ENGINE AND DYNAMOMETER SERVICE AND

FUEL CONSUMPTION MEASUREMENTS

Emin Yılmaz
Department of Technology
University of Maryland Eastern Shore
Princess Anne, MD 21853
(410)651-6470
E-mail: eyilmaz@mail.umes.edu

ABSTRACT

The goal of "ETME 499-Independent Research in Mechanical Engineering Technology" course is to introduce students to designing, manufacturing, debugging 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 gasoline engine, service the engine dynamometer, test the system and carry out some engine performance tests. If successful, engine tests will be incorporated into "EDTE 341-Power and Transportation course" or "ETME 301-Thermodynamics and Heat Power" course as one or two laboratory experiments. EDTE 341 course is a technical elective and ETME 301 is a required course in Mechanical Engineering Technology (MET) program. Gasoline engine was disassembled and serviced as a requirement for the laboratory part of EDTE 341 course. Servicing of the engine-dynamometer was completed as an ETME 499 project. Instrumentation for fuel consumption measurements were added and measurements were carried. Results indicate that, at constant load, as engine speed is increased fuel consumption has increased. Same trend is seen at constant speed; fuel consumption has increased as load is increased. Simulated fuel economy (miles/gal) graph indicate that engine is most economical if it is used at about 2500 rpm.

INTRODUCTION

Two Engine-Dynamometer systems to be used for Internal Combustion Engine related courses came with the new building when the department moved into it in 1985. Engines have the same model dynamometers, they were purchased as sets from Megatech Corporation[1] and they were never used since 1985. Since the systems were sitting too long I decided to overhaul the gasoline engine when I taught "EDTE 341-Power and Transportation" course few years ago. Engine was opened, cleaned and put together as part of the laboratory requirement for the course. Since dynamometer was leaking fluid, it needed service also. Most of the dynamometer service was completed past summer as part of an "ETME 499-Independent Research in MET" course. Equipment installations and modifications needed for fuel consumption measurements, and fuel consumption measurements have been completed recently.

Paper will cover (i). The experiences we had in servicing the engine and engine-dynamometer system, (ii). Installation of the instrumentation, (iii). Discussion of the results of measurements, and (iv). How engine-dynamometer and other engine tests can be incorporated into a related Mechanical Engineering Technology or Mechanical Engineering Laboratory course.

GASOLINE ENGINE DISASSEMBLY AND SERVICE

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

In fall semester of 1997 I was assigned to teach the EDTE 341 course. We had two engine-dynamometer systems in 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 only used once in 1985 to test SUN[2] Interrogator 1805-9 Engine Diagnostics unit. Diesel engine-dynamometer system, to date, was never used. Gasoline engine is a 1984 Pontiac 6000, 2.5 liter, throttle body injected, and 4-cylinder engine. Diesel engine is a 1984 Volkswagen and 4- cylinder engine. Both engines have the same model dynamometers. Engines are directly connected to the dynamometers by flexible-insert couplings. My plan was to use the gasoline engine-dynamometer system in other courses. Since the engine has been sitting more than 12 years I was hesitant to start the engine without properly servicing it. Therefore, I decided to service the engine as a laboratory exercise for EDTE 341 course. Allowing students to work on a real engine was also a big step forward in upgrading the level of the course for MET and Technology Education students.

Enrolment in EDTE 341 course was 5. Class was split into two groups. Initially one group worked on single piston transparent alcohol engine and the other group worked on 4 Hp Brigs & Stratton gasoline engine. After groups have finished disassembly, measurements, servicing and assembly of the small engines they started working on the Pontiac 6000 engine.

