

ENGINE AND DYNAMOMETER SYSTEM SERVICE AND FUEL CONSUMPTION MEASUREMENTS

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Abstract

The goal of the “ETME 499-Independent Research in Mechanical Engineering Technology” course is to introduce students to designing, manufacturing, upgrading, repairing and testing mechanical systems. The goal of laboratory part of “EDTE 341-Power and Transportation” course is to service small and/or large internal combustion engines. The purpose of this project was to service the gasoline engine, the engine dynamometer attached to it, and carry out some engine performance tests. If successful, the engine performance testing will be incorporated into the “EDTE 341-Power and Transportation course” or the “ETME 301-Thermodynamics and Heat Power” course as one or more laboratory experiments. EDTE 341 and ETME 301 are technical elective and required courses, respectively, for Mechanical Engineering Technology (MET) students. The gasoline engine was disassembled and serviced as a requirement for the laboratory part of the EDTE 341 course. Servicing of the engine-dynamometer system was completed as an ETME 499 project. Instrumentation for the fuel consumption measurements were added and the measurements were carried out. The results indicate that, at constant load, as the engine speed was increased the fuel consumption increased. The same trend was seen at constant speed; the fuel consumption increased as the load was increased. Simulated fuel economy (miles/gal) graph indicate that the engine economy was about flat at higher loads, but, was decreasing slightly at low loads when the engine speed was increased beyond about 1500 rpm.

Introduction

The two engine-dynamometer systems, one with a gasoline engine (Fig.1) and the other one with a diesel engine came with the new building when the department has moved into it in 1985. Both engines have the same model dynamometers, they were purchased as sets from Megatech Corporation¹. Since the systems were not frequently used, the author decided to overhaul the gasoline engine when he taught the “EDTE 341-Power and Transportation” course during the

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fall semester of 1997. The gasoline engine was opened, cleaned and put together as part of the laboratory requirement for the course. Since the dynamometer was leaking fluid, it needed service also. Most of the dynamometer service was completed during the summer of 2002 as a part of an “ETME 499-Independent Research in MET” course. Installation of the instrumentation and the fuel consumption measurements were completed during the fall semester of 2002.

Paper will cover:

1. The experiences we had in servicing the engine and the dynamometer,
2. Installation of the instrumentation,
3. Discussion of the results of measurements, and
4. How engine-dynamometer and other engine tests can be incorporated into a related Mechanical Engineering Technology or Mechanical Engineering Laboratory course.

The Gasoline Engine Disassembly and Service

The EDTE 341-Power and Transportation course is a required course for the Technology Education majors and it is a technical elective course for the MET majors. The course, most of the time, is taught by a part-time faculty. It is a three-credit hour course, and it has a two-hour lecture and a two-hour laboratory. The lecture part covers different types of transportation methods (land, marine, air and space), energy resources, gasoline and diesel engines, and turbines. The laboratory time is used to disassemble and service small engines. Students work in groups of two or three on one engine. The engine kits were purchased from Megatech Corporation in 1984. Most of them are Briggs&Stratton, 3 hp, 4 cycle gasoline engines. The others are Tecumseh, 2 hp, and two cycle gasoline engines.

The EDTE 341 course was taught by the author during the fall semester of 1997. The department of Technology has two engine-dynamometer systems in the Power and Transportation Laboratory. They were purchased in 1984 and came with the new, 50 000 square-ft Arts and Technologies building. The gasoline engine-dynamometer system was used once in 1985 to test SUN² Interrogator 1805-9 Engine Diagnostics unit. The diesel engine-dynamometer system, to date, was never used. The gasoline engine is a 1984 Pontiac 6000, 2.5 liter, throttle body injected, 4-cylinder engine. The diesel engine is a 1984 Volkswagen 4-cylinder engine. Both engines have the same model dynamometers. The engines are directly connected to the dynamometers by flexible-insert, rubber couplings. The plan was to use the gasoline engine-dynamometer system in other courses. Since the engine has been sitting unused too long it was unsafe to start the engine without properly servicing it. Therefore, the author decided to service the engine as a laboratory exercise for the EDTE 341 course. Allowing students to work on a real engine was also a big step forward upgrading the level of the course for MET and Technology Education students. The enrolment in the EDTE 341 course was five students, therefore the class was divided into two groups. Initially one group worked on the single piston transparent alcohol engine and the other group worked on a 4-hp Briggs&Stratton gasoline engine. After the groups finished disassembly, checking the wear limits, servicing and assembly of the small engines they started working on the Pontiac 6000 engine.

Starting with the draining of the fluids, the Pontiac engine was disassembled. The crankshaft was kept on the unit, but the pistons were removed for inspection and measurements. One bearing of the crankshaft and some valves were removed for inspection. The clearance between the crankshaft and the bearing was measured using a plastigauge. The valve clearances were checked using a dial indicator gauge attached to the engine head. The piston and the valve stem diameters were measured using micrometers. The valve spring heights were measured using a ruler. The cylinder bore diameter, out-of-round and taper were measured using a cylinder gauge. The piston ring end gaps and side clearances were checked using feeler gauges. The timing chain and the timing gears were removed, inspected and cleaned. The distributor was removed, inspected and cleaned. The camshaft was not removed, but it was inspected through the valve lifter holes. The cam lobe lifts of the camshaft were checked by measuring the minimum and maximum heights of the valve lifters while the camshaft was rotated. The oil and the gasoline filters were replaced. The gasoline tank was corroded and it was, temporarily, replaced with a plastic tank. The fuel pump filter was torn; therefore, it was also replaced.

