ENGINE AND VEHICLE DEMONSTRATIONS ON AQUANOL FUEL

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EXECUTIVE SUMMARY

Aqueous fuels have the potential for lower emissions and higher engine efficiency than can be experienced with gasoline or diesel fuels. Past attempts to burn aqueous fuel have been unsuccessful due to difficulties in initiating combustion. We adapted and used catalytic igniter technology developed by Automotive Resources, Inc. (Sandpoint, Idaho) to successfully ignite aqueous mixtures in both gasoline and diesel engine conversions. Detailed understanding of the catalytic ignition is necessary to design for optimal ignition timing. A MATLAB model has been written to perform studies on ignition timing and behavior. Improvements were made this year in our engine and vehicle test facilities that are necessary to quantify improvements of our conversion platforms. Test plans for stationary small engine testing and over the road vehicle testing have been formulated and are currently underway. The information gained in this research will enable future conversions to achieve higher efficiencies and lower emissions than currently possible on existing platforms.

DESCRIPTION OF PROBLEM

Lean burning in piston engines affords a means of achieving important environmental and fuel economy objectives. To overcome the difficulties related to lean burning, Mark Cherry of Automotive Resources, Inc. (ARI) originally developed the SmartPlug [1]. Several advantages of the SmartPlug design were noted over conventional spark ignition systems. These include increased power output, lower fuel consumption, extended lean-burn limits, and reduced emissions [2, 3]. The primary drawbacks of lean burn engines are de-rated power output per unit displacement and incompatibility with oxidation/reduction catalysts used in conventional exhaust clean-up systems [4].

Over the last three years ARI combined SmartPlug design with aqueous fuel technology to capture many of the benefits of lean burning without sacrificing power output. The aqueous fuel is a mixture of water and ethanol, called Aquanol. Simplot Corp. in Caldwell, Idaho produces the fuel. Previous screening tests with portable electric generators, lawnmowers, rotary engines, and even diesel engines have indicated dramatic reductions in NOx and hydrocarbon emissions. Increases in thermal efficiency have also been noted [1]. These improvements are sorely needed in small and large engines alike.

The National Institute for Advanced Transportation Technology (NIATT) at the University of Idaho is collaborating with ARI to investigate long-term catalytic engine performance as well as catalyst durability. Various projects are underway with sponsorship from the Idaho Transportation Department, the Idaho Department of Water Resources, the Idaho Space Grant Consortium, the U.S. Department of Defense, and the U.S. Department of Transportation's University Transportation Centers Program. These include small engine testing, conversion of fleet vehicles with spark ignition engines, and conversion of utility vehicles with turbocharged direct-injection diesel engines. Detailed understanding of combustion physics is necessary to successfully scale up characteristics from small, low compression engines, to larger high compression engines. This paper summarizes progress to date on our modeling effort, infrastructure improvements, and engine/vehicle conversions.

APPROACH AND METHODOLOGY

Both analytical and empirical tools have been used to study catalytic engine performance. A catalytic ignition model was written in MATLAB for the purpose of understanding ignition behavior in a catalytic plasma torch. The governing equations are outlined in this section. Results of parametric studies are reported in the next section. In addition, significant expansion of measurement capabilities have been achieved with the installation and improvement of a chassis dynamometer and small engine test facilities. The section discusses the configuration of this equipment for catalytic engine testing. The following section outlines ongoing and future testing of Aquanol conversion platforms.

Catalytic Ignition Model

Until recently, timing the ignition of the SmartPlug has been strictly empirical. To better understand the behavior of the catalytic ignition, we created a combustion model that will predict the ignition event for a given set of geometrical and state parameters. This section describes the background equations that are necessary to predict combustion timing associated with a catalytic ignition source.

Catalytically assisted ignition in internal combustion engines has two distinct phases. The first phase is catalytic oxidation of the fresh mixture entering the pre-chamber. Provided that the catalyst is above the surface ignition temperature for a given fuel, this begins as soon as the interface between the fresh charge and the residual gas from the previous cycle contacts the catalyst. The second phase is the auto-ignition of the unburned mixture that accumulates in the rear of the pre-chamber.

As a first attempt to study catalytic ignition of aqueous fuels, the igniter was divided into three zones for a lumped-parameter model. Each zone is assumed to be perfectly stirred (i.e., characterized by a single temperature and fuel concentration) and situated as in Fig. 1. Zone I is the main chamber and part of the pre-chamber without core; zone II is the region of the pre-chamber that surrounds the catalytic portion of the igniter core. This is the only zone where catalytic surface reactions take place. Also note that electrical heating is possible in this zone. Zone III is the region of the pre-chamber that surrounds the non-catalytic portion of the igniter core. This is the only region where gas-phase reactions take place. Pressure is assumed to be constant across all zones and determined by piston position. Mass is progressively transferred from zone I to zone III as the piston moves upward. The temperature and fuel concentrations in each zone are governed by equations of mass and energy conservation.

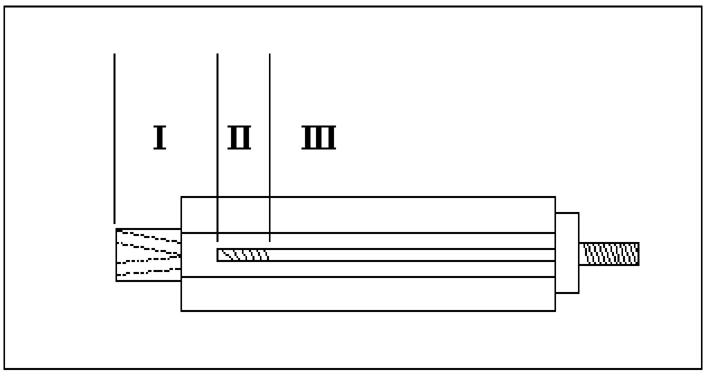

Figure 1 Igniter cutaway showing zones used in ignition calculations.