Starting with the draining of the fluids, Pontiac engine was disassembled. Crankshaft was kept on the unit, but, pistons were removed for inspection and measurements. One bearing of the crankshaft and some valves were removed for inspection. Clearance between crankshaft and the bearing was measured using plastigauge. Valve clearances

were checked using dial indicator gauge attached to the engine head. Piston and valve stem diameters were measured using micrometers. Valve spring heights were measured using a ruler. Cylinder bore diameter, out-of-round and taper was measured using cylinder gauge. Piston ring end gaps and side clearances were checked using filler gauges. Timing chain and timing gears were removed, inspected and cleaned. Distributor was removed, inspected and cleaned. Camshaft was not removed, but it was inspected through the valve lifter holes. Cam lobe lifts of the camshaft were checked using maximum height of the valve lifters. Oil and gasoline filters were replaced. Gasoline tank was corroded and it was, temporarily, replaced with a plastic tank. Fuel pump filter was torn, therefore, it was also replaced.

Engine, in general, was found to be in a very good condition. There was no rust inside the engine. However the engine coolant and engine oil were in a very bad condition. All expansion springs inside the water hoses were corroded. Engine oil looked like transmission fluid, with almost no viscosity. After inspection and measurements were completed, the engine was reassembled. Red RTV was used as a gasket for timing, thermostat housing and valve covers. After removing the corroded springs from inside of cooling hoses, 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 connections it was found that the fuel injector was clogged. After unclogging the fuel injector engine was started. Timing was adjusted using an inductive timing light.

DYNAMOMETER SERVICE

Engine dynamometer consists of an hydraulic pump, an oil reservoir, an oil filter, a oil-to-water heat exchanger, a load/unload valve and some gauges. Including the engine computer, they are all mounted inside a frame. Front panel of the frame carries all of the instrumentation related with the engine as well as with the dynamometer. Engine related gauges and components are: coolant and oil temperature gauges, oil pressure gauge, ignition switch, engine diagnostic connector, charge amps gauge, AC power switch for radiator cooling fan, and a digital engine tachometer. 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. 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 located at the top of the reservoir tank. Air hose must be disconnected after pressurizing the system. Otherwise oil may migrate into air hose when the air pressure increases during dynamometer operation.

Since the dynamometer hydraulic fluid was leaking it needed service. Dynamometer service and Engine-Dynamometer system testing was offered as "ETME 499-Independent Research in MET" course during spring semester of 2002. Student did not do much during the semester. However he continued working on it during summer and

fall semesters of 2002. Megatech Corporation was contacted to obtain user's and service manuals. Since the unit was old, they were not able to supply any manuals. Their knowledge of the system was also very limited. However they were able to find out what the composition of the fluid was and what air pressure needed to be used. Since there was no draining plug anywhere on the unit and hydraulic fluid exit hose of the heat exchanger was leaking, it was cut and removed to drain the remaining of the fluid. The removed hose and cut clamps were replaced with a new hose and new hose clamps. Since Megatech did not know how much fluid is needed to fill the system, approximate volume was calculated using 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. 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 four quarts of mystery oil were mixed to obtain approximate composition of 50.0% gear oil, 33.3% transmission fluid and 16.7% of mystery oil. 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 ignition switch with the old one, the dynamometer was connected to the engine and was tested. At this time it was the end of fall 2002 semester. Student wrote the report to conclude the project.

During testing it was found that the hydraulic pump was getting too hot at high engine speeds and high loads. Dynamometer was detached from the engine and hydraulic pump was disassembled to see if there was anything wrong with the pump. No service manual was available for the pump. Since web search did not lead to their webpage, it seems that Volvo Hydraulics[3], the manufacturer of the pump, is out of business. Megatech Corporation was not helpful either since they use different pumps on their new units. There was no corrosion inside the pump, bearings were rotating freely and there was no damage. Paying great attention to the markings on the gears, the pump was reassembled. Pump has five pistons of about one inch in diameter and one inch in stroke. One set of, about 45 degree, bevel gears facilitate reciprocating action of the pistons. Luckily, second round of testing did not generate as much heat in the pump.

