction.

6.2.3 Aftercooler – A Modine after-cooler, P/N 1A012865, will be used for after-cooling. An installation photo of the cooler is shown in Fig A4.6a. The aftercooler can be obtained from the suppliers listed in either A2.2 or A2.4.

6.2.4 Exhaust System – Install a long radius 90° elbow exhaust tube (Fig A4.10) at the discharge flange of the turbocharger housing, followed by a sufficient length of straight tubing to allow the sensors to be located 152 mm downstream of the elbow seam. Use good engineering practice in establishing the total length and diameter of the tube downstream of the sensors. A method to control exhaust back pressure is required.

6.2.5 Exhaust Gas Re-circulation System -- The components for the exhaust gas re-circulation system are installed by the manufacturer. Replacement parts can be obtained from the supplier listed in A2.2.

6.2.6 Fuel Supply – The laboratory fuel supply and filtration system is not specified. The fuel consumption rate is determined by measuring the rate of fuel flowing into the day tank. A method to control the fuel temperature is required. The fuel inlet restriction and return restrictions are to adhere to the Cummins Service Manual requirements.

6.2.7 Coolant System – The system configuration is not specified. A typical configuration consists of a non-ferrous core heat exchanger, a reservoir (expansion tank) and a temperature control valve. Pressurize the system by regulating air pressure at the top of the expansion tank. The system should have a sight glass to detect air entrapment.

Note 3: Caution – Although the system volume is not specified, an excessively large volume can increase the time required for the engine fluid temperatures to attain specification. A system volume of 35 L or less (including engine) has proven satisfactory.

6.2.7.1 Block the engine thermostat wide open.

6.2.8 Pressurized Oil Fill System – The oil fill system is not specified. A typical configuration includes an electric pump, a 20-L reservoir, and transfer hose.

6.2.9 External Oil System — Configure the external oil system according to Fig. A5.1. The external reservoir volume shall be 4 – 8 L. The external pumps shall be Viking Pump Model SG041825 and the nominal pump motor speed shall be 1140 r/min. A three-way valve system is permissible and allows the reservoir to be emptied back into the oil pan at the start of Stage B. The location of the three-way valve is not specified (location shown in Fig. A5.1 is for example only).

6.2.9.1 Oil Sample Valve Location -- The oil sample valve shall be located on the return line from the remote oil heat exchanger system to the engine. It is recommended that the valve be located as shown in (Fig. A4.3).

6.2.9.2 Brass or copper fittings can influence used oil wear metals analyses and shall not be used in the external oil system.

6.2.10 Crankcase Aspiration – Vent the blow-by gas at the port located at the left rear of the flywheel housing as shown in (Fig. A4.4a). The vent line must proceed in a downward direction cover port into the collection bucket. The collection bucket shall have a minimum volume of 19 L (5 gal).

6.2.11 Blowby Rate — The flow rate device and system configuration is not specified. Install the system according to good engineering practice and operate the flow rate device according to manufacturer guidelines.

6.3 System Time Responses – The maximum allowable system time responses are shown in Table 1. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report[12].

Table 1 Maximum Allowable System Time Responses

Measurement Type	Time Response (s)
Speed (RPM)	2.0
Torque	2.0
Temperature	3.0
Pressure	3.0
Flow	45.0

6.4 Oil Sample Containers — High-density polyethylene containers are recommended for oil samples.

Note 4: Precaution — Glass containers may break and may cause injury or exposure to hazardous materials, or both.

6.5 Mass Balance — A balance is required to measure the mass of the crossheads and tappets. An electronic or mechanical balance may be utilized. The balance shall have a minimum indication resolution of 0.1 mg.

7. Engine, Fluids and Cleaning Solvents

7.1 Test Oil -- Approximately 80 L of test oil is required to complete the test.

7.2 Test Fuel -- Approximately 8,000 L of ultra-low sulfur diesel fuel is required to complete the test. Purchase the fuel from the supplier listed in A2.1. The fuel shall have the properties and tolerances shown in A6.

7.3 Engine Coolant – Use 50/50 pre-mixed Fleetguard Compleat PG. The coolant can be obtained from local Cummins dealers.

7.4 Solvent – Use mineral spirits meeting ASTM D 235, Type II, Class C requirements for Aromatic Content (0-2% vol), Flash Point (142°F/61°C), and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). Obtain a certificate of Analysis for each batch of solvent from the supplier. (**Warning** – Combustible. Health Hazard.)

7.5 Pentane – Pentane used for cleaning components before measurement.

7.6 EnSolv® – Proprietary solvent that can be obtained from the supplier listed in A2.6.

Note 5: Warning – Use adequate safety precautions with all solvents and cleaners.

8. Preparation of Apparatus

8.1 Cleaning of Parts:

8.1.1 General – The preparation of test engine components specific to the Cummins ISB test are indicated in this section. Use the Cummins service publications[13] listed in A7 for the preparation of other engine components. Take precautions to prevent rusting of iron components. Additionally, any engraving of test parts for identification purposes are to be done on non-contact surfaces and the engraving must be followed by the pre-test cleaning as specified in following sections.

8.1.2 Engine Block – The engine block is a parent bore type. This test does not require a complete teardown. Do not clean the internal surfaces and passages of the engine block with solvent.

8.1.3 Rocker Cover and Oil Pan – Clean the rocker cover and oil pan. Use a brush as necessary to remove deposits.

8.1.4 External Oil System -- Flush the internal surfaces of the oil lines and the external reservoir with solvent. Repeat until the solvent drains clean. Flush solvent through the oil pumps until the solvent drains clean.

8.1.5 Crosshead Cleaning and Measurement – Do not handle the crossheads with bare hands; use gloves or plastic covered tongs.

8.1.5.1 Inspect the crossheads and clean with solvent. Use a non-metallic soft bristle brush if necessary.

8.1.5.2 Allow the crossheads to air dry (do not use compressed air).

8.1.5.3 Rinse the crossheads in pentane and air dry (do not use compressed air).

8.1.5.4 Measure crosshead mass to a tenth of a milligram (xxx.x mg).

8.1.5.5 If an electronic scale is used for mass measurement, then use the following procedure:

(a) Demagnetize (degauss) each crosshead prior to measurement

(b) Measure the crosshead twice, using two orientations 90° apart. If the difference between the two mass measurements is greater than 0.2 mg, the crosshead shall be demagnetized and the measurement process repeated.

8.1.5.6 Report the crosshead measurements on the form included in the TMC report package.

8.1.6 Tappet Cleaning and Measurement – Do not handle the tappets with bare hands, use Ensolv-compatible gloves or plastic covered tongs.

8.1.6.1 Inspect the tappets and clean with solvent. Use a non-metallic soft bristle brush if necessary.

8.1.6.2 Allow the tappets to air dry (do not use compressed air).

8.1.6.3 Rinse the tappets with Pentane and air dry (do not use compressed air).

8.1.6.4 For 30 min, soak the tappets in Ensolv solvent. Be sure each tappet is completely immersed in the Ensolv

8.1.6.5 Allow the tappets to air dry (do not use compressed air).

8.1.6.6 Measure the mass of each tappet, orienting the large circular flat surface in an upwards position, to a tenth of a milligram (xxx.x mg).

8.1.6.7 If an electronic scale is used for mass measurement, then use the following procedure:

(a) Demagnetize (degauss) each tappet prior to measurement

(b) Measure the tappet twice, using two orientations, both with the flat face upwards, 90° apart. If the difference between the two mass measurements is greater than 0.2 mg, the tappet shall be demagnetized and the measurement process repeated.

8.1.6.8 Report the tappet measurements on the forms included in the TMC report package.

8.1.7 <u>Camshaft Cleaning and Measurement</u> – Clean the camshaft with solvent. Avoid handling the camshaft with bare hands, use gloves. Contamination can adversely affect the wear results.

8.1.7.1 Use a Mitutoyo Snap Gauge, model 201-152, and a Mitutoyo Digital Indicator, model 543-252B to measure the camshaft lobes.

8.1.7.2 Measure three locations on each lobe: the front edge, the center, and the rear edge. The lobe measurement is the average of the three values.

8.2 <u>Engine Assembly:</u>

8.2.1 <u>General</u> — Except as noted in this section, use the procedures indicated in the Cummins service publications (A7). Assemble the engine with the components from the Engine Build Parts Kit in numerical order, from front to rear (A3).

8.2.2 <u>Parts Reuse and Replacement</u> -- Engine components may be reused or replaced at the discretion of the laboratory, except as per 8.2.5. The engine block may be reused provided that it meets the serviceability requirements, specifically blowby and cam bore, defined in the Cummins Service Manual.

8.2.3 Build-Up Oil – Use the Cummins branded oil that meets Cummins Engineering Standard 20078. The oil is available from local Cummins dealers.

8.2.4 Coolant Thermostat -- The engine coolant thermostat shall be locked open to close off the bypass passage in the engine block.

8.2.5 New Parts – The parts listed below are contained in the Engine Build Parts Kit and are not reusable. Clean the parts prior to use. With the exception of the fuel filter, replacement of any part listed below during a test will invalidate the test.

8.2.5.1 Rocker lever shafts

8.2.5.2 Rocker lever assemblies (exhaust and intake), complete with sockets

8.2.5.3 Tappets

8.2.5.4 Rocker lever sockets

8.2.5.5 Push rods

8.2.5.6 Valve crossheads

8.2.5.7 Camshaft

8.2.5.8 Test Oil Filter

8.2.5.9 Fuel Filter (replacement during a test does not invalidate the test)

8.2.6 The entire engine may be replaced during a reference period as long as the engine completes a specified 80-hour break in cycle specified in section 10.

