THE TRANSPORTABLE HEAVY-DUTY ENGINE EMISSIONS
TESTING LABORATORY

ANNUAL PROGRESS REPORT FOR THE PERIOD
APRIL 1990 THROUGH APRIL 1991

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EXECUTIVE SUMMARY

West Virginia University has designed and constructed a Transportable Emissions Testing Laboratory for measuring emissions from heavy duty vehicles, such as buses and trucks operating on conventional and alternative fuels. The laboratory facility can be transported to a test site located at, or nearby, the home base of the vehicles to be tested. The laboratory has the capability of measuring vehicle emissions as the vehicle is operated under either transient or steady state loads and speeds. The exhaust emissions from the vehicle is sampled and the levels of the constituents of the emission are measured.

The laboratory consists of two major units; a power absorber unit and an emissions measurement unit. a power absorber unit allows for the connection of a dynamic load to the drive train of the vehicle so that the vehicle can be "driven" through a test cycle while actually mounted on a stationary test bed. The emissions unit contains instrumentation and equipment which allows for the dilution of the vehicle's exhaust with air. The diluted exhaust is sampled and analyzed to measure the level of concentration of those constituents which have been identified to have impact on the clean environment.

The power absorber unit consists of equipment mounted on a flat bed fifth wheel tractor trailer. The wheels of the trailer can be removed and the bed of the trailer can be lowered to the ground using hydraulic jacks which are mounted to the test bed. Two sets of free running rollers are imbedded in the test bed. When the test bed is resting on the ground, the vehicle to be tested can be driven onto the bed with the drive wheels of the vehicle positioned on the free running rollers. Tandem drive axle vehicles use both sets of rollers and single axle vehicles use only one set.

The outer wheels of the dual wheel set on each side of the driver axle of the vehicle to be tested are removed. Special hub adapters are mounted in place of the outer wheels of the drive axle. A drive shaft is connected to the hub adapters on each side of the vehicle. The drive shafts on each side are connected through a drive train to a set of flywheels and to an electronically controlled power absorber. The flywheels consist of a series of selected discs to allow simulation of an inertia load equal to a gross vehicle weight up to 40,000 pounds in 250 pound steps. A computer control system controls the load generated by the power absorber. The computer also provides a signal for vehicle speed to be displayed on a video display screen which can be mounted next to the tested vehicle drivers compartment. The display screen provides directions to the driver of the vehicle regarding the vehicle speed which is desired throughout a pre-programmed test cycle. The test cycle used can be selected from a wide range of test cycles which can simulate both dynamic or steady state vehicle driving conditions. The driver can thus "drive" the vehicle through a test cycle which is preselected pattern of transient speed and load conditions. During the test cycle torque cells and speed transducers in the power absorber drive train measure the actual vehicle load and speed.

The emissions measuring equipment is located in a separate enclosed, instrument trailer which is parked near the power absorber test bed. A dilution tunnel is located on the roof of the instrument trailer. The full exhaust from the tail pipe of the vehicle being tested is ducted to the dilution tunnel where it is mixed with air and the quantity of diluted exhaust is precisely measured. Sampling probes withdraw diluted exhaust which is supplied to a number of different exhaust gas

Sampling probes withdraw diluted exhaust which is supplied to a number of different exhaust gas analysis instruments. The exhaust gas analysis instruments have the capability to measure the levels of the following exhaust gas constituents: carbon monoxide (CO), carbon dioxide (CO₂), oxides of nitrogen (NO_x), unburned hydrocarbons (HC), formaldehyde (HCHO), methane and particulate matter. Additional instruments or sampling devices can be installed whenever measurements of additional constituents are desired. A computer based, data acquisition system is used to continuously monitor a wide range of parameters important to the operation of the test and to record the test results.