INSTRUMENTATION AND FUEL SYSTEM MODIFICATIONS

For fuel consumption calculations, measurement of amount of fuel consumed is needed. One of the methods envisioned was to have the fuel tank on a scale and measure the decrease in the weight after a fixed time. This weight-loss method was not used since it was taught that hoses connected to the tank would transmit engine vibrations to cause reading errors. Also, at that time we could not locate a scale with about 10 kg weighing capacity and an accuracy of about 0.5 gram. This accuracy will 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 for student laboratory experiments.

A volumetric measuring method was installed for fuel consumption measurements. Engine had a submerged fuel pump. Five gallon fuel tank was replaced with a small,

plexiglas, transparent fuel tank (1.5 in. ID and 2 in. long) which was attached to the fuel pump as shown in Fig.1. The other end of the tank was connected to two burettes through a two-way valve. Originally, the overflowing fuel from the fuel injector system was returned back to the 250 ml (30 mm ID, 40 cm long) measuring burette. Later, since air accumulation in overflow return tube caused volume measurement errors, fuel overflow was prevented using the method described below. 500 ml (40 mm ID, 50 cm long) burette is used as a regular fuel tank. For measurements, 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, fuel use was switched to 250 ml burette and data was taken while fuel was consumed from 250 ml burette. At low engine speeds and loads, time for 50 ml fuel consumption was measured. To minimize the timing errors at high speeds and loads, 100 ml fuel consumption was used. This way timing errors was kept below about 2% (half a second in 30 seconds of timing). Since measuring tube is graduated at intervals of one cc, reading error in volume is less than 1% (Maximum 0.5cc in 50cc of timed volume).

Overflowing fuel caused a lot of problems. If the fuel is dropped into 250ml measuring burette without inserting the return tube into fuel, it caused vibrations 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 return tube was not transparent, we were not sure whether we needed to subtract hollow, filled or partially filled tube volume. To solve the transparency problem, the return tube was replaced with a polyethylene translucent tube. To our surprise it was observed that air bubbles were formed inside the tube, which continuously modified the amount of fuel remaining inside the return tube. A downward pitched, larger diameter and straight tube might solve the problem. However when the fuel is dropped into the measuring tube it will cause changes in the fuel level.

To solve the overflow problem a new fuel pump with lower outlet pressure was purchased. Rated output pressure of the pump was 5-9 psi. After installing the pump it was found that output pressure ranged from 7 psi down to 5 psi depending on the engine speed and load. Operation pressure of the fuel injector, according to service manual, is 9-13 psi. Fuel pressure regulator regulates the pressure at about 10 psi. Since the original fuel pump pressure always exceeds 10 psi, there is a continuous overflow of fuel. It was possible to reduce the fuel pump outlet pressure 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. Electrical current draw of the fuel pump, at battery voltage, is about 3.5 amps. Unfortunately, reducing the outlet pressure created air bubbles, quite often, at the inlet of the pump. If this arrangement was used, creation and disappearance of air bubbles would have changed the measured volume, therefore, it would have caused errors in volume measurements.

The current fuel system has two fuel pumps. The new pump (5-9 psi) is feeding the old pump. Due to higher pressure at the inlet of the old pump air formation is suppressed. Outlet pressure of the old pump is regulated by a rheostat. Rheostat setting is about 4 Ohms. A digital pressure gauge is used to continuously monitor the injector pressure.

Injector pressure is same as outlet pressure of the old fuel pump. Rheostat is adjusted, as needed, to keep the outlet pressure of the old fuel pump between 9 and 9.8 psi. Fig. 2 and Fig. 3 are two pictures of the engine-dynamometer system.

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 set speed and torque values. As seen from the power calculations, maximum power value of 28 hP is no close to the engine's rated power of at least 100 hP. Since there were severe vibration problems with the torque gauge above 50 ft-lb, higher torque measurements were not done. Currently I am trying to solve vibration problem. If the problem is solved, paper is accepted for publication and reviewers agree I shall add higher torque measurements to the results for final submission.