8.2.7 The cylinder head and power cylinder components cannot be replaced during the life of the engine.

8.3 Operational Measurements:

8.3.1 Units and Formats – See Annex A8.

8.3.2 Instrumentation Calibration

8.3.2.1 Fuel Consumption Rate Measurement Calibration — Calibrate the fuel consumption rate measurement system before every reference oil test sequence and within 9 months after the completion of the last successful calibration test. Volumetric systems shall be temperature-compensated and calibrated against a mass flow device. The flow meter located on the test stand shall indicate within 0.2% of the calibration standard. The calibration standard shall be traceable to national standards.

8.3.2.2 Temperature Measurement Calibration — Calibrate the temperature measurement systems before every reference oil test sequence and within 9 months after the completion of the last successful calibration test. Each temperature measurement system shall indicate within ± 0.5 °C of the laboratory calibration standard. The calibration standard shall be traceable to national standards.

8.3.2.3 Pressure Measurement Calibration — Calibrate the pressure measurement systems before every reference oil test sequence and within 9 months after the completion of the last successful calibration test. The calibration standard shall be traceable to national standards.

8.3.3 Temperatures

8.3.3.1 Measurement Location – The temperature measurement locations are specified in this section. The measurement equipment is not specified. Install the sensors such that the tip is located midstream of the flow unless otherwise indicated. Follow the guidelines detailed in the Data Acquisition and Control Automation II Task Force Report[12] for the accuracy and resolution of the temperature measurement sensors and the complete measurement system.

8.3.3.2 Coolant Out Temperature — Install the sensor as shown in Fig A4.14.

8.3.3.3 Coolant In Temperature – Install the sensor on the right side of the engine on the inlet pipe to the coolant pump intake housing as shown in Fig A4.14a.

8.3.3.4 Fuel In Temperature — Install a thermocouple at in the fuel pump inlet fitting as shown in Fig. A4.12. The maximum allowable thermocouple size is 3/16 in. Install the thermocouple to the center of the banjo fitting.

8.3.3.5 Oil Gallery Temperature — Install the sensor at the metric straight thread hole on the left front of the engine, near the ECM as shown in Fig. A4.11.

8.3.3.6 Intake Air Temperature – Install the sensor as shown on Fig A4.6. The sensor shall be located such that it is 6 – 8 “ upstream of the cobra elbow and so that there is at least 6” of straight tubing upstream of the sensor. Do not install the sensor upstream of the intake air pressure tap.

8.3.3.7 Intake Manifold Temperature — Install the sensor at the top of the aluminum snorkel on the air inlet tube as shown in Fig. A4.7. The insertion depth is to be 114 mm from the outside surface of the aluminum snorkel

8.3.3.8 Exhaust Temperature – Install the sensor as shown in Fig. A4.10.

8.3.3.9 Oil Sump Temperature – Install the sensor at an insertion depth of 60 mm from the outside pan boss identified as the Factory/OEM metric threaded hole as shown in Fig. A4.4.

8.3.3.10 Additional – Monitor any additional temperatures that the laboratory considers beneficial. Measurement of the EGR Cooler gas inlet and outlet and coolant inlet and outlet is highly recommended.

Note 9: Additional exhaust sensor locations are recommended, such as the exhaust ports and pre-turbine (front and rear). The detection of changes in exhaust temperature(s) is an important diagnostic.

8.3.4 Pressures:

8.3.4.1 Measurement Location and Equipment – The pressure measurement locations are specified in this section. The measurement equipment is not specified. Follow the guidelines detailed in the Data Acquisition and Control Automation II Task Force Report[12] for the accuracy and resolution of the pressure measurement sensors and the complete measurement system.

Note 10: Caution — A condensation trap should be installed at the lowest elevation of the tubing between the pressure measurement location and the final pressure sensor for Crankcase Pressure, Intake Air Pressure, and Exhaust Pressure. Route the tubing to avoid intermediate loops or low spots before and after the condensation trap.

8.3.4.2 Oil Gallery Pressure — Measure the pressure at the metric straight thread fitting on the left front of the engine, located near the ECM as shown in Fig. A4.11.

8.3.4.3 Oil Filter Inlet Pressure — Measure the pressure at the 1/8-in. NPT port located on the remote oil filter assembly as shown in Fig. A4.3.

8.3.4.4 Oil Filter Outlet Pressure — Measure the pressure at the 1/8-in. NPT port located on the remote oil filter assembly as shown in Fig. A4.3.

8.3.4.5 Intake Manifold Pressure — Measure the pressure at the 1/4-in. NPT port located in the air heater block at the top-front of the intake manifold as shown in Fig. A4.8.

8.3.4.6 Crankcase Pressure — Measure the pressure at a dipstick port located on the left side of the test engine.

8.3.4.7 Intake Air Pressure — Measure the pressure on the intake air tube as shown in Fig. A4.6. The pressure tap shall be located such that it is 6 – 8 " upstream of the cobra elbow and so that there is at least 6" of straight tubing upstream of the sensor.

8.3.4.8 Exhaust Pressure After Turbo — Measure the pressure, flat wall, on the exhaust tube as shown in Fig. A4.10.

8.3.4.9 Fuel Pressure — Measure the pressure on the engine-mounted outlet of the fuel filter, as shown in Fig. A4.13.

8.3.4.10 Coolant Pressure – Measure the pressure on top of the expansion tank.

8.3.4.11 Additional – Monitor any additional pressures considered to be beneficial. Measurement of the EGR cooler inlet and outlet coolant pressures and inlet and outlet gas pressure is highly recommended.

8.3.5 Flow Rate

8.3.5.1 Flow Rate Location and Measurement Equipment — The flow rate measurement locations are specified in this section. The equipment for the blow-by rate and the fuel rate are not specified. Follow the guidelines detailed in the Data Acquisition and Control Automation II Task Force Report[12] for the accuracy and resolution of the flow rate measurement system.

8.3.5.2 Blow-by — The device or type of system used to measure the blow-by flow rate is not specified. Use engineering judgment and the manufacturer's guidelines concerning the installation and use of the blow-by rate measurement device.

8.3.5.3 Fuel Flow — The fuel consumption rate is determined by measuring the fuel flowing to the day tank.

9. Engine/Stand Calibration and Non-Reference Oil Tests

9.1 General – Calibrate the test engine and the test stand by conducting a test with a blind reference oil[12]. Submit the results to the ASTM Test Monitoring Center (TMC) for determination of acceptance according to the Lubricant Test Monitoring System (LTMS)[12].

9.1.1 Because the ISB common rail engine is a parent bore block and is not completely rebuilt before each test, an engine is not referenced to a stand. The stand is calibrated for use with different ISB common rail engines as supplied from the CPD.

9.2 New Test Laboratory / Stand -- A new test laboratory is defined as a laboratory that has never successfully calibrated a test stand. The first test stand at a new laboratory requires two successful calibration tests to establish its first calibration period. All subsequent calibration periods on that stand or any other stand within that laboratory will only require one successful calibration test.

9.3 Stand Calibration Period:

9.3.1 The first two calibration periods on a test stand are 12 months or 12 operationally valid non-reference oil tests from the completion of the last successful calibration test.

9.3.2 All subsequent calibration periods on a test stand are 18 months or 12 operationally valid non-reference oil tests from the completion of the last successful calibration test.

9.3.3 Last Start Date -- A non-reference oil test may begin provided the warm-up is started prior to the expiration of the calibration period.

9.4 Stand Modification and Calibration Status -- Modification of the test stand control systems or the conducting of any non-standard test, or both, can invalidate the calibration status. A non-standard test includes any test conducted under a modified procedure, non-procedural hardware, controller set-point modifications, or a combination thereof. The TMC should be contacted prior to any changes to determine the effect upon the calibration status.

9.5 Test Numbering System:

9.5.1 General — The test number has four parts, W-X-Y-Z. W represents the test stand number, X represents the run number for that stand and has a XXX format, Y represents the eight-digit serial number from the RAC label for that engine, and Z represents the number of test hours completed by that engine block prior to starting the test and has a format XXXX. The hours on the engine value does NOT include the 80 hour break-in time nor does it include time for warm up and cool down run times. For example, test number 64-002-57216596-0350 indicates stand number 64, test number 002 for that stand, engine serial number 57216596, and the engine has 0350 test hours prior to starting this test on engine block 57216596. Every test start (reference oil and non-reference oil) will increment X by one.

9.5.2 Reference Oil Tests – The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, follow the sequential stand run number by a letter suffix (A for the first rerun, B for the second, and so forth).

9.5.3 Non-Reference Oil Tests -- No letter suffix will be added to X for aborted or operationally invalid non-reference oil tests.

9.6 Reference Oil Test Acceptance:

9.6.1 Reference oil test acceptance is determined in accordance with the LTMS[12].

9.7 Reference Oil Accountability:

9.7.1 Laboratories shall provide a full accounting of the identification and quantities of all reference oils used. With the exception of the oil analyses required in section 11.6, perform no physical or chemical analyses of reference oils without written permission from the TMC. In such an event, include the written conformation and the data generated in the reference oil test report.

9.7.2 Retain used reference oil samples for 90 days from the EOT date.

9.8 ***Donated Reference Oil Test Programs*** - The surveillance panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

9.9 Adjustments to Reference Oil Calibration Periods

9.9.1 *Procedural Deviations* – On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

9.9.2 *Parts and Fuel Shortages* - Under special circumstances, such as industry-wide parts or fuel shortages, the surveillance panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

9.9.3 *Reference Oil Test Data Flow* - To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

9.9.4 *Special Use of the Reference Oil Calibration System* - The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

10. Test Procedure

10.1 *New Engine Break-In* The engine break-in procedure consists of a sequence of 15-minute cycles run for a total of 80 hours. Unless otherwise stated changes in load and speed are to be done at a rapid rate. This break-in cycle is only required for first time use engines. The engine is installed in almost an "as-received" condition. The OE oil cooler may be left installed as received, OE fuel filter and peripherals are allowed.