The laboratory utilizes approximately 150 amperes of 220 volt three phase electrical power and approximately 100 amperes of 220 volt single phase power. Electrical power generator sets are part of the laboratory and can be used whenever electrical power is not available at the test site. No other utilities are required. It is preferable that the laboratory be set up inside a bus shed, airport hanger or other large building to provide protection from the weather during testing. However, when no indoor space is available the laboratory can be set up and operated outdoors. The largest component of the laboratory is the power absorber test bed which is 31 feet long and 8 feet wide. Space is required to allow this unit to be positioned and the vehicle to be tested to be backed onto the test bed from the side. The instrument trailer which is 26 feet long may be positioned nearby and on any side of the power absorber test bed.

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INTRODUCTION

The purpose of the transportable heavy-duty emissions testing laboratory is to monitor the performance and emissions of heavy-duty vehicles that are in service in the field. These heavy-duty vehicles include inter- and intra-city buses as well as trucks. The vehicles may use alternate fuels such as compressed natural gas (CNG), liquefied natural gas (LNG), methanol, ethanol and others or may use gasoline or diesel fueled vehicles.

A number of alternate fuel vehicles are now or will soon be in use in various metropolitan regions throughout the country. This laboratory will conduct measurements to make possible a comparative analysis of the emissions from these vehicles. The laboratory will be transported to near the "home base" of the vehicles so that the testing can be completed without taking the vehicles out of service for an extended length of time. An objective is to minimize both the impact on the vehicle's schedule of use as well as the cost of testing. Before the advent of this laboratory, it was practical only to test new engines and a very limited number of used engines. It would generally be necessary to remove the tested vehicles from service for an extended period of time in order to conduct emissions testing. The vehicles or their engines would then have to be transported or driven to a testing facility. The high cost of obtaining measurements of emissions from vehicles operating in the field has resulted in only a very limited amount of information being obtained. More extensive information concerning emissions from service vehicles is needed by governmental policy makers, engine and vehicle manufactures, and by fuel suppliers so that effective actions may be taken to reduce the adverse effects of heavy-duty vehicle emissions on the environment.

MAJOR COMPONENTS

The laboratory consists of two major elements, an emissions measurement system and a dynamometer system. The emissions measurement system utilizes an 18 inch diameter, 20 feet long full exhaust dilution tunnel housing four probes for the collection of diluted exhaust. The system includes instrumentation for measuring levels of carbon monoxide (CO), carbon dioxide (CO₂), oxides of nitrogen (NO_x), total hydrocarbons (THC), formaldehyde, methanol and methane. Sample lines from the probes are heated to the temperature appropriate for the gas being collected. In addition, a secondary dilution tunnel supplies emissions to 70-mm (2.75 in.) fluorocarbon-coated fiberglass filters for the collection of particulates. An environmental chamber is used for the conditioning of the filters before use or weighing (as per 40 CFR 86, Subpart N).

The emissions measurement instrumentation is all mounted in an enclosed trailer with air ride suspension. The dilution tunnel is mounted on the roof of the trailer and all instrumentation is mounted inside. The gas analyzers are mounted in a gas analysis bench which is also mounted on vibration and shock isolating pads. System operation functions are controlled and monitored through a computer in the instrumentation trailer. The outputs of the emission analyzers and other temperature and pressure transducers are also connected to the computer located in the instrument trailer.

The second major element of the transportable laboratory is a dynamometer system to which the truck or bus to be tested can be connected. The dynamometer system is mounted on a flat bed tractor trailer. The bed of the trailer can be lowered to the ground and in the lowered position the top of the test bed is approximately 13 inches above the ground. The vehicle to be tested is driven onto the test bed. The bed contains two sets of free running rollers on which the driven wheels of the vehicle are positioned.

The outer wheels of the dual wheels on each side of the driven axle are removed and replaced by hub adapters. Adjustable drive drafts connect these hub adapters to the power absorbing components of the system which are located on the test bed on each side of the vehicle being tested. The components of the dynamometer system are identical on each side. They are tied together mechanically by the rollers upon which the test vehicle sits to act as one unit. The major components of the dynamometer system on each side of the test vehicle are a flywheel to simulate vehicle inertia and an air cooled eddy current power absorber to simulate road and aerodynamic loads. These components provide the capability to simulate level or uphill steady speeds and/or operation with transient acceleration and deceleration.