Gas-phase ignition timing is arbitrarily defined as the crank angle when the gas-phase reaction rate exceeds the surface reaction rate. It is assumed that reactions on the catalyst surface are mass transfer limited, while gas-phase reactions obey an Arrhenius relationship. Shortly after gas-phase ignition, the mixture in the pre-chamber will auto ignite and torch the main chamber.

Instantaneous temperature in each zone can be found by integrating equation (1). $\dot{E}_{zone}$ is the time rate of change of sensible energy within a particular zone. $\dot{E}_{core}$ is the heat transfer from the catalytic core element to the gas mixture. $\dot{E}_{wall}$ is the heat transfer from the gas mixture to the pre-chamber wall. $\dot{E}_{comp}$ is the compressive work done on the system by the piston. $\dot{E}_{trans}$ is the sensible heating/cooling from mass transfer between zones. $\dot{E}_{hom}$ is the sensible heating from homogeneous reactions. $\dot{E}_{het}$ is the sensible heating from heterogeneous reaction.

$$\dot{E}_{zone} = \dot{E}_{core} - \dot{E}_{wall} + \dot{E}_{comp} + \dot{E}_{trans} + \dot{E}_{\mathrm{hom}} + \dot{E}_{het} \quad (1)$$

A detailed description of each term in the energy equation is given below. In these equations, "i" is an index from 1-3 indicating that the equation applies to each zone. The subscript "j" is an index that denotes particular chemical species. $\dot{E}_{zone}$ can be used to determine the instantaneous temperatures in each zone. This results in Eq. (2), which is a differential equation for temperature. In this equation, (m) is the mass in the zone, and (Cv) is the average specific heat for the mixture.

$$\dot{E}_{zone\,i} = m_i Cv_i \frac{dT}{dt} \tag{2}$$

$\dot{E}_{core}$ and $\dot{E}_{wall}$ are assumed to follow a simple convection model. We chose to use an average value for the convective heat transfer coefficient (h). Surface area (A_{surf_core}, $A_{surf\_prechamber}$) is the circumference of the parameter times the length of the zone. (T_{core}) is temp of catalytic core element and (T) is the instantaneous temperature of the gas mixture in the particular zone. Equations (3) and (4) show the formulas for $\dot{E}_{core}$ and $\dot{E}_{wall}$.

$$\dot{E}_{core_i} = h_{core} A_{surf\_core\,i} \left(T_{core} - T_i \right) \tag{3}$$

$$\dot{E}_{wall_i} = h_{wall} A_{surf\_prechamber_i} \left(T_i - T_{wall} \right) \tag{4}$$

$\dot{E}_{comp}$ is assumed to follow a polytropic process. For an open system, this term is a function of the volume of each zone and the time rate of change of pressure as shown in Eq. (5). $\dot{E}_{trans}$ accounts for mass flux entering and leaving each zone. Each species concentration, specific heat, and associated enthalpy are tracked. Equation (6) shows the formula for sensible heating/cooling due to mass transfer. (Ax) is the cross sectional area available for mass transfer and (v) is the transport velocity. This interface velocity is derived from conservation of mass in a piston-cylinder with the volume in each zone constant. Enthalpy (H) is summed over all species and is a function of instantaneous temperature. (M) refers to molecular weight, and (c) refers to concentration.

$$\dot{E}_{comp_i} = V_{ol_i} \frac{dp}{dt} \tag{5}$$

$$\dot{E}_{trans_i} = A_{x_i} v_i \left[\sum_j H_j(T_i) M_{ji} c_{ji} - H_j(T_{i-1}) M_{ji} c_{ji} \right] \quad (6)$$

$\dot{E}_{hom}$ represents energy liberation from a two-step reaction mechanism. In the first step, ethanol is oxidized into H_2O and CO. In the second step, the CO is oxidized to CO_2 [5]. (LHV) is the lower heating value, and (k) is the corresponding reaction rate [6]. $\dot{E}_{het}$ applies only in zone II, where the catalyst is present. This describes the slower surface reaction. In Eq. (8) (C_{area}) is the concentration of active sites on the catalytic surface and (S) is a sticking coefficient.

$$\dot{E}_{\mathrm{hom}_i} = M_{ethanol} k_{ethanol_i} c_{ethanol_i} LHV_{ethanol} + M_{CO} k_{CO_i} c_{CO_i} LHV_{CO} \quad (7)$$

$$\dot{E}_{het_i} = \left(\frac{1}{(c_{area_i})^m} S \sqrt{\frac{RT_i}{2\pi M_{ethanol}}} \right) M_{ethanol} c_{ethanol_i} LHV_{ethanol} \quad (8)$$

Instantaneous species concentrations (O_2, N_2, H_2O, CO_2, CO, and C_2H_5OH) can be found by integrating the mass transfer equation. The time rate of change in concentration results in several differential equations (one for each species in each zone). (Vol) is the gas volume in each zone. Tracking the species concentrations is necessary.

$$\frac{dc_{ji}}{dt} = A_{x_{i-1}} v_{i-1} c_{ji-1} - A_{x_i} v_i c_{ji} + Vol_i \frac{dc_{ji_{react}}}{dt} \quad (9)$$

By plotting section temperatures and concentrations as a function of crank angle, it is possible to detect departure from a motoring trace. For the purposes of this analysis, this point of deviance defines the onset of catalytic assisted gas phase ignition. Studies have been conducted to determine the relative impact of changes in igniter geometry, water concentration, catalytic surface temperature, and compression ratio. These results are plotted in a later section.

Infrastructure Improvements

Conducting research on alternative fueled engines requires sophisticated instrumentation. Table 1 lists items that have been added to NIATT's Clean Vehicle Technologies Center. Descriptions of each component are detailed in sections below. Research is being conducted on both stationary engines and over-the-road vehicles. Engines are tested in the Small Engine Test Facility, and vehicles are tested both on the road and on the chassis dynamometer located in University of Idaho Agricultural Engineering's Martin Laboratory.