10.1.1 Oil Charge for Break-In Pressure charge the engine with 14.5 kg of Cummins branded CES 20078 oil. This amount includes oil in the filter.

10.1.2 Break-In Cycle Run the break-in according to Table 3 for 80 h.

10.1.3 Post Break-In Drain the break-in oil. The engine may now be used for testing and is ready to be equipped and assembled per Sections 6 and 8.

10.2 *Pretest Procedure*

10.2.1 Pretest Oil Charge Pressure charge the engine with 14.5 kg of test oil. This amount includes oil in the filter (non-test filter p/n LF3970).

10.2.2 Cam and Tappet Break-In Start the engine and idle (no load) for no more than 10 seconds. Ramp the engine to 3000 r/min and no load within 5 seconds and hold those conditions for 30 seconds. This step is done only once, at the first start-up for new test parts. Do not run this step for all subsequent start-ups on the same set of test parts. Proceed straight to the 1300 r/min and no load conditions of the engine warm-up as specified in section 10.2.3.1.

10.2.3 Engine Warm-Up Procedure Perform all engine start-ups according to the following, changing set points in a step-wise fashion:

10.2.3.1 Run the engine at 1300 r/min and no load for 2 minutes. (If the start-up is for Stage A, start the auxiliary oil pump.)

10.2.3.2 Increase load to 200 Nm for 5 minutes.

10.2.3.3 Increase load to 400 Nm for 5 minutes.

10.2.3.4 Increase speed to 2600 r/min and load to 600 Nm for 5 minutes.

10.2.4 Pretest Oil Flush Operate the engine at 1600 r/min and 440 Nm for 15 minutes. Shut the engine down according to Section 10.2.5 and drain all the oil for 30 minutes. Replace the non-test oil filter with another non-test filter and repeat the test oil charge, the engine warm-up and operate the flush conditions for 15 minutes. Shut down (10.2.5) and drain all the oil for 30 minutes. Replace the oil filter with a test filter.

10.2.5 Engine Shutdown Perform all non-emergency shutdowns according to the following, changing set points in a step-wise fashion:

10.2.5.1 From Stage A:

-Decrease engine speed to1300 r/min and load to 440 Nm for 1 min.

-Decrease load to 200 Nm for 1 min.

-Run engine at low idle and no load for 2 min.

10.2.5.2 From Stage B

-Run engine at 1300 r/min and 200 Nm for 2 min.

-Run engine at low idle and no load for 2 min.

10.3 *350-h Two Stage Test Cycle*

10.3.1 Test Oil Charge Pressure charge the engine with 14.5 kg of test oil. This amount includes oil in the filter.

10.3.2 Test Conditions Warm-up the engine according to Section 10.2.3 and run the 350-h test conditions shown in Table 4 and Table 5. At the conclusion of the 350-h test, shutdown the engine according to Section 10.2.5.

Table 3. Break-in Cycle

Sub Cycle	Load	**Speed**	Time (Sec)
1.	0 %	800 RPM	144
2.	800 Nom	1,600 RPM	36
3.	800 Nom	2,600 RPM	360
4.	0 %	3,000 RPM	36
5.	800 Nom	2,600 RPM	144
6.	800 Nom	Lug from 2,600 RPM to 1,600	36

		RPM	
7.	800* Nom	1,600 RPM	108
8.	0 %	3,000 RPM	36

* During step 7, turbo surge conditions may occur in the induction system requiring torque to be reduced about 3-8%.

Table 4. Test conditions

Test Parameter	Stage A	Stage B	Units
Time, h	100	250***	
Engine speed	1,600 ± 10	Varies	RPM
Torque	Resultant	Varies	Nm
Fuel Rate	20.0 ± 0.3	Varies	kg/hr
Coolant out temp	99 ± 3	99 ± 3	Deg. C.
Coolant pressure	99 -107	99-107	kPa
Intake manifold pressure	Resultant	Varies	kPa
Intake manifold temp	68 ± 2	68 ± 5	Deg. C
Inlet air temp	25 - 35	25 - 35	Deg. C.
Turbine inlet temp	Resultant	Varies	Deg. C.
Oil pan temp	110 ± 2	110 ± 2	Deg. C.
Oil pressure	Resultant	Varies	kPa
Intake air restriction	1 – 3	0 – 4	kPav
Exhaust back pressure	6 – 8	4 max	kPa @ Step 2 of Stage B
Fuel temp	40 ± 2	40 ± 2	Deg. C.
Fuel lift pump pressure	Record	Record	kPa

** Intended set point, but may vary due to cyclic conditions.

*** Stage B length is determined by test time. A minimum of 32,000 cycles shall be completed for the test to be valid.

10.3.3 Oil Samples – Take 120 ml oil samples every 25-h from 0 to 100 h and every 50 hours from 150 h to end-of-test from the sample valve as shown in Fig. A4.3. Be sure to take a purge (120 ml for Stage A and 30 ml for Stage B) prior to taking the sample. During Stage A return the purge to the auxiliary oil reservoir; during Stage B discard the purge. Oil samples are to be taken prior to forced additions.

10.3.4 Stage A Details

10.3.4.1 Run at retarded timing (-16 maximum) to generate 3.25% +/- 0.25% soot at 100 hours. Use Cummins engineering tool to change final timing as indicated on engineering tool display.

10.3.4.2 Oil Addition / Drain – Initially establish the full mark as the oil scale weight after 4 h of running Stage A. At 25, 50, 75, and 100 h, drain a sufficient amount of oil to obtain an oil weight that is 1000 g below the full mark. Add back 1000 g of fresh test oil. For any 25-h period in which the oil weight is already more than 1000 g below the full mark, do not perform the force drain.

10.3.4.3 At the 100 h oil add, after the oil fill, close the auxiliary oil system suction valve, allow the auxiliary oil pumps to empty the external oil reservoir and force the oil into the oil pan. When the external reservoir is empty, close the external oil valves and turn-off the external oil pumps. (This can be done in the final minutes while the engine is still operating at Stage A conditions).

10.3.4.4 *Data Collection Minima for Stage A* – take snapshot readings of all operational data every 6 minutes.

10.3.5 Stage B Details

10.3.5.1 The test cycle time is twenty-eight (28) seconds in duration maximum. This cycle is repeated for 250 hours, refer to Table 5.

10.3.5.2 Return timing to default (native timing) using Cummins engineering tools software.

10.3.5.3 No fresh oil replacement or additions are allowed throughout Stage B.

10.3.5.4 Stage B length is based on test time. A minimum of 32,000 cycles shall be completed for the test to be valid. The cycle counter advances at the completion of the last low idle step.

10.3.5.5 *Data Collection Minima for Stage B* – At least every 12 cycles, capture snapshot of all data 1s before end of rated speed stage (5 s into step 2 of Table 5). Every 1,000 cycles take two (minimum) consecutive full-cycle traces of speed and load at 10 Hz.

Table 5 Stage B Test Cycle

Step	Step Timer	Accumulated Time	Operation	NGET Throttle Position %	Speed (RPM)	Load (Nm) {Nominally observed}
0	-	-	Idle	0	750 – 850	No load excitation
1	2.5	2.5	Accelerate to step 2 conditions	100	Ramp up	Ramp up
2	6.0	8.5	Rated speed	100	2,600*	WOT(800 nominal)
3	2.0	10.5	Lug** to step 4 conditions	0	Ramp down	Ramp down
4	1.0	11.5	Idle	0	750 – 850	No load excitation
5	2.5	14.0	Accelerate to speed & load within 1.5 sec.	75***	Peak 1,600 to 1750 for minimum 0.5 second	550 – 750 N•m
6	2.0	16.0	Lug** to step 7 conditions	0	Ramp down	Ramp down
7	1.0	17.0	Low Idle	0	750 – 850	No load excitation
8	2.5	19.5	Accelerate to speed & load within 1.5 sec.	75***	Peak 1,600 to 1750 for minimum 0.5 second	550 - 750 N•m

9	2.0	21.5	Lug** to step 10 conditions	0	Ramp down	Ramp down
10	1.0	22.5	Idle	0	750 – 850	No load excitation
11	2.5	25.0	Accelerate to speed & load within 1.5 sec.	75***	Peak 1,600 to 1750 for minimum 0.5 second	550 - 750 N•m
12	2.0	27.0	Lug** to step 13 conditions	0	Ramp down	Ramp down
13	1.0	28.0	Idle	0	750 – 850	No load excitation

*Engine speed average (6 seconds) to be 2,600 +/- 50 RPM. Initial overshoot between 2650 and 2800.

**Engine speed must come to idle before reaching a no load condition

***Approximate throttle position to reach specified speed and load.

10.4 Post-Test

10.4.1 Drain all the test oil for 30 minutes. Remove the test oil filter.

10.4.2 Install a non-test oil filter. Charge the engine with 14.5 kg of Cummins branded CES 20078 oil. Circulate the oil through the engine for 15 min using an oil flush cart. At the end of 15 min, drain all the flush oil.

10.4.3 Remove, clean and measure tests parts per section 8.1.

11. Calculations, Ratings and Test Validity

11.1 Crosshead Mass Loss -- Use the procedure shown in 8.1.5 to determine individual EOT crosshead mass. Report the crosshead measurements and calculations.

11.1.1 Separate the crossheads into intake and exhaust groups.

11.1.2 Calculate the mass loss for each crosshead (pre-test - post test) and report the results. Calculate the average crosshead mass loss for both the intake and exhaust groups.