TABLE 1. Recorded Data and Calculated Fuel Consumption Rates

Engine Speed, rpm	Torque Ft-lb	Mea. Fuel Volume, cc	Measured Time, s	Calc. Fuel Consumption cc/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

Graphs of the fuel consumption as a function of engine speed and engine load are given in Fig. 4 and Fig. 5. As seen from the graphs, as expected, fuel consumption rates are higher for higher engine speeds and for higher engine loads. An interesting graph is

Fig.6. Here an attempt was made to estimate 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 is set at the highest gear for all load and speed combinations given in the table, miles traveled is proportional to the engine speed. Thus one can calculate fuel economy at any speed using the following equation:

mpg = (20/2000)*N*96.77/FCR

Where:
N   = engine speed, rpm
FCR   = Fuel consumption rate at N rpm, cc/min
96.77 = Fuel consumption rate at 2000 rpm, cc/min

Fig. 6 indicates that engine economy is about flat at higher loads, but, decreasing slightly at low loads when engine speed is increased beyond about 1500 rpm. 3% (±1.5%) error bars are shown on all graphs.

PLANS FOR USING 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. However, best course to fit engine performance testing would be an ICE course. Those MET programs that do not have ICE course but do have a thermodynamics course with laboratory component might incorporate the experiment into thermodynamics course. At this time, since our "ETME 301-Thermodynamics and Heat Power" course has no laboratory component, it will be incorporated into "EDTE 341-Power and Transportation" course. In near future, this and other thermodynamics related experiments will be part of ETME 301 course. An engine emissions experiment and performance of different types and grades of fuels may be two additional experiments using the same setup.

CONCLUSIONS

Gasoline engine and engine-dynamometer system were serviced as requirements for EDTE 341 and ETME 499 courses. Instrumentation were installed, fuel pump/tank modifications were made, and fuel consumption measurements were completed by the author. Project involved servicing two complicated systems, and designing, installing and testing instrumentation for fuel consumption measurements. This was a successful and a useful project for students involved. Students were very exited and liked working on a full size engine.

Planned extensions for this project are: (a) solving vibration problems of torque meter, (b) taking measurements at higher engine loads, beyond 50 ft-lb, and (c) measuring effect of engine speed and engine load on emissions.