Table 1 Clean Vehicle Technologies Center Infrastructure Improvements

Item	Use
9" Dynamometer	Engines up to 40 hp
13" Dynamometer	Engines up to 800 hp
Data Acquisition System	Combustion Pressure Trace Capture
Fuel Measurement System	Engine Testing and Automotive Testing
UI Chassis Dynamometer	Automotive Steady State Testing
FTIR and Five-Gas Analyzer	Exhaust Gas Species Concentration
Fueling Station	Mixing and Fueling Aquanol Vehicles

The Small Engine Test Facility is located in University of Idaho Mechanical Engineering's Gauss Johnson Laboratory. Both dynamometers and the data acquisition system are permanent features of the SETF. The fuel measurement system, Fourier Transform Infrared Spectrometer (FTIR), and five-gas analyzer are used in both the Small Engine Test Facility and the Martin Laboratory.

Engine Bay Dynamometer System

The engine bay dynamometer system consists of two Land and Sea water-brake absorbers with closed loop throttle and load control by a remote computer. The 9-inch absorber is used for smaller engines, up to 160 hp and 200 foot pounds, while the 13-inch absorber is used for automotive engines up to 800 hp and 660 foot pounds. DYNO-MAX software controls the throttle and absorber torque while acquiring data such as engine speed, engine temperature, exhaust gas temperature and fuel flow. The software is also able to calculate the Brake Specific Fuel Consumption (BSFC) and horsepower real time. Figure 2 shows a sample screen shot of the software. Automated dyno runs can be programmed to create a complete a BSFC map or simulate accelerations and other dynamic events. Automated runs also provide a significant improvement for repeatability of measurements.

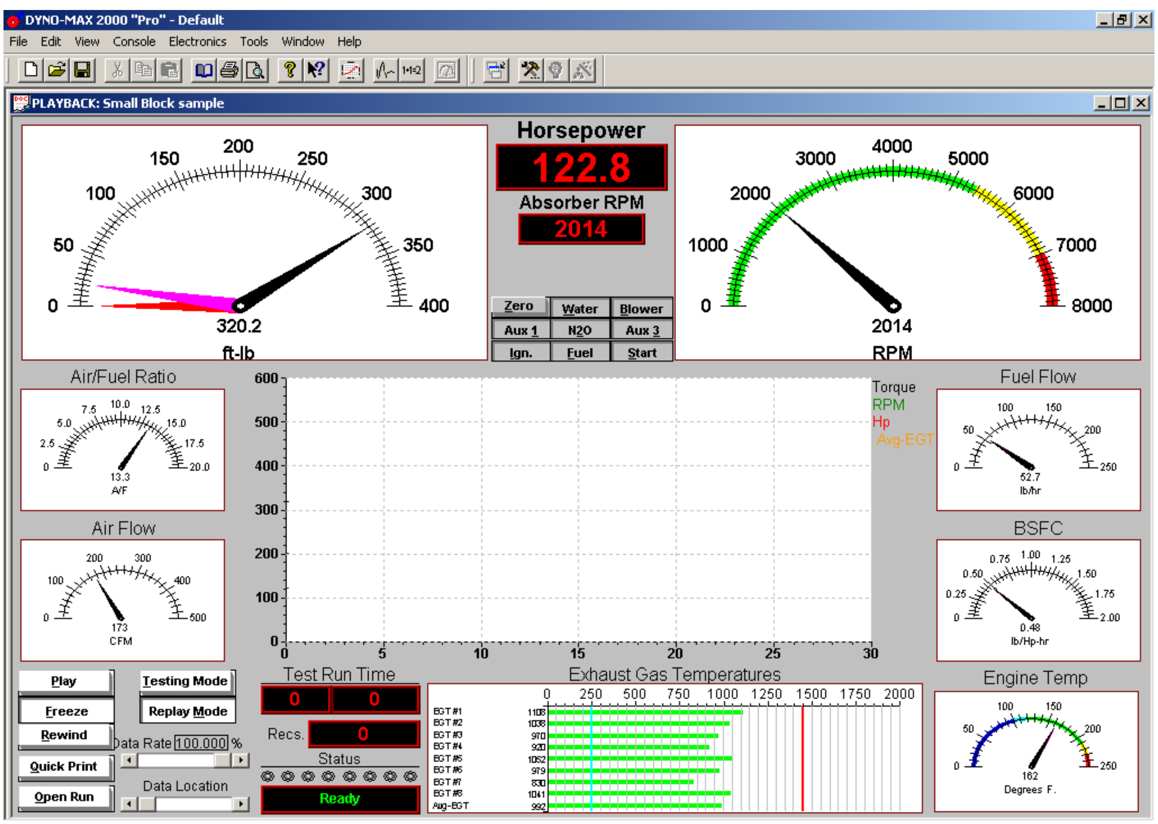

Figure 2 Screen shot of DYNOMAX software.

Figure 3 is a diagram of dynamometer connections. The throttle servo, load servo and handheld dyno computer are mounted on a mobile cart. The load and throttle are also manually adjustable from this point.