11.1.3 Use Practice E 178, two-sided test at a 95% significance level to determine if any crosshead mass loss values are outliers (keeping the intake and exhaust groups separate). Report the outlier screened average crosshead values for both the intake and exhaust groups. If no outliers were identified, these values will be the same as the values calculated in section 11.1.2.

11.1.4 Calculate the overall outlier screened average crosshead mass loss as follows:

CAWL = (OACWLI + OACWLE) / 2

Where:

CAWL = outlier screened average crosshead mass loss

OACWLI = outlier screened average intake crosshead mass loss (section 11.1.3)

OACWLE = outlier screened average exhaust crosshead mass loss (section 11.1.3)

11.1.5 Calculate and report the Average Crosshead Mass Loss Adjusted to 3.50 % Soot as follows:

ACWL = CAWL – 1.3 (TGAAVG – 3.50)

Where:

ACWL = Average Crosshead Mass Loss Adjusted to 3.50% Soot

CAWL = outlier screened average crosshead mass loss

TGAAVG = mathematical average of the nine soot measurements from 25 to 350 h

11.2 <u>Tappet Mass Loss</u> -- Use the procedure shown in 8.1.6 to determine individual EOT tappet mass. Report the tappet loss measurements and calculations.

11.2.1 Separate the tappets into intake and exhaust groups.

11.2.2 Calculate the mass loss for each tappet (pre-test - post-test) and report the results. Calculate the average tappet mass loss for both the intake and exhaust groups.

11.2.3 Use Practice E 178, two-sided test at a 95% significance level to determine if any tappet mass loss values are outliers (keeping the intake and exhaust groups separate). Report the outlier screened average tappet mass loss values for both the intake and exhaust groups. If no outliers were identified, these values will be the same as the values calculated in section 11.2.2.

11.2.4 Calculate the overall outlier screened average tappet mass loss as follows:

TWL = (OATWLI + OATWLE) / 2

Where:

TWL = outlier screened average tappet mass loss

OATWLI = outlier screened average intake tappet mass loss (section 11.2.3)

OACTLE = outlier screened average exhaust tappet mass loss (section 11.2.3)

11.2.5 Calculate and report the Average Tappet Mass Loss (Soot Adjusted) as follows:

11.2.5.1 For all tests starting on or before January 24, 2007:

ATWL = TWL – 76 (TGAAVG – 3.50)

Where:

ATWL = Average Tappet Mass Loss (Soot Adjusted)

TWL = outlier screened average tappet mass loss

TGAAVG = mathematical average of the nine soot measurements from 25 h to 350 h

11.2.5.2 For all tests starting on or after January 25, 2007:

ATWL = TWL – 39 (TGAAVG – 3.48)

Where:

ATWL = Average Tappet Mass Loss (Soot Adjusted)

TWL = outlier screened average tappet mass loss

TGAAVG = the mathematical average of the nine soot measurements from 25 h to 350 h provided that average falls within the range of 2.92 to 4.04. If the average is less than 2.92, then use 2.92. If the average is greater than 4.04, then use 4.04.

11.3 Camshaft Wear -- Use the procedure shown in 8.1.7 to determine individual lobe camshaft wear. Report the camshaft wear.

11.3.1 Separate the cam lobes into intake and exhaust groups.

11.3.2 Calculate the wear for each cam lobe (pre-test - post-test) and report the results. Calculate the average camshaft wear loss for both the intake and exhaust groups.

11.3.3 Use Practice E 178, two-sided test at a 95% significance level to determine if any camshaft wear values are outliers (keeping the intake and exhaust groups separate). Report the outlier screened average camshaft wear values for both the intake and exhaust groups. If no outliers were identified, these values will be the same as the values calculated in section 11.3.2.

11.3.4 Calculate the overall outlier screened average camshaft wear as follows:

ACSW = (OACSWI + OACSWE) / 2

Where:

ACSW = outlier screened average camshaft wear

OACSWI = outlier screened average intake camshaft wear (section 11.3.3)

OACSWE = outlier screened average exhaust camshaft wear (section 11.3.3)

11.4 Oil Analyses -- Analyze the oil samples for wear metals, TBN, TAN, TGA Soot (per D5967, Annex A4), and viscosity at 100°C (per D5967, Annex A3) according to the schedule and methods shown in A11 and report.

11.5 Fuel Analyses — Report the analyses provided by the fuel supplier. Report the analyses of the final batch if more than one fuel batch was used.

11.5.1 Additional Analyses -- Perform the following analyses on the 120 ml new and EOT fuel samples, and report.

11.5.1.1 API Gravity at 15.6 °C (60 °F), Test Method D 4052

11.5.1.2 Total Sulfur, % wt., Test Method D5453 (D 2622, or D 4294 can be substituted)

11.6 Assessment of 28-second Cycle Validity Data will be collected at an acquisition rate of at least 10 Hz and the resulting plot of Speed (RPM) and Torque versus time. The resulting plot of the cycle will indicate that the engine achieved the conditions set forth in the test procedure.

11.7 Assessment of Test Validity –Tests must complete no less than 32,000 cycles during Stage B within the 250 hours to be operationally valid. Tests must meet the 100 h soot window of 3.25 ± 0.25% to be operationally valid.

12. REPORT

12.1 *Reporting Reference Oil Test Results*

For reference oil tests, the standardized report form set and data dictionary for reporting test results and for summarizing operational data are required. Report forms and the Data Dictionary are available from the TMC. Fill out the report forms according to the formats shown in the Data Dictionary. When transmitting data electronically, a Header Data Dictionary shall precede the Data Dictionary. The latest version of this Header Data Dictionary can be obtained from the TMC either by ftp (internet) or by calling the Test Engineer responsible for this particular test. Round the data in accordance with Practice E 29.

12.1.1 During the test, if the engine is shut down or operated out of test limits, record the test hours, time, and date on the appropriate form. In addition, all prior reference oil tests that were deemed operationally or statistically invalid should be noted in the comment section.

12.1.2 When reporting reference oil test results, transmit the test data electronically by utilizing the ASTM Data Communications Committee Test Report Transmission Model (see Section 2 – Flat File Transmission Format) which is available from the TMC. Transmit the data within five working days of test completion. Mail a copy of the final test report within 30 days of test completion to:

ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489

12.2 *Deviations from Test Operational Limits*

Report all deviations from specified test operational limits on the appropriate form.

13. PRECISION AND BIAS

13.1 *Precision*

13.1.1 Test precision is established on the basis of operationally valid reference oil test results monitored by the TMC.

13.1.1.1 *Intermediate Precision Conditions* – Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE : The Intermediate precision is the appropriate term for the method rather than repeatability which defines more rigorous within-laboratory conditions.

13.1.1.2 *Intermediate Precision Limit (i.p.)* – The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 6 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.1.3 *Reproducibility Conditions* – Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

13.1.3.4 *Reproducibility Limit (R)* – The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 6 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.2 Test precision, as of July 14, 2006 is shown in Table 6.

TABLE 6

Test Precision

Measured Units		
Test Result	Intermediate Precision, (i.p.)	Reproducibility, (R)
Average Camshaft Wear, μm	18.2	18.7
Average Tappet Mass Loss, mg	34.7	39.6
Average Crosshead Mass Loss, mg	0.97	1.31

13.1.3 The TMC will be able to update precision data as it becomes available.

13.2 *Bias*

No estimate of bias is available.

ANNEXES

(Mandatory Information)

A1. Safety Precautions

A2. Mandatory Supplier List

A3 Engine Build Parts Kit

A4. Sensor Locations and Special Hardware

A5. External Oil System

A6. Fuel Specification

A7. Cummins Service Publications

A8. Specified Units and Formats

A9. Oil Analyses

A1. SAFETY PRECAUTIONS

A1.1 The operating of engine tests can expose personnel and facilities to safety hazards. Personnel trained and experienced with engine testing should perform the design, installation, and operation of test stands.

A1.2 Guards (shields) should be installed around all external moving, hot, or cold components. Design the guard to contain the energy level of a rotating component should the component break free. Fuel, oil, coolant and electrical wiring should be properly routed, guarded, grounded and kept in good order.

A1.3 The test stand should be kept free of oil and fuel spills and tripping hazards. Containers of oil or fuel, or both, should not be permitted to accumulate in the testing area. Fire fighting equipment should be immediately accessible. Normal precautions should be observed whenever using flammable solvents for cleaning purposes.

A1.4 Safety masks, glasses, or hearing protection, or a combination thereof, should be worn by personnel working on the test stand. No loose or flowing clothing, including long hair or other accessory to dress, should be worn near rotating equipment. Personnel should be cautioned against working alongside the engine and driveline while the engine is running.

A1.5 Interlocks should automatically shutdown the engine when an anomaly in any of the following occur: engine or dynamometer coolant temperature, engine oil pressure, dynamometer field current, engine speed, exhaust temperature, excessive vibration or when the fire protection system is activated. The interlock should include a method to cut off the fuel supply to the engine at the injector pump (including the return line). A remote fuel cut off station (external to the test stand) is recommended.

A1.6 Employ other safety precautions as required by regulations.

A2. MANDATORY SUPPLIER LIST

A2.1 Obtain PC-10 test fuel from the supplier listed below:

Chevron Phillips Chemical Company LP
10001 Six Pines Drive, Suite 4036B
The Woodlands, TX 77387-4910
Phone: 832-813-4859
Fax: 832-813-4907
Email: fuels@cpchem.com

A2.2 Obtain the test engine, the engine build parts kit, ECM, and the oil adapter plate from the CPD listed below. Direct questions or correspondence concerning Cummins test parts to the CPD listed below.