The engine, in general, was found to be in a very good condition. There was no rust inside of the engine. However the engine coolant and the engine oil were in a very bad condition. All of the expansion springs inside the water hoses were corroded. The engine oil looked like transmission fluid, with almost no viscosity. After the inspection and the measurements were completed, the engine was reassembled. Red RTV was used as a gasket for timing chain cover, thermostat housing cover and valve covers. After removing the corroded springs from inside of the cooling hoses, the engine was flushed, several times, with water and filled in with 50% antifreeze and water solution. There was no coolant overflow tank; therefore a plastic overflow tank was added. After adding the engine oil, the engine was attempted to start, but, it would crank but not start. After carefully checking all of the electrical and vacuum connections it was found that the fuel injector was clogged. After unclogging the fuel injector, the engine was started and the timing was adjusted using an inductive timing light.

The Dynamometer Service

The engine dynamometer consists of a hydraulic pump, an oil reservoir, an oil filter, an oil-to-water heat exchanger, a load/unload valve and some gauges. Including the engine computer, they are all mounted inside a frame. The front panel of the frame carries all of the instrumentation related with the engine as well as with the dynamometer. The engine related gauges and components are: coolant and oil temperature gauges, oil pressure gauge, engine ignition switch, engine diagnostics connector, charge amps gauge, AC power switch for the radiator cooling fan, and a digital engine tachometer. The dynamometer related gauges and components are: heat exchanger oil inlet and exit temperature gauges, air pressure gauge, load/unload valve handle and a large, 4.5 in. torque indicator gauge. The unit also has an oil-quality observation window located at the top of the filter housing. Hydraulic system needs to be pressurized to about 50 psi using a quick air connector which is located at the top of the reservoir tank. The air hose must be disconnected after pressurizing the system, otherwise the dynamometer fluid will migrate into the air hose when the air pressure increases during the dynamometer operation (we found it the hard way!).

Since the dynamometer hydraulic fluid was leaking it needed service. The dynamometer service and the engine-dynamometer system testing was offered as “ETME 499-Independent Research in MET” course during the spring semester of 2002. The student did very little during the semester, however he continued working on it during the summer and the fall semesters of 2002. Megatech Corporation was contacted to obtain user and service manuals. Since the unit was old, they were not able to supply any of the requested manuals. Their knowledge of the system was also very limited. However, they were able to determine what the composition of the dynamometer fluid was and what air pressure needed to be used. Since there was no draining plug anywhere on the unit and the hydraulic fluid exit hose of the heat exchanger was leaking, the exit hose and the clamps were cut and the hose was removed to drain the remaining of the fluid. The removed hose and the clamps were replaced with a new hose and new screw-type hose clamps. Since Megatech did not know how much fluid was needed to fill the system, an approximate volume was calculated using the dimensions of the components on the unit. The needed composition of the fluid was: 50% SAE 90 gear oil, 30% transmission fluid and 20% mystery oil. Two gallons of 80W85 gear oil, one gallon of 89-90 gear oil, four quarts of Dextron/Mercon transmission fluid, four quarts of type-F transmission fluid and 4.5 quarts of mystery oil were mixed to obtain approximate composition of 49% SAE 90 gear oil, 33% transmission fluid and 18% of mystery oil. Mystery oil is an oil additive and it is used to improve viscosity index of the oils. The air inlet connector on the reservoir tank was removed and the mixture was poured into the unit using 1/8 in.-pipe threaded hole. After replacing the wrongly connected new engine ignition switch with the old one, the dynamometer was connected to the engine and it was tested. At this time it was the end of the fall 2002 semester. The student wrote the report to conclude the project.

During the testing of the dynamometer it was found that the hydraulic pump was getting too hot at high engine speeds and loads. The dynamometer was detached from the engine and the hydraulic pump was disassembled to see if there was anything wrong with the pump. No service manual was available for the pump. Since the author’s web search did not lead to their webpage, it seems that Volvo Hydraulics³, the manufacturer of the pump, was out of business. Megatech Corporation was not helpful since they use different pumps on their new units. There was no corrosion inside the pump, the pump bearings were rotating freely and there was no apparent damage. Paying great attention to the markings on the gears, the pump was reassembled. The pump has five pistons of about one inch in diameter and one inch in stroke. One set of bevel gears facilitate reciprocating action of the pistons. Luckily, the second round of testing did not generate as much heat in the pump.

The Fuel System Modifications and Installation of Instrumentation

For the fuel consumption calculations, measurement of the amount of the fuel consumed was needed. One of the methods envisioned was to have the fuel tank on a scale and measure the decrease in the weight after a set fixed time. This envisioned fuel-weight-loss method was not used since it was thought that hoses connected to the tank would transmit engine vibrations to cause reading errors on the scale. Also a weighing scale with about 10 kg weighing (and preferably full-scale tare) capacity and an accuracy of about 0.5 gram was not available. This accuracy would cause, at most, about 1% error in 100 grams of fuel consumed. Since the current

method of volumetric measurement turned out to be a complicated one, this weight-loss method will be tried later for possible use in student laboratory experiments.

A volumetric measuring method was installed for fuel consumption measurements. The engine had a submerged fuel pump. The five-gallon fuel tank was replaced with a small, Plexiglas, transparent fuel reservoir (1.5 in. ID and 2 in. long). The Plexiglas fuel reservoir was attached to the fuel pump as shown in Fig. 2. The trailing end of the reservoir was connected to two burettes (Fig. 3) through a two-way valve. Originally, the overflowing fuel from the fuel injector pressure regulator was returned back to the 250 ml (30 mm ID, 40 cm long) measuring burette. Later, since accumulation of the air in the overflow return tube caused large volume measurement errors, fuel overflow was prevented using the method described below. A 500 ml (40 mm ID, 50 cm long) burette was used as a regular fuel tank. Both burettes were filled with gasoline before the start of the measurements. Engine was warmed up and adjustments were made while fuel was being consumed from the 500 ml burette. Then, the fuel use was switched to 250 ml burette and the data was taken while fuel was consumed from 250 ml burette. At low engine speeds and loads, the time for 50 ml of fuel consumption was measured. To minimize the timing errors at high speeds and loads, the time for 100 ml of fuel consumption was used. By using two different amounts of fuel consumed, the timing errors were kept below about 2% (half a second in 30 seconds of timing). Since the measuring, 250 ml burette is graduated at one ml intervals, reading error was less than 1% (maximum 0.5ml in 50ml of the timed volume).