Data Acquisition System

To determine the timing of the catalytic combustion event, a data acquisition system capture scylinder pressures at a rate up to 200kHz. Figure 4 shows the layout of the data acquisition system. PCB Piezo-electric pressure transducers create a static charge per psi of pressure. PCB charge mode amplifiers convert the charge to a voltage. IOtech model DBK-4

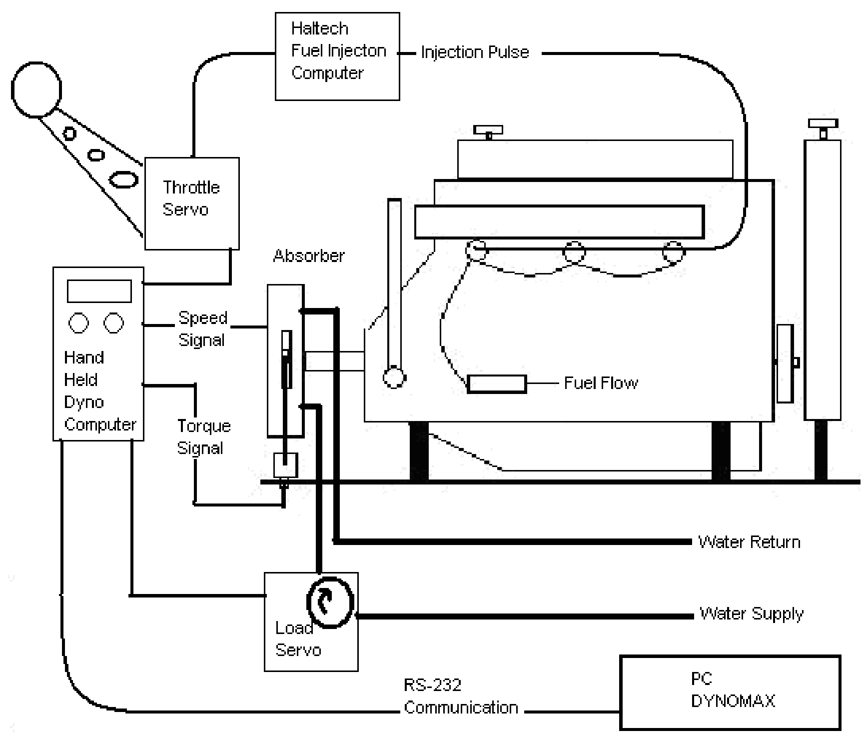

Figure 3 Engine bay dynamometer connection diagram.

signal conditioners filter out noise in the system as well as supply current to the charge amplifiers. The IOtech series 2000 PC board converts the voltage signal to digital. A 1000 pulse per revolution shaft encoder is used as an external clock to trigger each acquisition. A

Daqview program pressure1.DAQ takes all the pressure data and saves it to a MATLAB daqv.mat for post acquisition analysis.

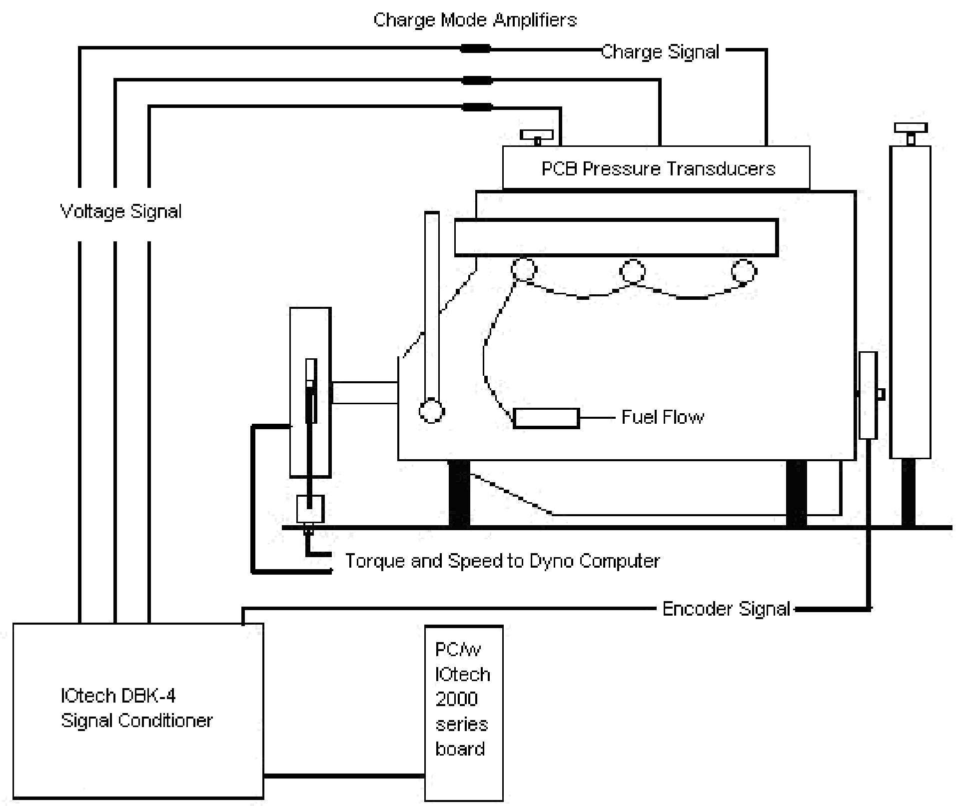

Figure 4 Diagram of the data acquisition system.

Table 2 shows the PCB pressure transducer and charge mode amplifier conversions factors used for the acquisition Yanmar.

Table 2 PCB Pressure Transducer and Charge Mode Amplifier Conversion.

	Transducer		**Amplifier**	
Channel	PCB serial no.	pC/psi	PCB serial no.,	mV/pC
CH00-0-0	ou812	1.2	MLR-TM1	10
CH00-0-1	ou813	1.2	MLR-TM2	10
CH00-1-0	ou814	1.2	MLR-TM3	10
CH00-1-1	ou815	1.2	MLR-TM4	10

Post Acquisition Analysis

Two MATLAB programs are used to analyze the pressure data; motor.m and press.m. Motor.m is used to take the motoring pressure trace and save it for comparison with combustion pressure traces. This requires that non-combustion runs be performed prior to pressure analysis. Press.m graphs each cylinder's motoring traces on top of combustion traces to study combustion behavior. Press.m also overlays pressure traces from multiple cylinders to determine if one cylinder is firing erratically. Figures 5 and 6 show the output from Press.m. Figure 6 shows that the ignition timing is about 10° before top dead center (BTDC) by comparing the fired pressure trace to the motoring trace.