Test Engineering, Inc.
12718 Cimarron Path
San Antonio, TX 78249-3423
Phone: (210) 690-1958
Fax: (210) 690-1959

A2.3 The 3" x 14" Dual-pass baffle remote oil heat exchanger is available from:

Kinetic Engineering
2055 Silber Road, Suite 101
Houston, TX 77055
Phone (800) 392-5889
www.kineticeengineering.com

A2.4 The Modine aftercooler (P/N 1A012865) can be obtained from the supplier shown in A2.2 or either of the two suppliers shown below:

Kraft Power Corporation
1229 Nessley Road
Lancaster, PA 17601

Local Mack Trucks dealers:

When ordering the Modine cooler from Mack Trucks Inc., instruct the dealers to use P/N 5424 03 928 031. Because it is a non-stocked part in the Mack parts distribution system, it will appear as an invalid P/N. Explain that the P/N is valid and that you want to have it expedited on a Ship Direct purchase order. It will then be shipped from Modine to you, bypassing the normal parts distribution system.

A2.5 The remote oil filter head adapter is available from the supplier listed below.

LOFA Industries Inc.
250 Hembree Park Drive, Suite 122
Roswell, GA 30076
Ph: 770-569-2928
www.lofa.net/remoteoil_backpage.html

A2.6 Ensolv is available from:
Enviro Tech International
2525 West Lemoyne Ave
Melrose Park, IL 60160
Ph: 888-324-7400
www.ensolv.com

A2.7 Vulkan Driveline Coupling p/n VKL3415 is available from:
American Vulkan USA
2525 Dundee Road
Winter Haven, FL 33484
Ph: 863-324-8637

A3. ENGINE BUILD PARTS KIT

Table A3.1 Engine Build Parts Kit

Description	Part Number	QTY
Camshaft	3954099	1
Tappet	3947759	12
Crosshead	3943626	12
Push Rod	3941253	12
Rocker Shaft	3935892	12
Rocker Lever, Intake (short)	3937219	6
Rocker Lever, Exhaust (long)	3937220	6
Rocker Support	3941559	6
Oil Pan Seal	3959797	1
Rear Seal	4890833	1
Test Oil Filter	3937736	1
Rocker Cover Seal	3954324	1

A4. SENSOR LOCATIONS AND SPECIAL HARDWARE

A4.1 Figure Description:

A4.1.1 Oil Heat Exchanger Bypass Plate (Fig. A4.1)

A4.1.2 Remote Filter Head Adapter (Fig A4.2)

A4.1.3 Remote Oil Filter (Fig A4.3)

A4.1.3a Remote Oil Cooler (Fig A4.3a)

A4.1.4 Oil Pan Modifications (Fig A4.4 and Fig A4.5)

A4.1.4a Blowby Elbow to Blowby Barrel (Fig A4.4a)

A4.1.5 Intake Air System (Fig A4.6, Fig A4.6a, Fig A4.7, and Fig 4.8)

A4.1.6 Aftercooler Installation (Fig A4.9)

A4.1.7 Exhaust System (Fig A4.10)

A4.1.8 Oil Gallery Temperature and Pressure (Fig A4.11)

A4.1.8a Crankcase Pressure Measurement Point (Fig A4.11a)

A4.1.9 Fuel Temperature (Fig A4.12)

A4.1.10 Fuel Pressure (Fig A4.13)

A4.1.11 Coolant Temperature Outlet (Fig A4.14)

A4.1.11aCoolant Temperature Inlet (Fig A4.14a)

A4.1.12 Entire Test Installation (Fig A4.15)