The overflowing fuel from the fuel injector pressure regulator caused a lot of problems. If the overflowing fuel was dropped into 250ml measuring burette without inserting the overflowing fuel return tube into the fuel inside the burette, it caused oscillations in the liquid level. If the tube is inserted into the fuel inside the burette, corrections to the 50 ml or 100 ml readings needed to be made to account for the volume of the tube. Since the return tube was not transparent, no one was sure whether the inserted portion of the tube was empty, filled or partially filled. To solve the opacity problem, the return tube was replaced with a polyethylene translucent tube. To our surprise it was observed that air and/or fuel vapor bubbles were formed inside the tube, which continuously modified the amount of the fuel remaining inside the return tube. It was theorized that a downward pitched, larger diameter and straight tube with air/vapor release hole might solve the problem. However, when the fuel was dropped into the measuring burette it would have caused oscillations in the fuel level.

To solve the overflow problem a new fuel pump with lower outlet pressure was purchased. The rated output pressure of the pump was 5-9 psi. After installing the pump it was found that the output pressure of the pump ranged from 5 psi to 7 psi depending on the engine speed and the load. The operation pressure of the fuel injector, according to the service manual, was 9-13 psi. The fuel pressure regulator regulates the pressure at about 10 psi. Since the original fuel pump pressure always exceeded 10 psi, there was a continuous overflow of fuel. The fuel pump outlet pressure was reduced by reducing the voltage on the fuel pump using a rheostat. About 1.5 ohm resistance was enough to reduce the pump pressure below 10 psi. The electrical current draw of the fuel pump, at battery voltage, was about 3.5 amps. Unfortunately, reducing the outlet pressure have created bubbles (the dissolved air in the fuel was released or the fuel has evaporated=cavitation), quite often, at the inlet of the pump. If this arrangement was used, creation and disappearance of the bubbles inside the Plexiglas fuel reservoir would have

increased or decreased the fuel consumption rate from the measuring burette, therefore, it would have caused errors in the measurement of the fuel volume consumed.

As seen in Fig.4, the current fuel system had two fuel pumps. The new fuel pump (5-9 psi outlet pressure) was feeding the old (original) fuel pump. Due to higher pressure at the inlet of the old fuel pump, bubble formation was suppressed. The outlet pressure of the old pump was regulated by a rheostat. The rheostat setting was about 4 Ohms. A digital pressure gauge was used to continuously monitor the fuel injector pressure. The injector pressure was same as the outlet pressure of the old fuel pump. The rheostat was adjusted, as needed, to keep the outlet pressure of the old fuel pump between 9 and 9.8 psi. Fig. 5 is another view of the engine-dynamometer system.

The Results and Discussions

A set of tests were run at different engine speeds and loads to measure fuel consumption rates. The recorded data is given in Table 1 along with the calculated fuel consumption rates and calculated developed engine power. Developed engine power was calculated using the set speed and the set torque values. As seen from the power calculations, the maximum calculated 28 hp is not close to the engine's rated power of at least 100 hp. Since there were severe vibration

TABLE 1. The Recorded Data and The Calculated Fuel Consumption Rates and Power

Engine Speed, rpm	Torque Ft-lb	Mea. Fuel Volume, ml	Measured Time, s	Fuel Consumption ml/min	Developed Power, hp
1000	20	50	65.5	45.80	3.81
1000	40	50	62.0	48.39	7.62
1000	50	50	57.0	52.63	9.52
1500	20	50	55.5	54.05	5.71
1500	40	50	43.0	69.77	11.43
1500	50	50	34.0	88.24	14.29
2000	20	50	40.0	75.00	7.62
2000	40	50	31.0	96.77	15.24
2000	50	100	52.1	115.20	19.05
2500	20	50	30.0	100.00	9.52
2500	40	50	23.0	130.43	19.05
2500	50	50	20.0	150.00	23.81
3000	20	50	24.0	125.00	11.43
3000	40	100	40.0	150.00	22.86
3000	50	100	33.5	179.10	28.57

problems with the torque gauge above 50 ft-lb loads, higher torque measurements were not done. Unfortunately, to date, the author did not have time to look into gauge vibration problems. If the torque gauge vibration problem is solved, higher torque measurements can be incorporated into experiment.

The graphs of the fuel consumption rates as a function of the engine speed and the engine load are given in Fig. 6 and Fig. 7. As seen from the graphs, as expected, the fuel consumption rates are higher for the higher engine speeds and for the higher engine loads. An interesting graph is Fig. 8. Here an attempt was made to estimate the engine's fuel economy in units of miles driven per gallon of fuel consumed (mpg). Arbitrarily a 20 mpg was assumed at 2000 rpm and at an engine torque of 40 ft-lb. Assuming that transmission was set at the highest gear for all load and speed combinations given in the table, the miles traveled is proportional to the engine speed. Thus one can calculate fuel economy at any speed using the following equation:

$$\text{mpg} = (20/2000) * N * 96.77 / \text{FCR}$$

Where:

N = engine speed, rpm

FCR = Fuel consumption rate at N rpm, ml/min

96.77 = Fuel consumption rate at 2000 rpm and 40 ft-lb torque, ml/min

Fig. 8 indicates that the engine economy was about flat at higher loads, but, it was decreasing slightly at low loads when engine speed was increased beyond about 1500 rpm. The 3% ($\pm 1.5\%$) error bars are shown on all graphs.