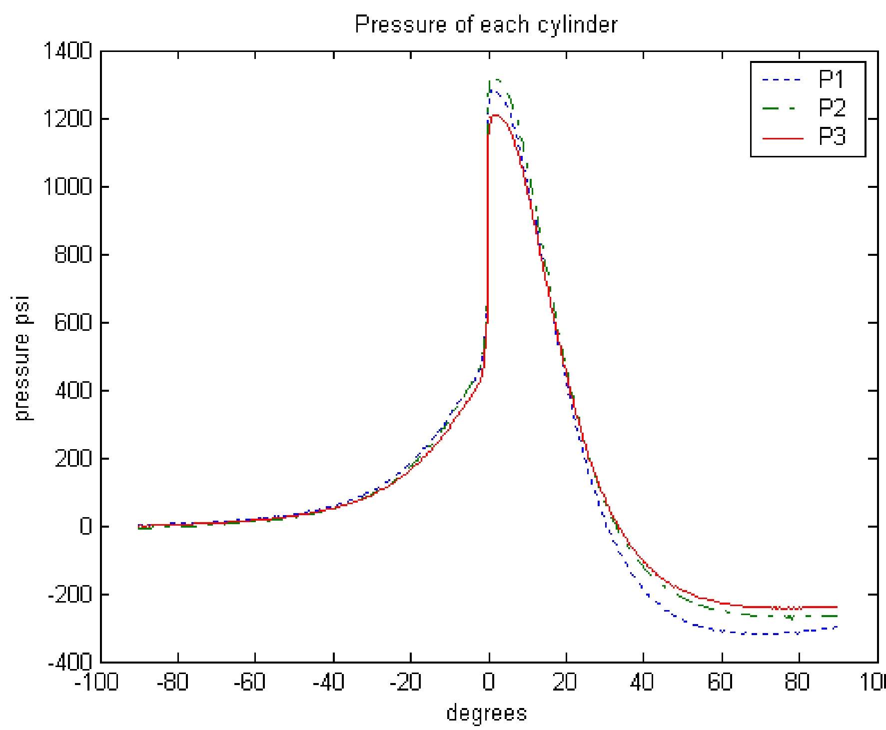

Figure 5 Overlay of all cylinder pressures showing relative firing strength.

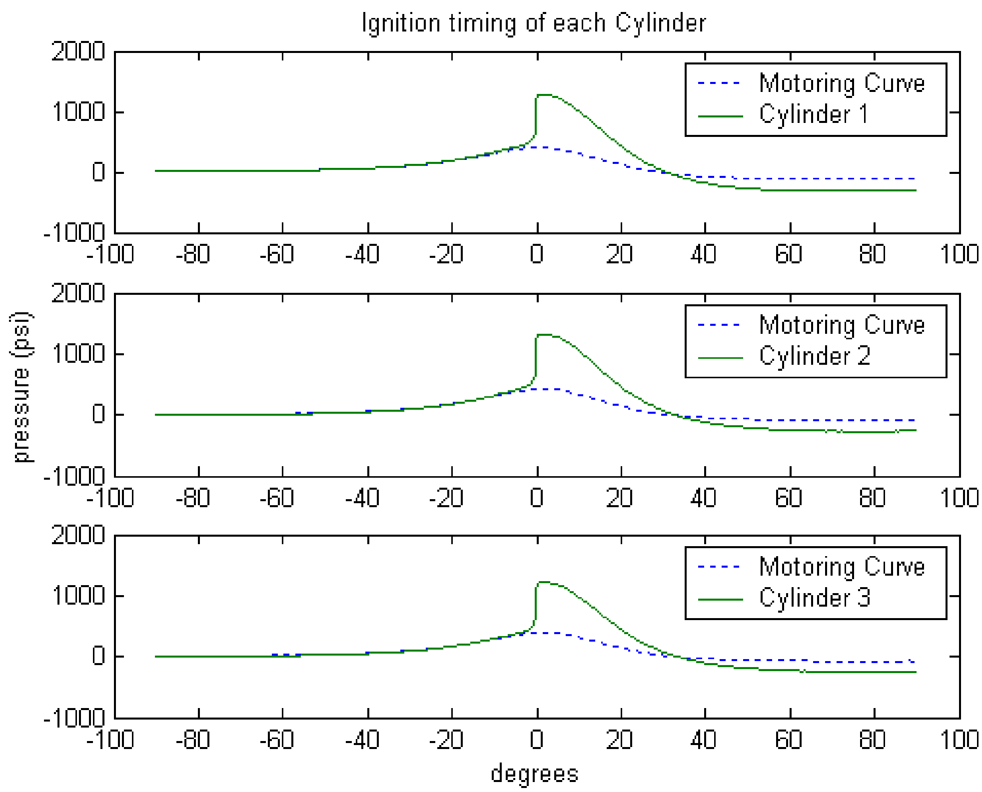

Figure 6 Example output graph of Press.m used to determine ignition timing.

Figure 7 Image of the fuel cart as used in stationary testing.

Fuel Measurement System

Fuels used in the engine bay are diesel, gasoline, kerosene, and alcohol/water. A fuel flow meter is required to capture valuable BSFC data. A multiple fuel measurement system by Max machinery measures the fuel flow rate to accuracy better than 0.5 percent. This measurement system is mounted on a cart designed for easily changing fuel types (Fig. 7). The system is removable from the cart for mobile use on vehicles that are carbureted, fuel injected and diesel. Its mobility permits in-vehicle use during street driving or chassis dynamometer testing.

The system includes a display unit, conditioning unit, and fuel tank. The fuel tank is removable with quick connectors for another tank with a different fuel type after flushing the system. Quick connectors also used on the supply, and return lines from the engine facilitate fast engine changes. Figure 8 is a diagram of the connections to the engine and dynamometer computer.