The power train connecting the components incorporates gear boxes to increase the shaft speed of the flywheel and power absorber. The increase in speed allows their size to be reduced. The speed ratio to the flywheels was optimized to result in the smallest flywheels which would provide the required inertia as well as provide safe levels of radial and tangential stresses at the highest speeds of rotation. The flywheels consist of a set of 8 steel discs which can be selectively connected to simulate a broad range of vehicle weights. The diameter of the largest disc is approximately 4 feet and the total weight of flywheels on each side of the test vehicle is approximately 6,000 pounds.

The speed ratio to the power absorbers was selected so that at the highest speed of the vehicle being tested the power absorbers operate below at their maximum safe speed which is 4500 rpm. It is a characteristic of eddy current type power absorbers that at the low end of their speed (less than 100 rpm), they do not produce significant torque. The selected speed ratio allows the power absorbers to operate above this lower threshold whenever the tested vehicle speed is greater than 3 kilometers per hour (1.9 mph). The use of the gear boxes in the drive train also allows the flywheels and power absorbers to be mounted on an axis perpendicular to the tested vehicle's axle. Having the flywheel and power absorbers on an axis perpendicular to the axis of the drive axle of the test vehicle allows the equipment to fit in the relatively small footprint of a flat bed semi-trailer. The trailer test bed is 9.4 meters (31 feet) long and 2.4 (8 feet) wide.

The power from the tested vehicle into the dynamometer is measured using in-line torque transducers located in the drive train on each side of the vehicle as close as possible to the hub adapters. The computerized data acquisition system measures the torque and speed from each of these 22,600 Newton meters (16,667 lb-ft) capacity torque transducers with 60-tooth speed sensors. The resolution of the torque measurement is within 12 Newton meters (8 ft-lb) over its range.

The computerized data acquisition system measures the following items; listed by subsystem categories.

Emissions subsystem:

- Main dilution tunnel temperature
- Secondary dilution tunnel temperature
- Secondary dilution sampling pump rate
- Main dilution tunnel differential pressure
- Main dilution tunnel absolute pressure
- Ambient air temperature
- Low level carbon dioxide analyzer reading
- Carbon monoxide analyzer reading
- Nitrogen oxides analyzer reading
- Hydrocarbon analyzer
- Heated line temperatures

Mechanical subsystem:

- Vehical axle output torque
- Power absorber torque
- Power absorber angular velocity
- Torque set point for power absorbers
- Truck speed (actual) to the driver
- Truck speed (schedule) to the driver

Other measurements:

- Reference zero for analog to digital converter
- Reference span for analog to digital converter

Other outputs:

- Computer screen information for the operator
- Alarms for abnormal testing conditions or safety

CAPABILITIES

The chassis dynamometer is capable of testing heavy-duty vehicles ranging in gross vehicle weight rating (GVWR) from 45,000 Newtons (10,000 lb) to 180,000 Newtons (40,000 lb). The minimum increment in inertial weight is within 1100 N (250 lb). This weight range assumes that the outside diameter of the tire of the tested vehicle is between 1.0 meter (39 in.) and 1.2 meter (48 in.) inclusive. The coupling assembly of the hub adapters allows for the possible variations in ride height of vehicles whose tires are in this size range.

The power absorbers are capable of resisting continuous power up to 317 kilowatts (425 hp) and torques up to 44,456 Newton meters (32,789 lb-ft). While the dynamometer system is designed to cope with speeds up to 105 kilometers per hour (65 mph), it is recommended that test cycles be designed with a maximum speed of not greater than 97 km/h (60 mph) to allow for some driver error during the operation of a test. The dynamometer with its control system is capable of accurately supporting a wide range of transient test cycles. There is no constraint on the duration of a test cycle. The methods and procedures used to sample and analyze the emissions follow as closely as possible the recommendations of the U.S. Environmental Protection Agency for heavy duty engine certification testing as stated in the 40 CFR 86, Subpart N. The total volume of the mixture of exhaust and dilution air through the dilution tunnel is measured by measuring the temperature and pressure of the diluted exhaust as it passes through a critical flow venturi. The flow through the dilution tunnel is adjustable in four steps from approximately 1000 to 4000 cubic feet per minute.