The Plans for Using the Engine and Dynamometer System

Currently, there is no stand-alone laboratory or an "Internal Combustion Engines" (ICE) course in MET program at UMES. Some ME programs have laboratory courses in which they use Engine Performance testing. The best course to fit the engine performance testing would be an ICE course. Those MET programs that do not have an ICE course but do have a thermodynamics course with laboratory components might incorporate the experiment into a thermodynamics course. At this time, since our "ETME 301- Thermodynamics and Heat Power" course has no laboratory component, the engine testing experiment will be used as a demonstration experiment in "EDTE 341-Power and Transportation" course. In the near future, this and other thermodynamics related experiments will be part of the ETME 301 course. An engine emissions experiment, and performance of different brand and grades of the gasoline fuels may be the two additional experiments which can use the same setup.

Conclusions

The gasoline engine and the engine-dynamometer system were serviced as requirements for the EDTE 341 and ETME 499 courses. The instrumentation were installed, the fuel pump/tank modifications were made, and the fuel consumption measurements were completed by the

author. The project involved servicing two complicated systems, and designing, installing and testing the instrumentation for the fuel consumption measurements. This was a very successful and a very useful project for the students involved. Students were very excited and liked working on a full size engine.

Planned extensions for this project are:

- (a) solving vibration problems of the torque meter,
- (b) taking measurements at higher engine loads, beyond 50 ft-lb, and
- (c) measuring the effect of the engine speed and the engine load on emissions.

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1. Megatech Corporation, 555 Woburn Street, Tewksbury, MA 01876, (800)433-3488, <http://www.megatechcorp.com/>
2. Equiserv, 355 Exchange Ave. Conway, AR 72032, <http://www.equiserv.com/>
3. Volvo Flygmotor AB, Sweden, <http://www.volvo.com/>

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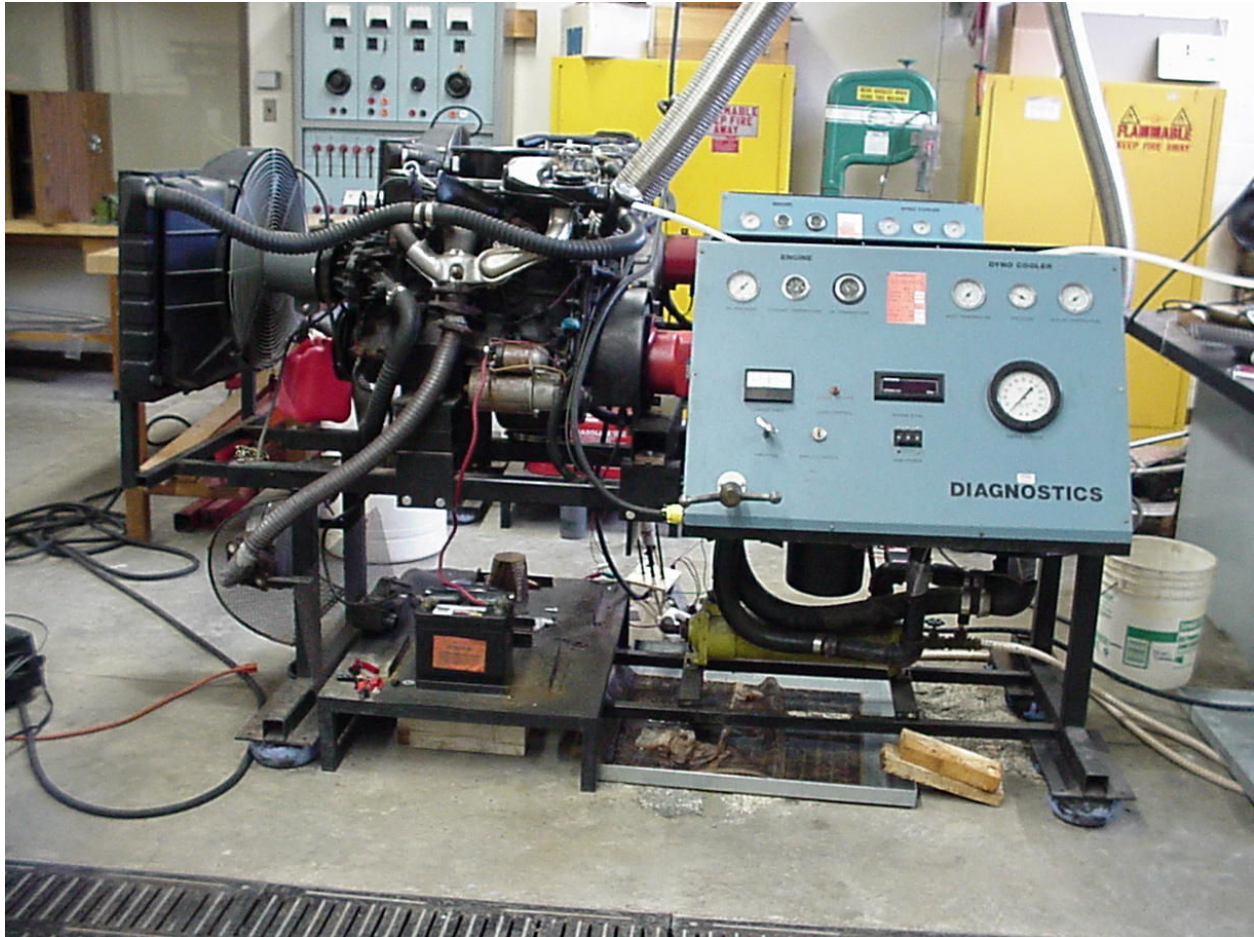


Figure 1. The Megatech Engine and the Dynamometer System.