The conditioning unit contains two flow meters, two pumps, a vapor eliminator, pressure regulator, and a heat exchanger. Flow meters measure fuel flow to and from the engine. The heat exchanger cools the fuel coming from the engine so the fuel is not heated prior to going back into the supply line. The vapor eliminator reduces air bubbles in the lines. The combination of the two pumps and pressure regulator are used to adapt between different fuel systems. The regulator can be adjusted to the desired fuel pressure of the engine tested.

The display unit connects to the conditioning unit via an interface cable. The display unit subtracts the counts from the two meters and obtains a total flow rate of the engine. The display unit also uses a thermocouple inside the conditioning unit to factor the temperature when converting the volumetric flow rate to mass flow rate. The display unit also contains a flow rate 0-5 volt pulse that is connected to the dynamometer computer for automated BSFC tests.

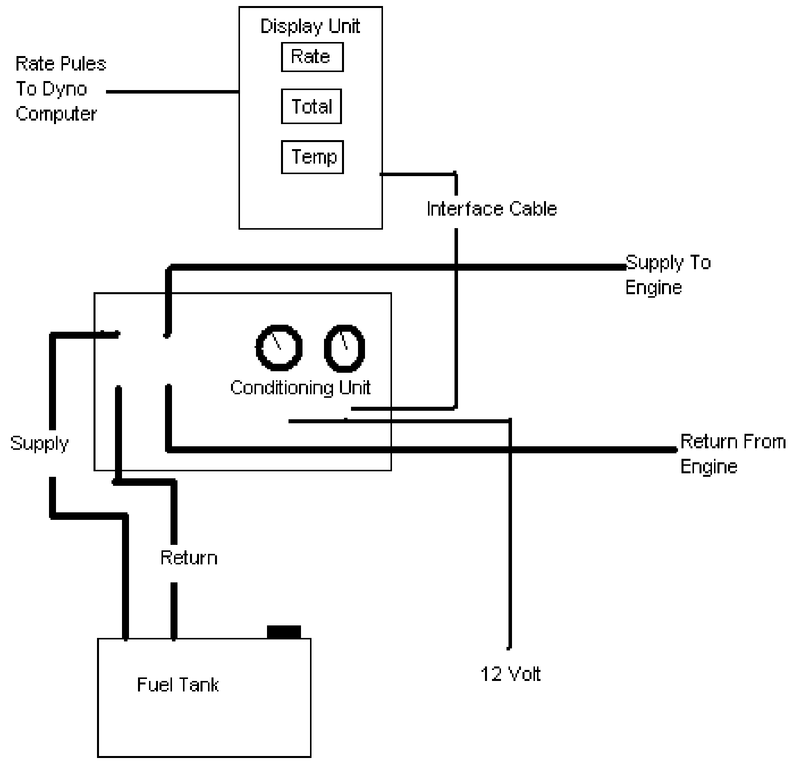

Figure 8 Diagram of connections to the fuel-conditioning cart.

UI Chassis Dyno

Several years ago, the University of Idaho purchased a Superflow SF-602 rolling chassis dynamometer that was only recently installed in the Agriculture Engineering building. The dyno was upgraded with components made available since the original purchase. The dyno now has enhanced features for diesel testing, but can also be used to test gasoline and alternative fueled vehicles. Figure 9 shows the unit before installation.

The original dyno had few controls, and data acquisition was done with a 386 computer. While installing the system, we ran into several problems with computer hardware and software compatibility. We consulted a Superflow representative who helped us make

Figure 9 Image of the Superflow SF-602 chassis dyno before installation.

the system operational. However, the the dyno had poor usability and reliability problems that necessitated an upgrade in both software and data acquisition hardware.

To enhance the chassis dyno's capabilities and robustness, we purchased Superflow's upgrade package, which includes a new graphical interface, upgraded computer, and improved circuitry on the data acquisition boards. It also has a built-in controls package that allows the user to set parameters, and the system will perform those in an automated control loop. Some features are lugging curves, BSFC maps, and RPM, torque, or power set points. The data is collected in the new computer, and the new interface makes it easier to graph and post process the data. Also, there is a remote controller that allows the operator to set the parameters and controls from inside the vehicle. Figure 10 shows an overview of the connections to and from the dyno package.

The chassis dyno has many targeted uses for the NIATT's research. The system is used for the biodiesel project's over the road testing, as well as setting up newly converted vehicles. The FutureTruck team has plans to evaluate their vehicles before and after conversion for comparative results. Our on-road test platforms will also use the dyno for tuning and