ACKNOWLEDGMENTS

REFERENCES

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/
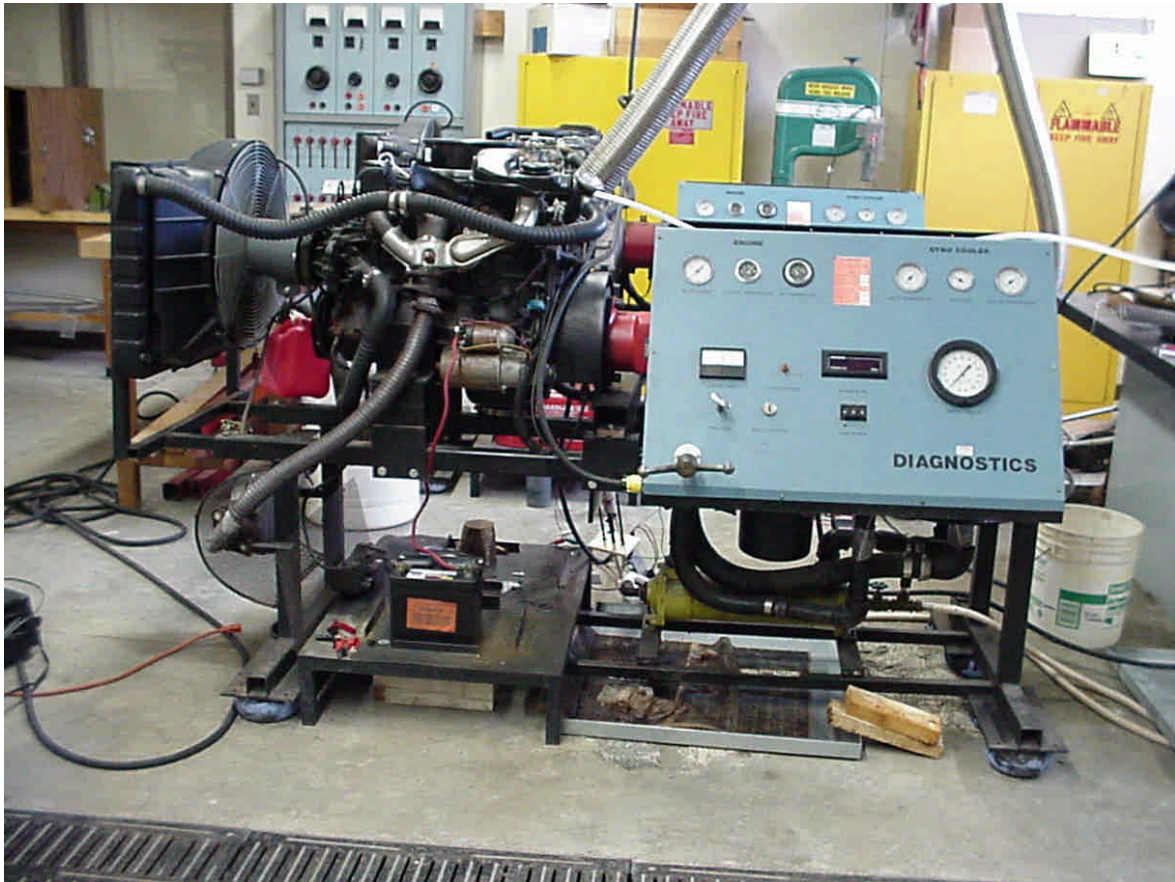
3. Volvo Flygmotor AB, Sweeden, http://www.volvo.com/