FIG A4.1

FIG A4.2

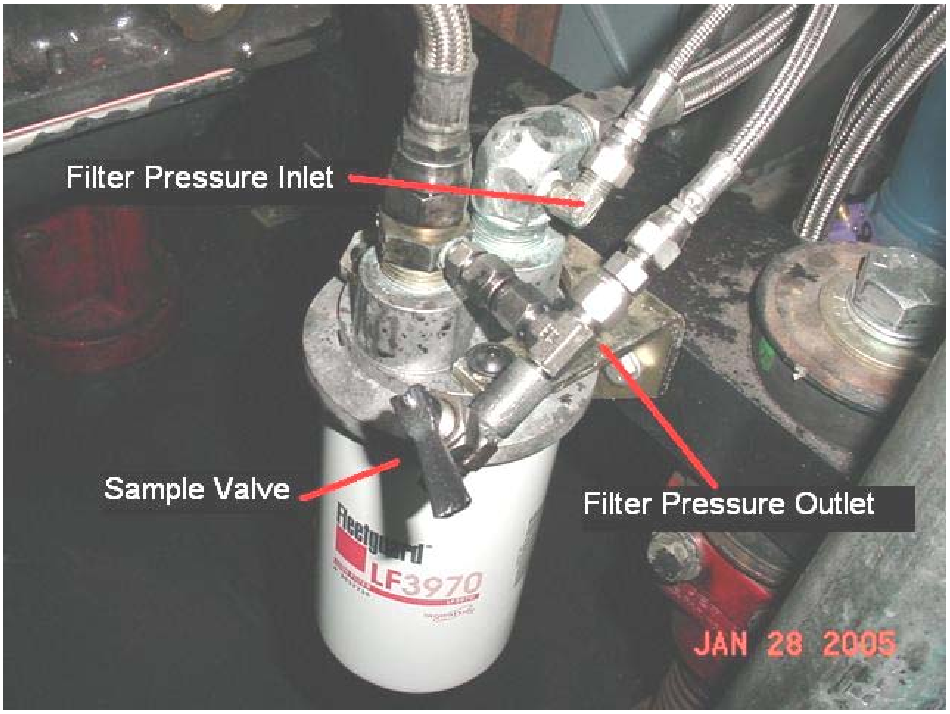

FIG A4.3

FIG A4.3a

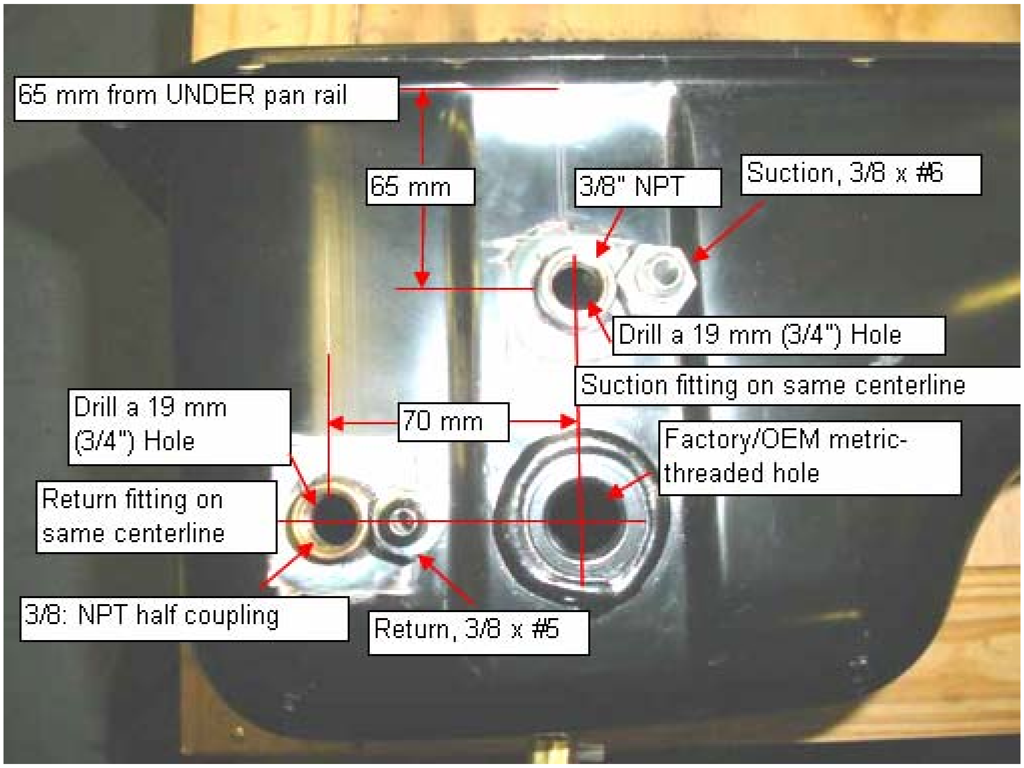

FIG A4.4

FIG A4.4a

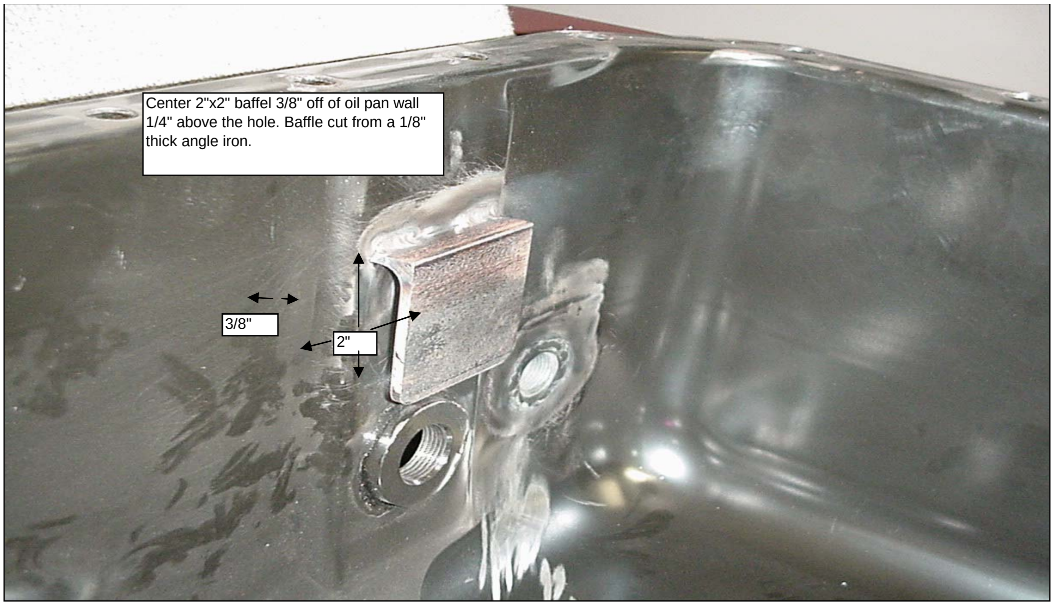

FIG A4.5

FIG A4.6

FIG A4.6a

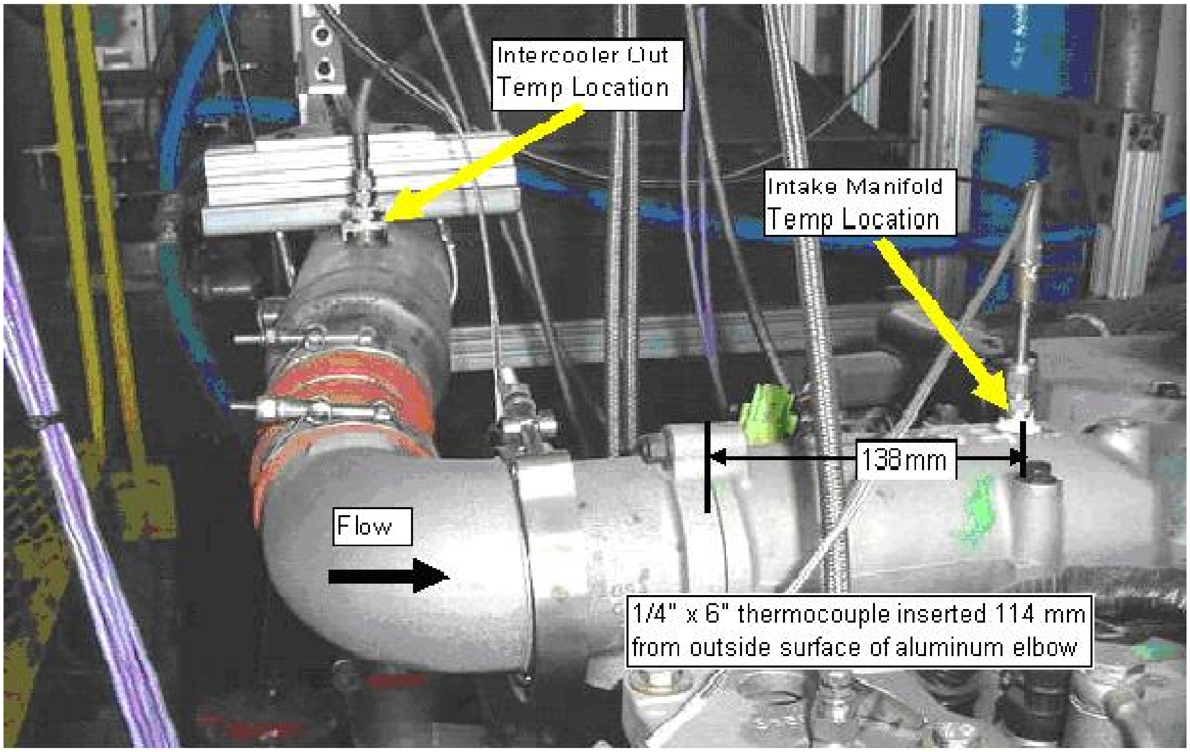

FIG A4.7

FIG A4.8

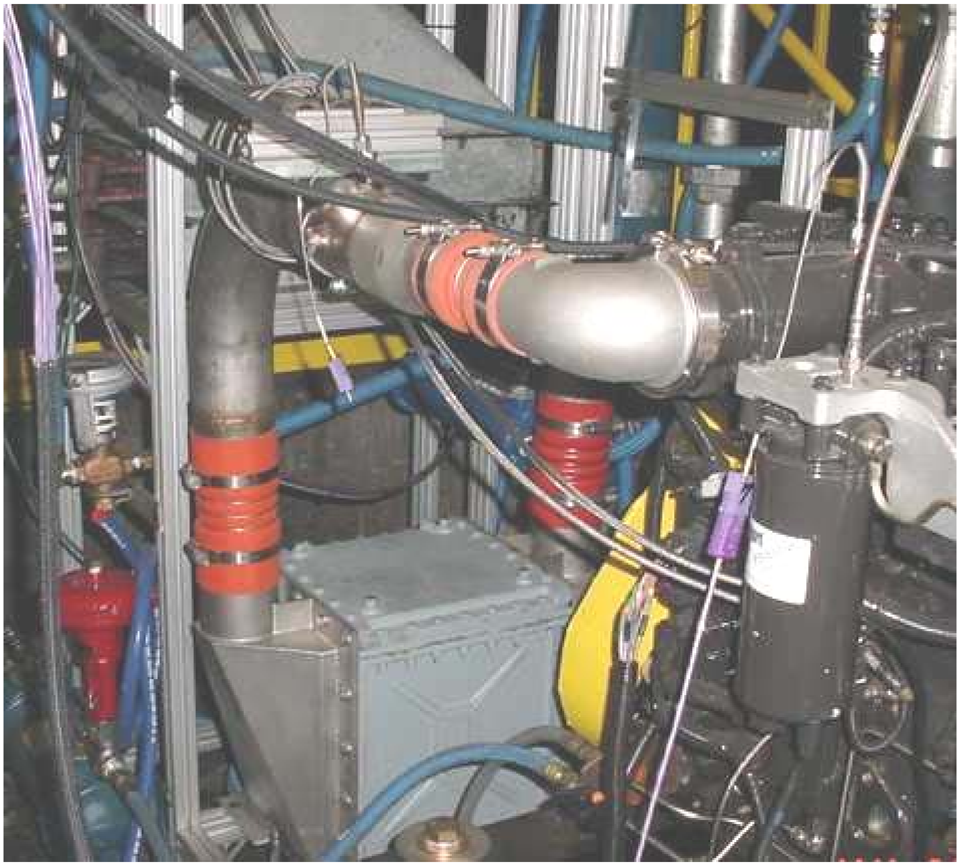

FIG A4.9

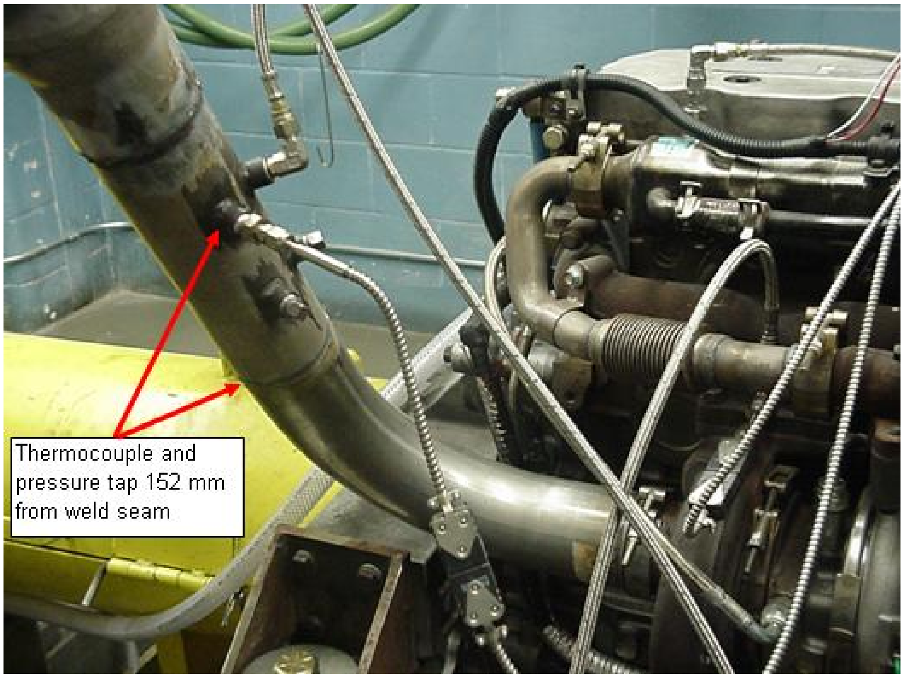

FIG A4.10