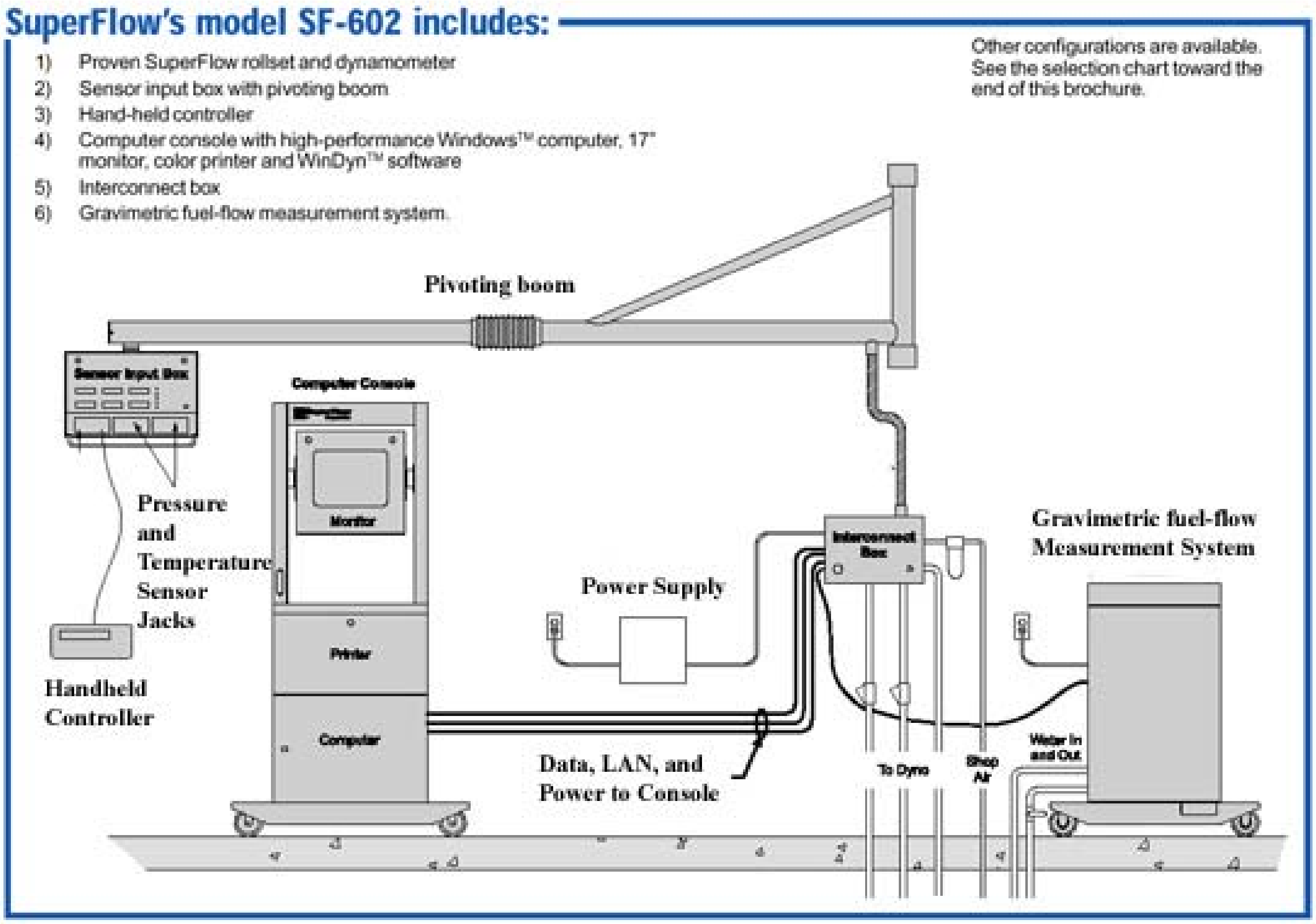

Figure 10 Schematic of data acquisition on the chassis dyno.

emissions and fuel economy testing. Currently the fuel meter that is tied into the system works with diesel fuel only. There is no emissions collection on the current system either. Use of our stand-alone fuel metering system, five-gas analyzer, and FTIR are necessary to collect data on our research platforms.

Figure 11 Image of van preparing for chassis dyno testing.

Five-Gas Analyzer and FTIR

We have two different apparatus for emission testing in our engine test facility. A five-gas analyzer from EMS is used to get concentrations of typical exhaust products, and a Fourier Transform Infrared Spectrometer (FTIR) is used for more exotic and precise measurements of exhaust emissions. Last year, a senior design project combined both analyzers into a single, mobile apparatus that provides better accuracy and backup measurements. Alcohol-based fuels produce emissions that are not found in gas or diesel engines; because of this, the EPA, and common emission test equipment do not track these products.

The EMD five-gas analyzer is a flow-through meter with individual sensors for specific species. Small percentages of the exhaust stream are pulled through a probe placed in the exhaust system, and are assumed to be representative of the total mixture in the exhaust stream. Sensors measure oxygen, NOx, CO, CO_2, and unburned Hydrocarbons. The unit has its own pump, and separate exhaust lines for water and products. The five-gas analyzer requires calibration every few months. Sensors need replaced every 2 to 5 years, depending on the sensor and the severity of its use.

The FTIR operates on a completely different principle. Though it is a flow-through devise like the five-gas analyzer, the FTIR uses a method of measurement that is quite different. A pump diverts some of the exhaust stream through heated lines that prevent water precipitation. This mixture flows into a chamber where a laser penetrates the gas. Depending on the species, a photo detector picks up the intensity spectrum over a frequency range. The frequency band excited and magnitude thereof correspond to a species and concentration. Special computer programs and significant verification were necessary in setting the machine up. Another important difference between the two devices is that the FTIR takes a snapshot of the gas in the cell, where the five-gas gives a continuously updated stream of the sensor outputs. The FTIR will be especially helpful in identifying various aldehydes, and other unknown elements in an Aquanol exhaust stream.

Fueling Station

One of the problems with working on alternative fuel engines is the lack of infrastructure for fueling. For our research we desire a specific mix of ethanol and water. Our ethanol comes from various sources, and it comes in different "proof" from each supplier. A container that is not sealed well will tend to absorb water from its surroundings. Clearly, we needed the

Figure 12   Image of the fueling station after project completion.

ability to measure concentration of water in the fuel accurately so that performance and emissions results are repeatable. A senior design group built a fueling station (Fig. 12) that precisely meters flow of water and ethanol into a mixing chamber where they measure concentration.

The fueling station is comprised of flow controllers, pumps, mixing tanks, and a test loop (Fig. 13). The station uses two flow controllers, one for alcohol and a second for water. The alcohol flow controller stays constant, while the water is adjustable with an indexed meter for desired concentrations. The fueling station has three pumps—a smaller pump for the water and ethanol and a large transfer pump for emptying the mixing tank. The two fuel pumps have the electrical motors separated from the pump itself. They are sealed in aluminum boxes with constant airflow required for pumping the volatile 190 proof ethanol.