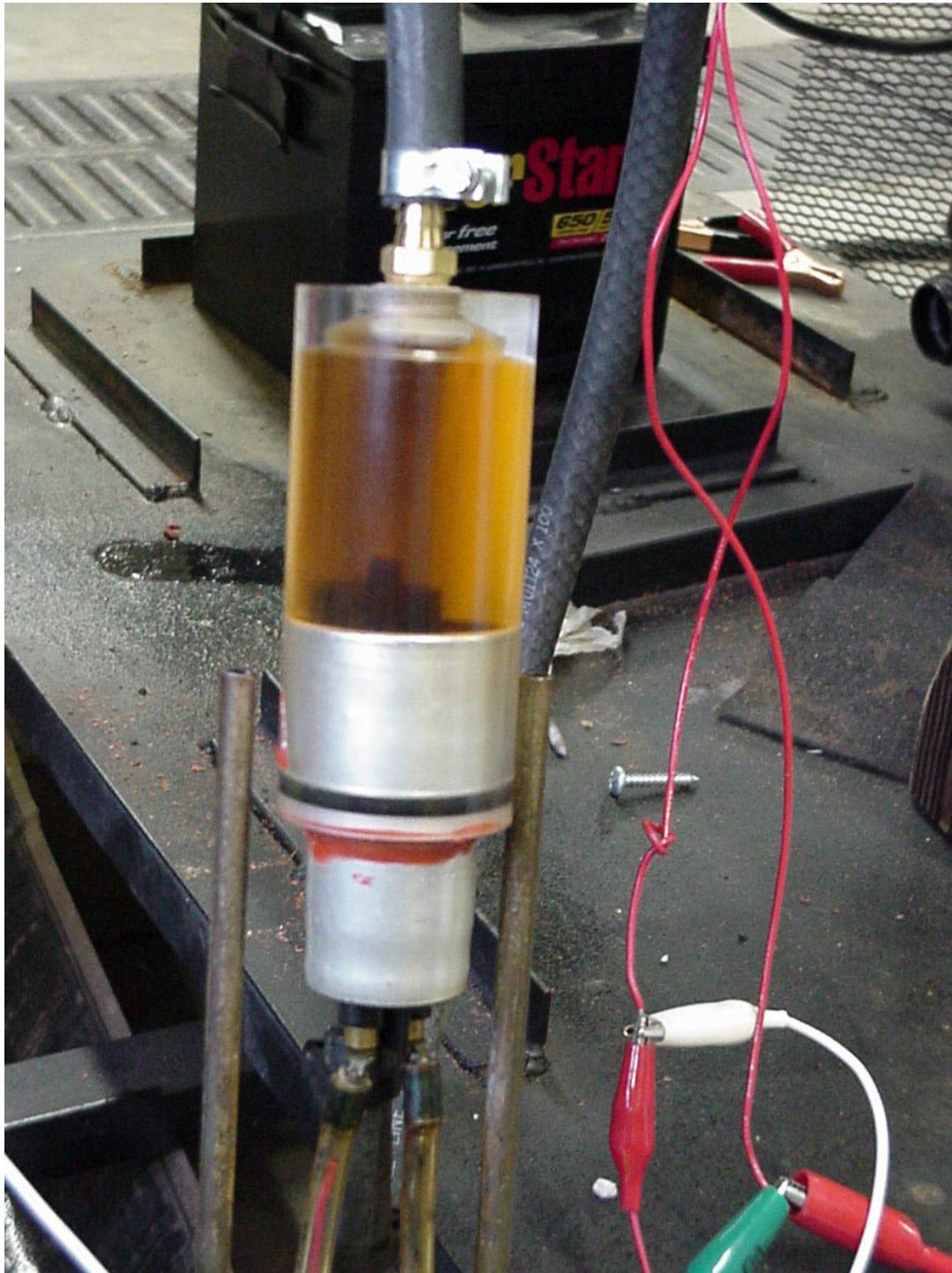


Figure 2. The New Fuel Reservoir (at top) and The Old Fuel Pump (at bottom).