The emissions analysis equipment is capable of collecting and analyzing low and high carbon monoxide (LCO and HC), carbon dioxide (CO₂), oxides of nitrogen (NO_x) and total hydrocarbons (THC) as well as formaldehyde, methane and methanol. For non-diesel fueled vehicles, particularly those using methanol, one of the four probes may be used to collect formaldehydes. The formaldehyde is absorbed in a canister which is later evaluated at an analytical laboratory. Heating elements are used to maintain the appropriate temperature in the sample lines connecting the probes from the dilution tunnel to the analyzers in the instrumentation trailer. In addition, inlet tubes are connected to the sample lines at the dilution tunnel end to allow for the introduction of calibration gases. Particulates are collected by 70-mm (2.75 in.) filters which are mounted in the flow stream from the secondary dilution tunnel.

OPERATING PROCEDURE

Prior to beginning the test, each of the gas analyzer instruments is zeroed and calibrated using calibration gases with traceability. The dynamometer is calibrated using the coast down test described in 40 CFR 86.1218-85. The torque transducers are calibrated using standard dead weights.

In preparation for testing; the vehicle to be tested has the outer rims on the drive axle removed. That set of rims is then replaced with a set of hub adapters. The test vehicle is then backed up a ramp until the drive axle is centered over the idler rollers located in the floor of the test bed. Once in place level, the vehicle is chained in place for safety. The drive shafts of the power train of the dynamometer system are coupled to the hub adapters. The inertia of the flywheels is adjusted to correspond to the inertia of the vehicle being tested. This is done by fixing the appropriate combination of the eight attachable/detachable flywheel discs to the four rotating discs which are part of the flywheel assembly on each side of the test vehicle. A cooling fan is located in front of the test vehicle to deliver air directly to the radiator of the vehicle to provide sufficient flow for normal engine operation. The exhaust transfer tubes are connected to the one or two exhaust pipes of the vehicle to be tested and connected to the inlet of the dilution tunnel. This completes the set-up of the vehicle for testing.

A video display is positioned near the driver's position of the tested vehicle. The computer system supplies the video display with speed set points to direct the driver in control of the vehicle speed. The line of set points is graphically displayed on the video monitor with the time interval of the test as the ordinate axis and the speed in miles per hour as the abscissa. Against that line is displayed

- the actual speed of the vehicle. Additionally, the operator is provided with a digital display of the prescribed and actual speed at the bottom of the display screen. During the test run the computer-based control system provides commands to the power absorbers to maintain the prescribed torque to simulate the aero-drag and rolling resistance which the test vehicle would encounter under actual operating conditions. The flywheel provides the dynamic inertia to the vehicle.

As the test cycle is executed, four probes in the dilution tunnel direct streams of diluted exhaust to the gas analyzers, the methanol analyzer or the formaldehyde cartridges and for bag samples. Another probe directs diluted exhaust to the secondary dilution tunnel. The flow through the secondary dilution tunnel is controlled by mass flow controllers. The exit gas from the secondary dilution tunnel passes through a 70-mm (2.75 in.) filter to collect particulates. The filters are conditioned and weighed in an environmental chamber located in the instrument analysis formaldehyde cartridges and dilute exhaust and background bag samples are taken to an analytical laboratory at West Virginia University for analysis.

CONSTRUCTION STATUS

During the past year all components of the laboratory have been designed, built or purchased. The assembly of the entire system has been substantially completed. The system is currently in operation for the purpose of checking out the performance of the system and undergoing a program of refinement of the testing procedures and calibration. It is expected that the laboratory will be ready for testing in the field in the fall of 1991.

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