EMIN YILMAZ

Emin Yilmaz is a Professor of Engineering Technology at the University of Maryland Eastern Shore. He has MS and BS degrees in Mechanical Engineering and a Ph.D. degree from the University of Michigan in Nuclear Engineering. He is a heavy user of computers in courses and in his research. He developed and taught several laboratory courses in engineering and engineering technology. You may contact him by telephone (410-651-6470) or by e-mail (mailto:eyilmaz@mail.umes.edu) for further information. Web Page: http://www.facstaffwebs.umes.edu/eyilmaz.
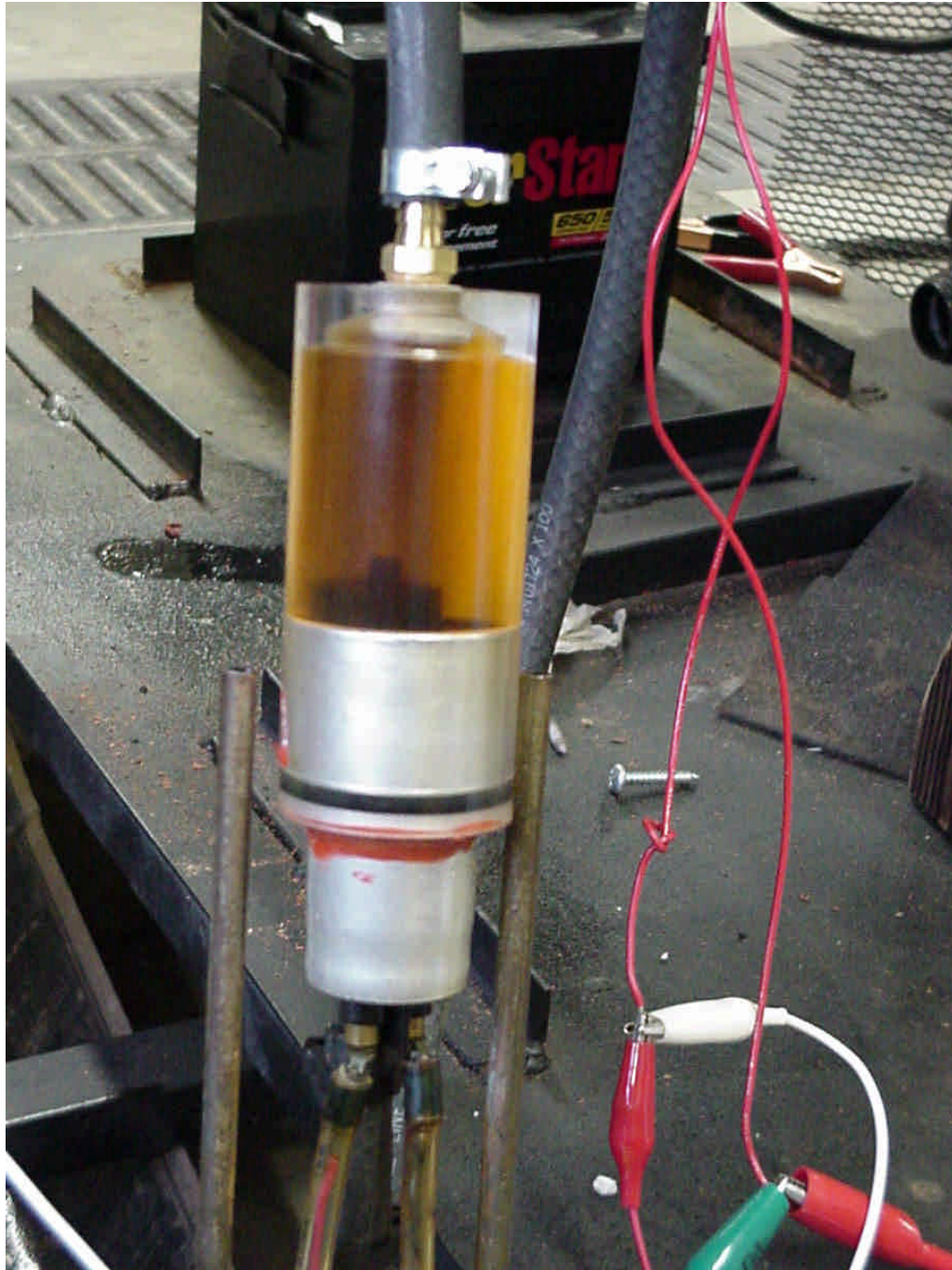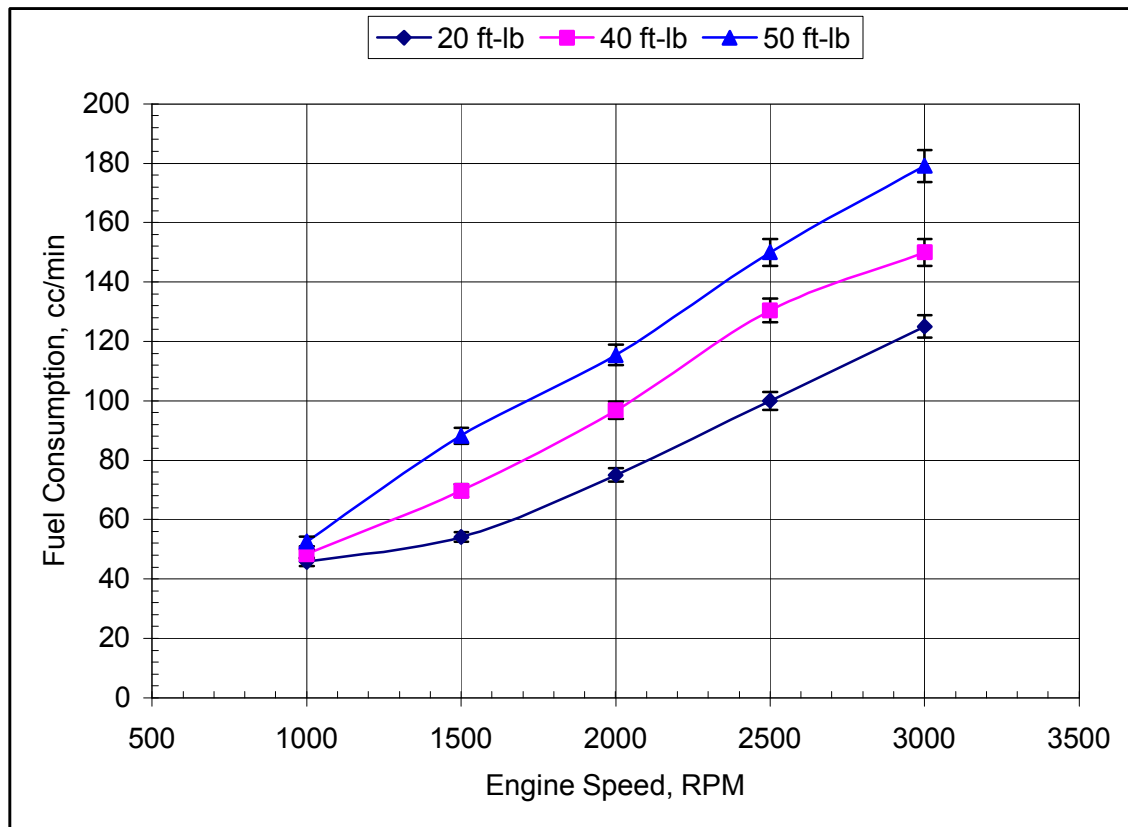
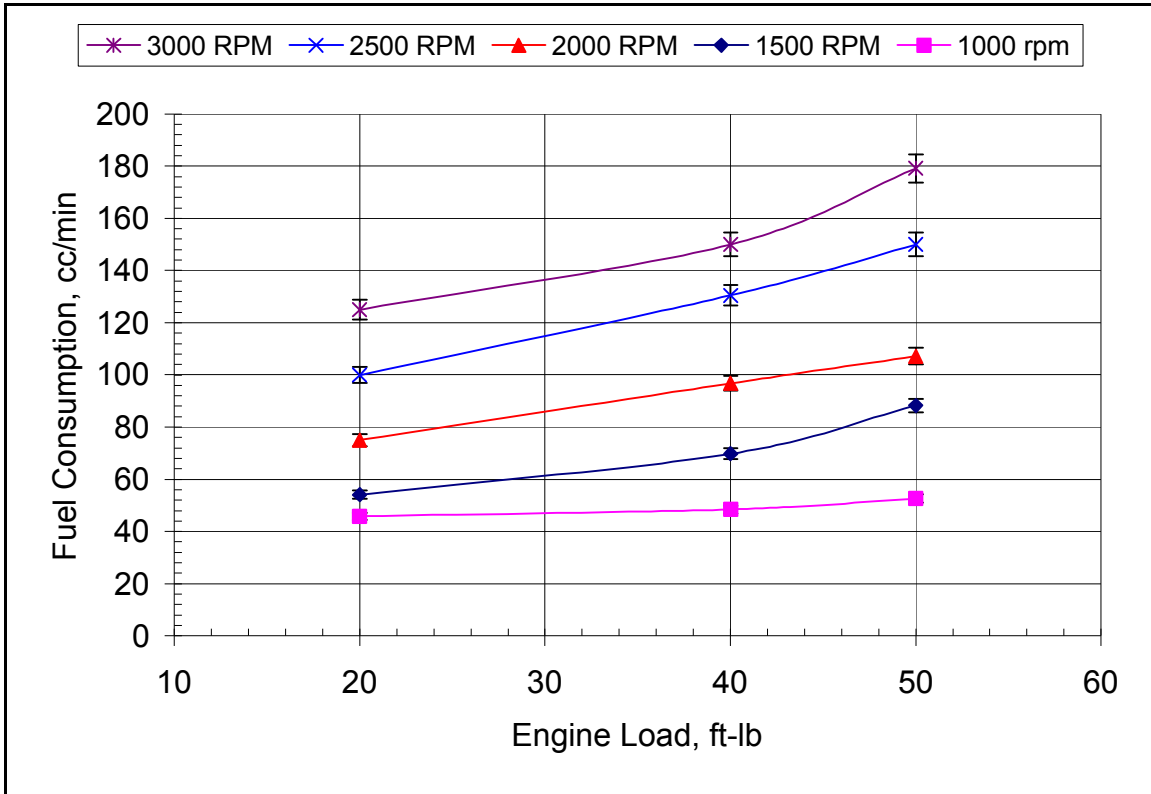**Figure 1. New Fuel Tank (at top) and Old Fuel Pump (at bottom).**