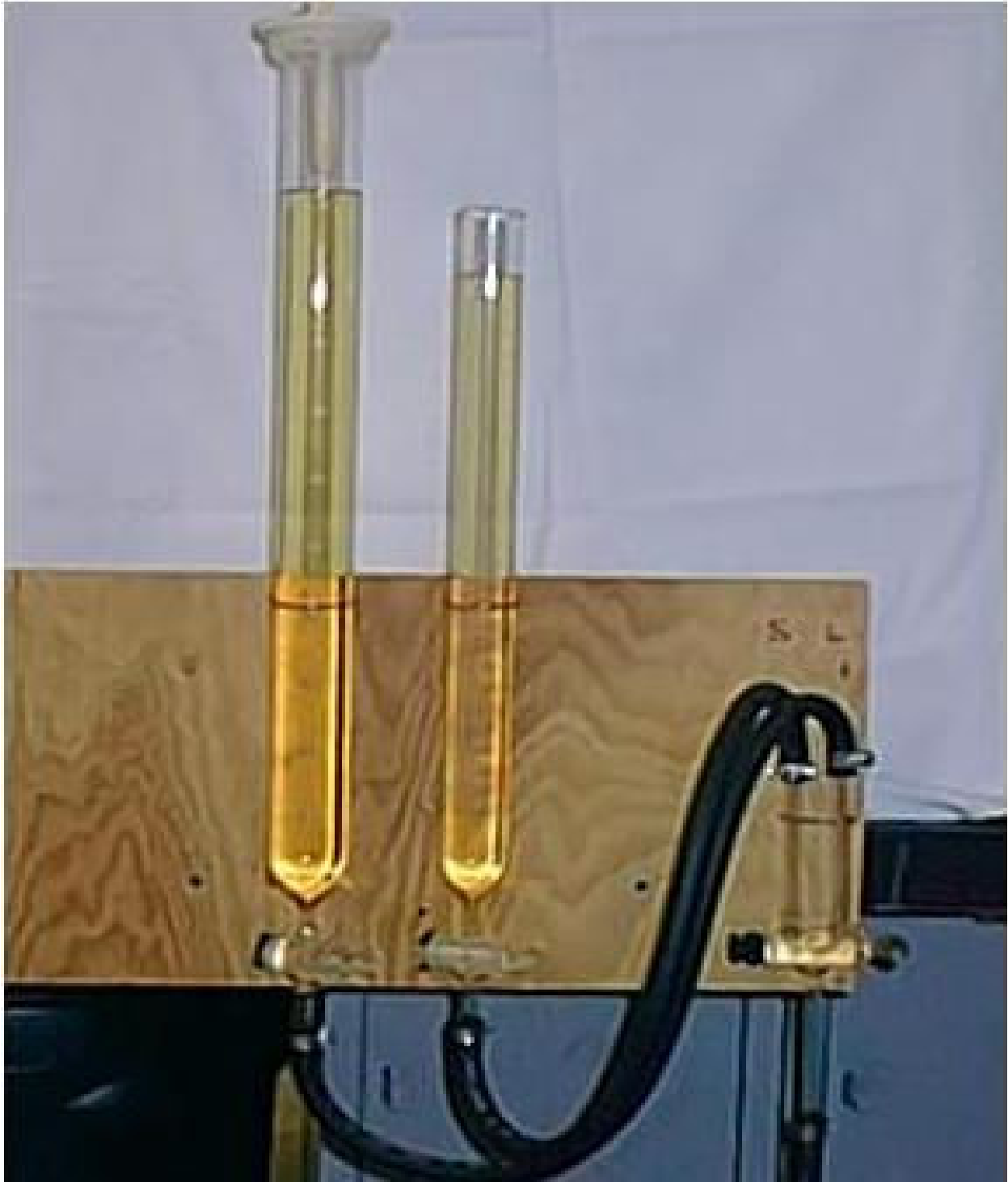


Figure 3. The Volumetric Fuel Measuring System. 500 ml Fuel Reservoir, and 250 ml Measuring Burettes.



Figure 4. The New Fuel Pump (at top, horizontal), The New Fuel Reservoir/Old Fuel Pump (at center) and The Rheostat with an Adjustment Knob.

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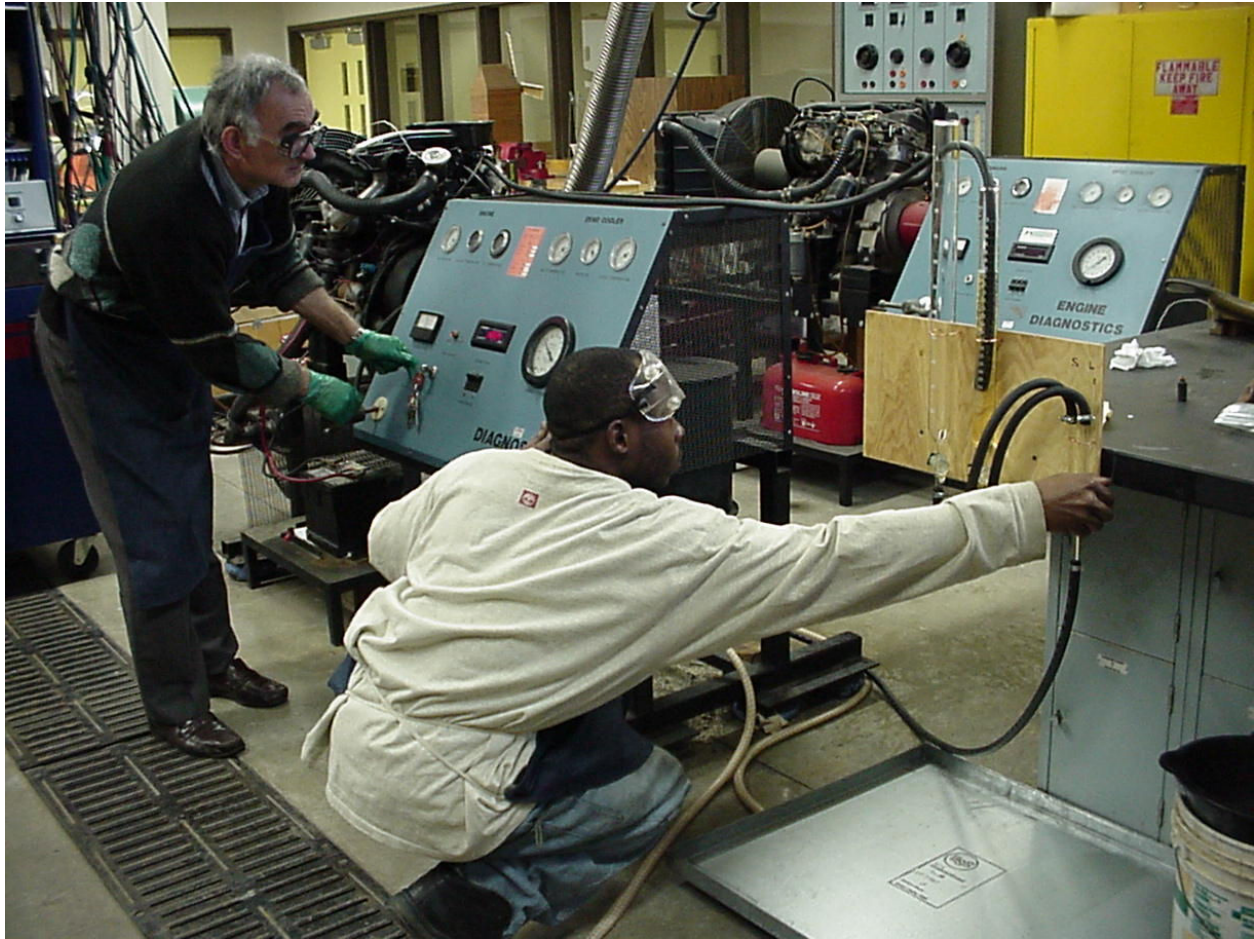


Figure 5. The Dynamometer and The Volumetric Fuel Measuring System.