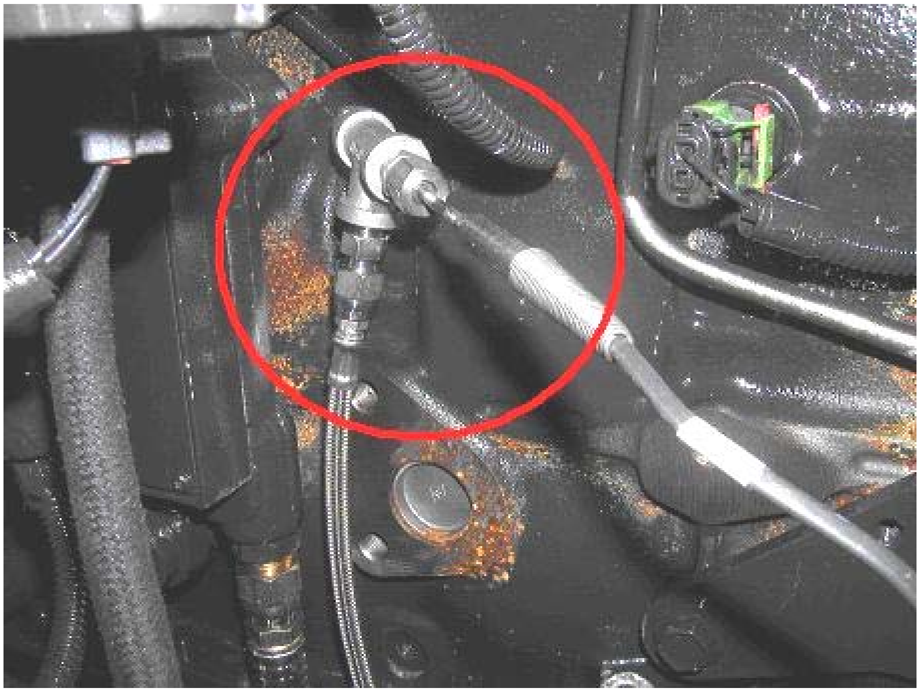

FIG A4.11

FIG A4.11a

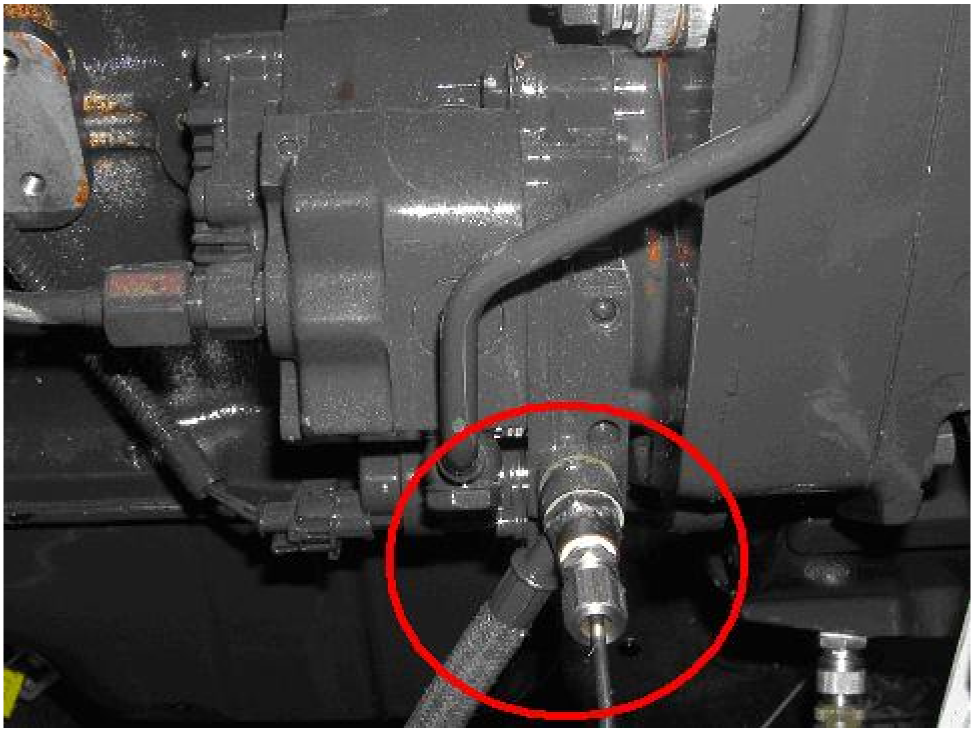

FIG A4.12

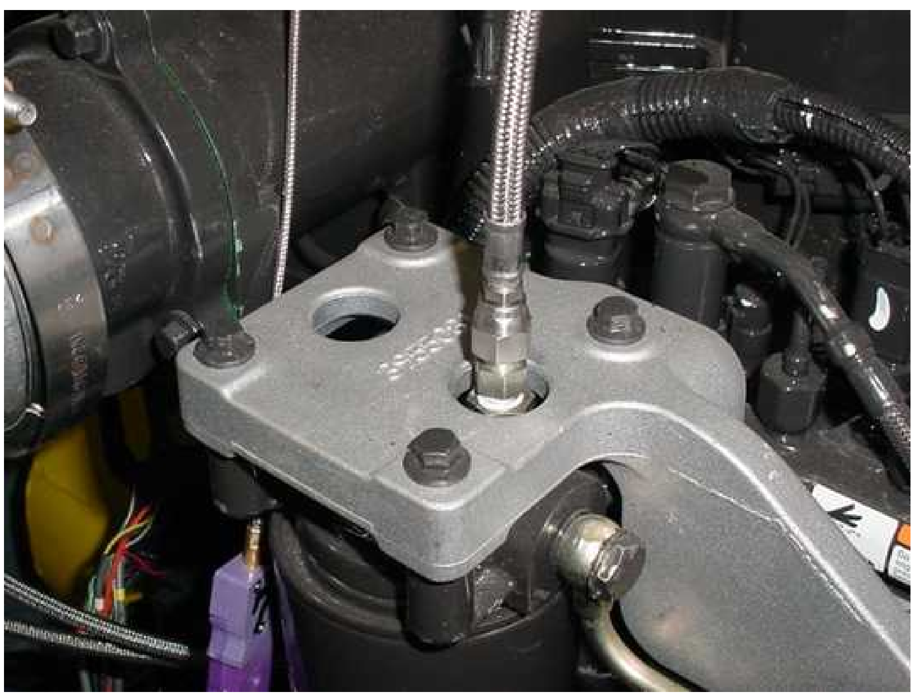

FIG A4.13

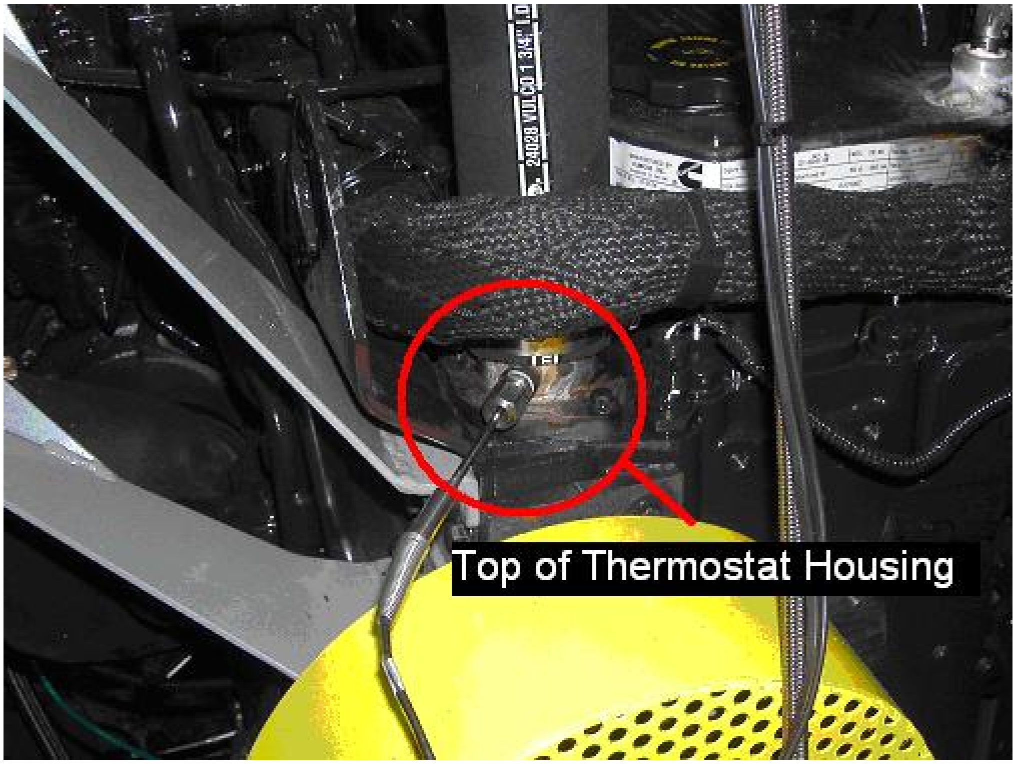

FIG A4.14

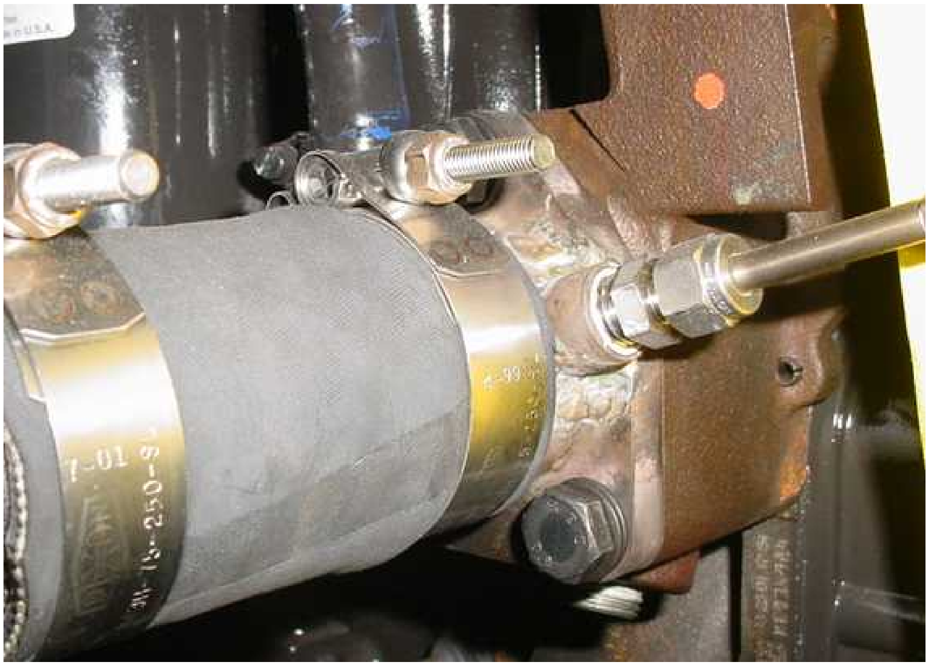

FIG A4.14a

FIG A4.15

A5. EXTERNAL OIL SYSTEM

Fig.A5.1 External Oil System

Hoses:
Supply – 8 mm (5/16 in.)
Return – 6 mm (1/4 in.)
Vent – 12 mm (1/2 in.) min