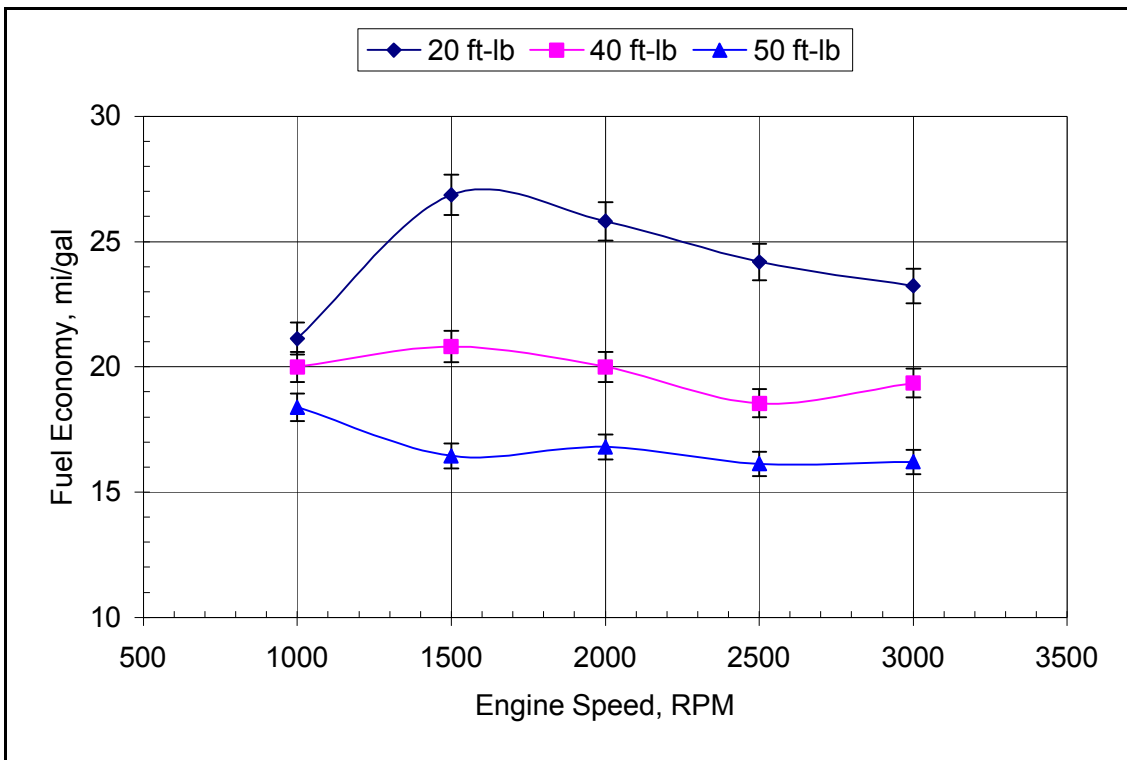**Figure 2. Megatech Engine and Dynamometer System.**

10

Figure 3. Dynamometer and Volumetric Fuel Measuring System.

Figure 4. Fuel Consumption as a Function of Engine Speed

Figure 5. Fuel Consumption as a Function of Engine Load.

Figure 6. Estimated Fuel Economy of the Engine.