(The author and Mr. Callwood testing the system. Photo was taken by Dr. Leon Copeland)

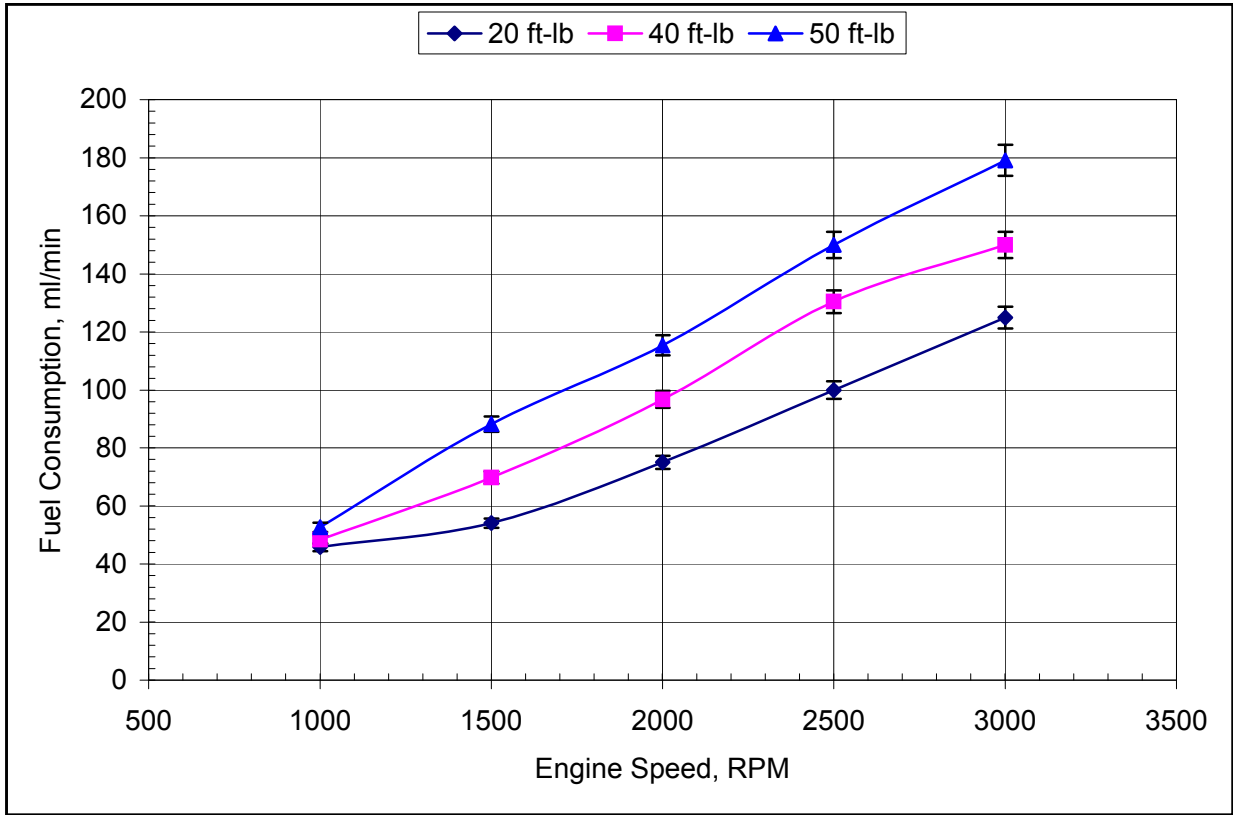


Figure 6. Fuel Consumption as a Function of Engine Speed.