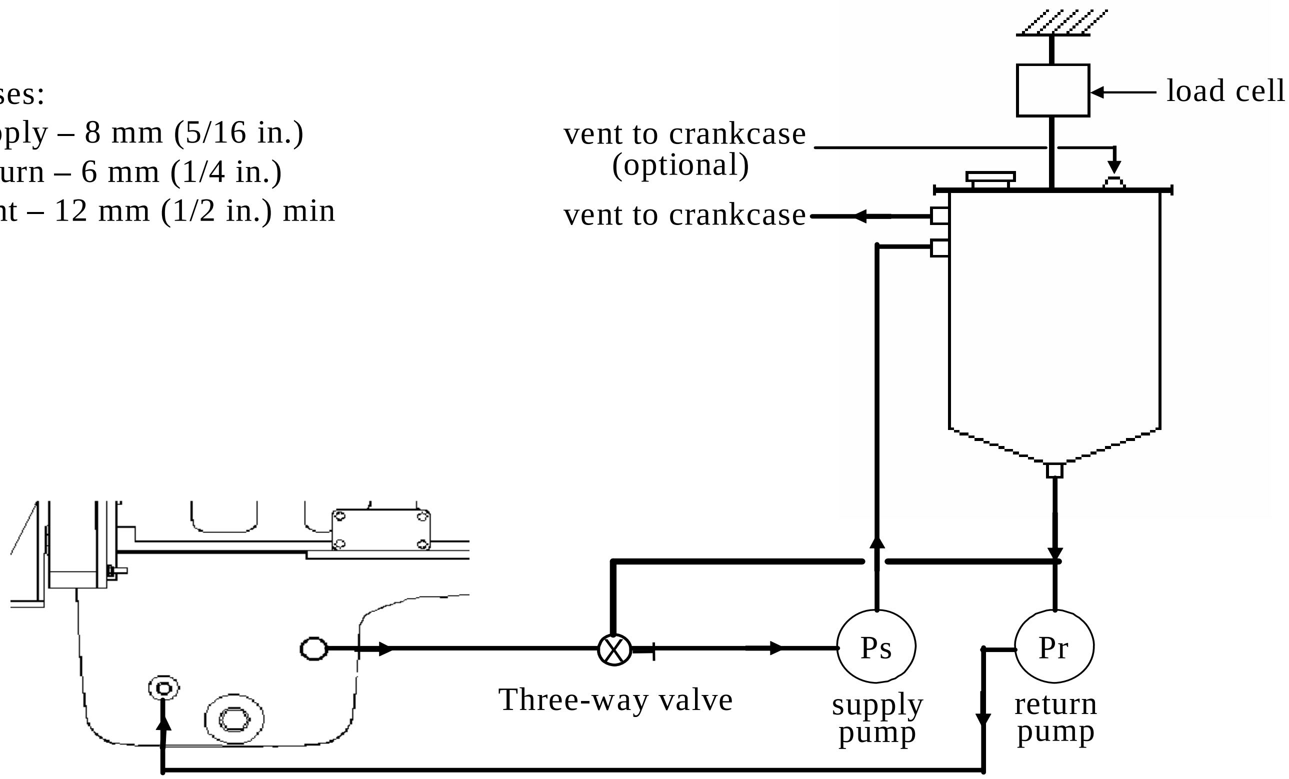

FIG. A5.1

A6. FUEL SPECIFICATION

Property	Specification	Test Method
Additives	Lubricity additive only	
Distillation Range, ºC, 90%	293 – 332	ASTM D 86
Specific Gravity	0.840 – 0.855	ASTM D 4052
API Gravity	34 – 37	ASTM D 4052
Corrosion, 3 h at 50 ºC	1 max	ASTM D 130
Sulfur, mass ppm	7 – 15	ASTM D 5453
Flash Point, ºC	54 min	ASTM D 93
Pour Point, ºC	-18 max	ASTM D 97
Cloud Point, ºC	Report	ASTM D 2500
Viscosity at 40 ºC, cSt	2.0 – 2.6	ASTM D 445
Ash, weight %	0.005 max	ASTM D 482
Carbon Residue on 10% Bottoms	0.35 max	ASTM D 524
Net Heat of Combustion	Report	ASTM D 3338
Water and Sediment, volume %	0.05 max	ASTM D 2709
Total Acid Number	0.05 max	ASTM D 664
Strong Acid Number	0 max	ASTM D 664
Cetane Index	Report	ASTM D 976
Cetane Number	43 – 47	ASTM D 613
Accelerated Stability, mg/100 mL	1.5 max	ASTM D 2274
Composition		
Aromatics, wt %	26 – 31.5	ASTM D 5186
Olefins, vol %	Report	ASTM D 1319
Saturates, vol %	Report	ASTM D 1319
SLBOCLE, g	3100 min[A]	ASTM D 6078[A]

A7. CUMMINS SERVICE PUBLICATIONS

A7.1 General preparation techniques, as well as, engine specifications, component specifications and torque values for Cummins ISB engines are detailed in the Cummins publication titled, Troubleshooting and Repair Manual ISB^{e} and ISB (Common Rail Fuel System) Series Engines, Bulletin No. 4021271, printed June 30, 2004.

A8. SPECIFIED UNITS AND FORMATS

A8.1 Specified Units:

A8.1.1 The parameters in this test method are specified in metric units except for pipe fittings, tubing and tubing fittings. Pipe fittings, tubing and tubing fittings are available worldwide and are not interchangeable with metric-sized equivalents because of differences in thread dimensions, therefore, no metric conversion is stated. The ports are standard straight thread and are not interchangeable with metric-sized equivalents.

A8.1.2 <u>Test Report</u> — Record operational parameters according to Table A8.1. Report test results in the units and with the significant digits shown in Table A8.2. Round test results in compliance with Practice E29.

A8.1.3 <u>Measurements and Conversions</u> — With the exceptions noted in A8.1.1, all parameters have been specified in S.I. units. The intent of this test method is to measure all parameters directly in S.I. units. If parameters are measured in inch-pound units, then the laboratory shall be able to demonstrate to the TMC that the measurements are within the tolerance after conversion to S.I. units.

Note A8.1: Caution -- Significant error can occur due to rounding or tolerance stacking, or both, when converting from inch-pound units to S.I. units.

Table A8.1 Minimum Resolution of Recorded Measurements

Parameter	Record data to Nearest
Speed	1 r/min
Power	1 kW
Torque	1 N•m
Fuel Flow	0.1 kg/hr
Coolant In Temperature	0.1 °C

Coolant Out Temperature	0.1 °C
Fuel In Temperature	0.1 °C
Oil Gallery Temperature	0.1 °C
Intake Air Temperature	0.1 °C
Exhaust (Tailpipe) Temperature	1 °C
Intake Manifold Pressure	0.1 kPa
Crankcase Pressure	0.01 kPa
Exhaust Pressure	0.1 kPa

Table A8.2 Significant Digits for Test Results

Parameter	Round off to Nearest
Mass Loss	0.1 mg
Sludge	0.1 merit
Filter Plugging	1 kPa

A8.2 Specification Format — Specifications are listed in three formats: 1) target 2) target and range, and 3) range with no target.

A8.2.1 Target – A target specification has no tolerance, therefore, the only acceptable value is the target. A representative specification format is xx.xx (target). For example, the oil pan oil charge is listed as 14.5 kg.

A8.2.1.1 A parameter with a target shall not be intentionally calibrated or controlled at a level other than the target.

A8.2.2 Target and Range – A target and a range specification implies the correct value is the target and the range is intended as a guide for maximum acceptable variation about the mean. A representative specification format is xx.xx ± x.xx (target ± range). For example, the engine speed is 1600 ± 10 r/min.

Note A8.2: The mean of a random sample should be equivalent to the target. Operation within the range does not imply that parameter will not bias the final test results.

A8.2.3 Range with No Target – A range with no target specification is used when 1) the parameter is not critical and control within the range is sufficient or 2) the measurement technique is not precise, or both. A representative specification format is xx.xx - xx.xx ($range_{low}$ – $range_{high}$). For example, the coolant system pressure is 99 – 107 kPa.

A9. OIL ANALYSES

	Parameter				
Sample Hour	Metals[A]	TAN[B]	TBN[C]	Vis @ 100 °C[D]	TGA Soot[E]
0	X	X	X	X	X
25	X	X	X	X	X
50	X	X	X	X	X
75	X	X	X	X	X
100	X	X	X	X	X
150	X	X	X	X	X
200	X	X	X	X	X
250	X	X	X	X	X
300	X	X	X	X	X
350	X	X	X	X	X

[A] D 5185 (Copper, Iron, Lead, Chromium, Aluminum)

[B] D 664

[C] D 4739

[D] D 5967 Annex 3 or D 445

[E] D 5967 Annex 4

Cummins ISB Footnotes

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.0B on Automotive Lubricants. Current edition approved XXX. Published YYYY.

[2] American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own

responsibility.

[3] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

[4] Annual Book of ASTM Standards, Vol 05.01

[5] Annual Book of ASTM Standards, Vol 05.04

[6] Annual Book of ASTM Standards, Vol 05.02

[7] Annual Book of ASTM Standards, Vol 05.03

[8] Annual Book of ASTM Standards, Vol 14.02

[9] Annual Book of ASTM Standards, Vol 14.03

[10] Available from the Coordinating Research Council, Inc., 219 Perimeter Parkway, Atlanta, Georgia 30346.

[11] Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

[12]Available from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

[13] Available from a Cummins parts distributor

[14] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 Phone: (412) 365-1000, Fax: (412) 365-1047