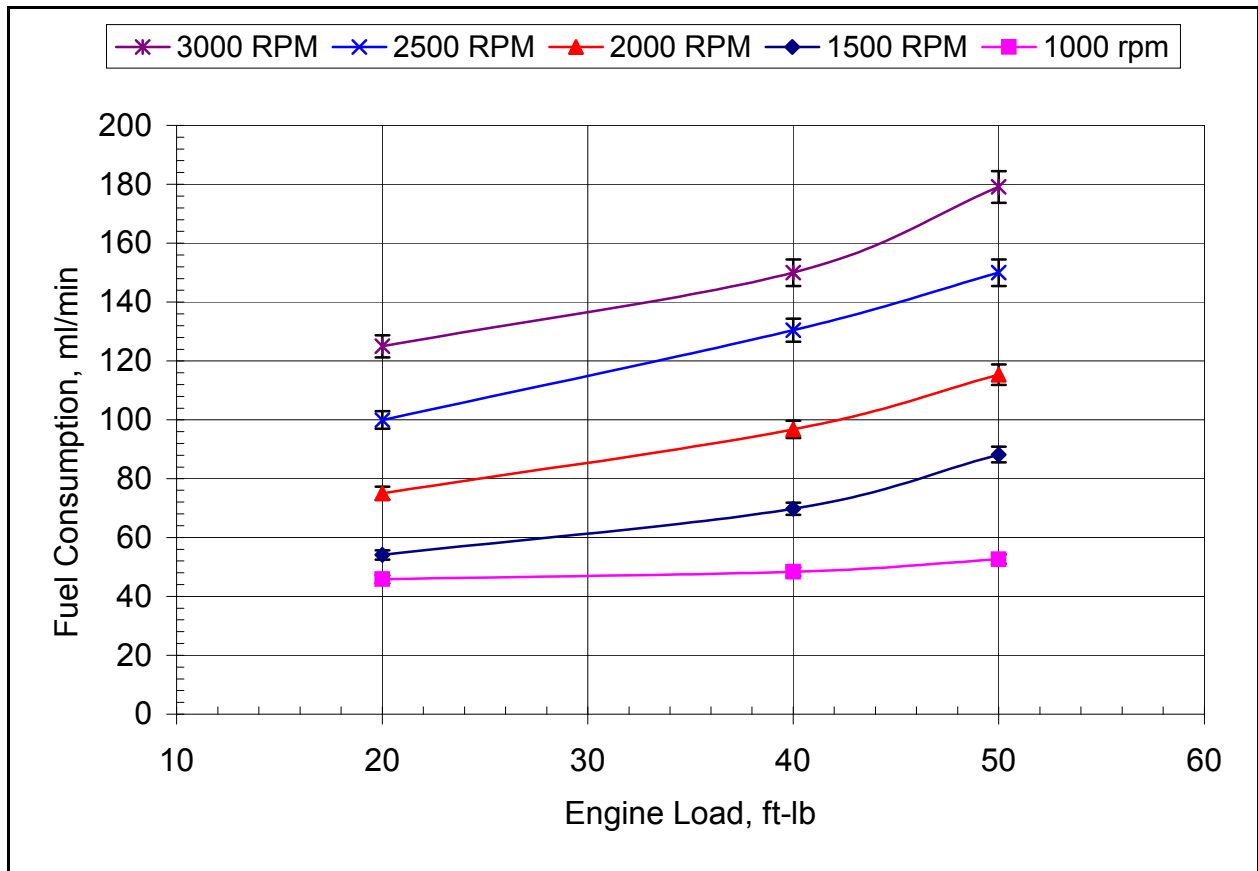


Figure 7. Fuel Consumption as a Function of Engine Load.

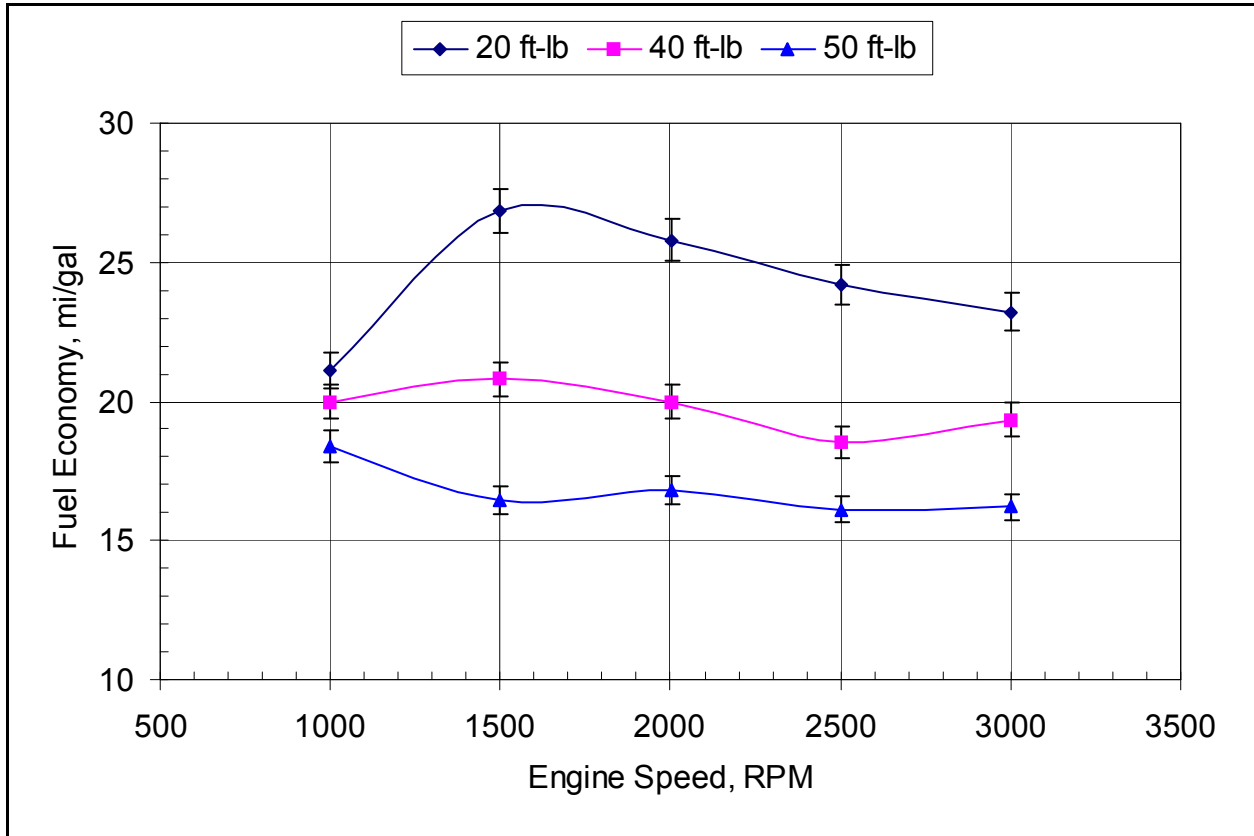


Figure 8. Estimated Fuel Economy of the Engine.