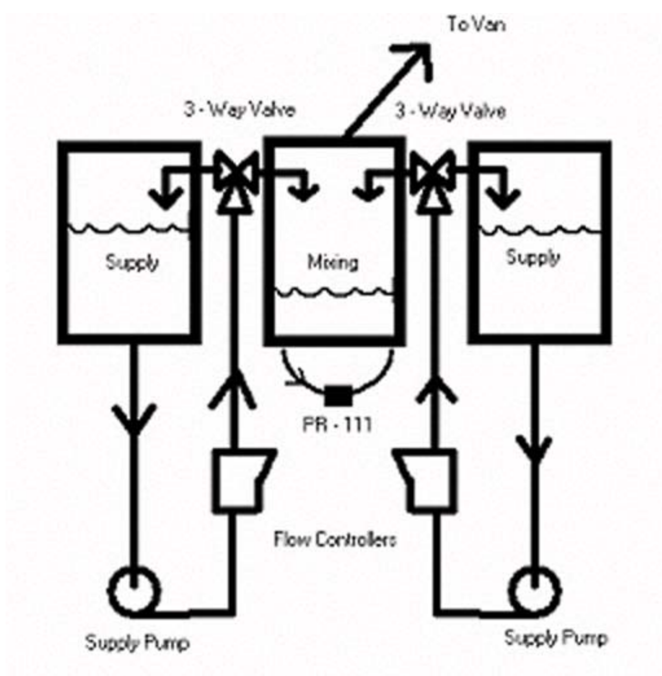

Figure 13 Schematic of the fueling station flow path.

The fueling station uses a refractive index to verify the mixture. Testing shows that the refractive index for a water alcohol mixture follows an increasing curve from 0 percent to 85 percent ethanol. A PR-111 digital refractometer was purchased from AFAB Corporation. The output was scaled from refractive index to percent ethanol. A recirculating loop in the mixing tank measures the mixed fuel for concentration. If the concentration is less than desired, water or ethanol can be added to get the intended mixture.

The fueling station is convenient for mixing both large and small batches of fuel. The Aquanol van requires 35 gallons of fuel to fill up. Previous filling of the van was a tedious process, and there was no way to really confirm the mixture going into the tank. Batches as small as a single gallon can be mixed for use in the engine test facility.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

To date we have made headway in the areas of catalytic modeling and preparing for Aquanol platform testing. Results verifying our catalytic ignition model with previously collected Aquanol engine data show a remarkably close match, and parametric studies have similar trends as those observed in our Aquanol testing. With our new infrastructure improvements nearly complete, we are beginning our plan for engine and vehicle testing over the next few months. At the conclusion of the testing, we will have two separate data point to compare both diesel and gasoline baselines with Aquanol conversions.

Catalytic Model Predictions

Equations outlined in the approach and methodology section were implemented in a MATLAB Model. Solutions began at the start of compression and proceeded until $\dot{E}_{hom}$ exceeded $\dot{E}_{het}$. The crank angle where this occurs will be taken as the point of gas phase ignition. Running the model with parameters from the test engine, we were able to produce results that agree with previously recorded test data. Plots of energy release can be plotted for

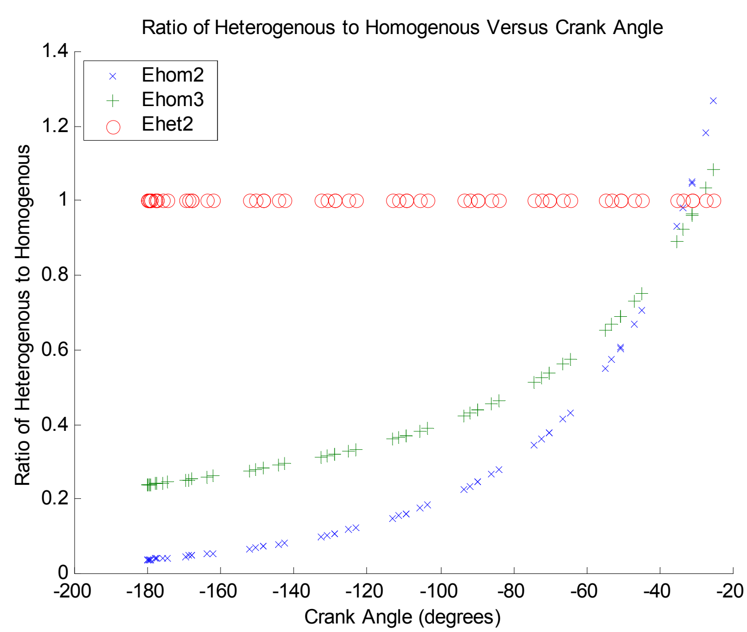

Figure 14 Homogeneous reaction rate exceeds the heterogeneous rate at about 30° BTDC.

each of the zones. We also compare the homogeneous and heterogeneous reaction rates and approximate temperatures in each zone as a function of crank angle.

Using a ratio of heterogeneous to homogeneous reaction heat release, we can plot the results with respect to the crank angle (Fig. 14). Crank angle appears on the horizontal axis and the ratio of $\dot{E}_{het}$ to $\dot{E}_{hom}$ is vertical. The number after the variable in the key refers to the zone where reactions are being tracked. We used the heterogeneous reaction rate at each point to determine the ratio. This is why $\dot{E}_{het}$ appears to be a constant value. When not plotted as a ratio, $\dot{E}_{het}$ is a nearly straight line with slight positive slope. By our previous definition of ignition, we can see the point where the homogeneous reaction rate exceeds the heterogeneous reaction rate. Figure 14 shows that the ignition timing is about 30° before top dead center (TDC). The heterogeneous reaction rate is nearly constant, while the homogeneous reaction rate starts slowly, but grows exponentially. These trends are typical for catalytic reactions.

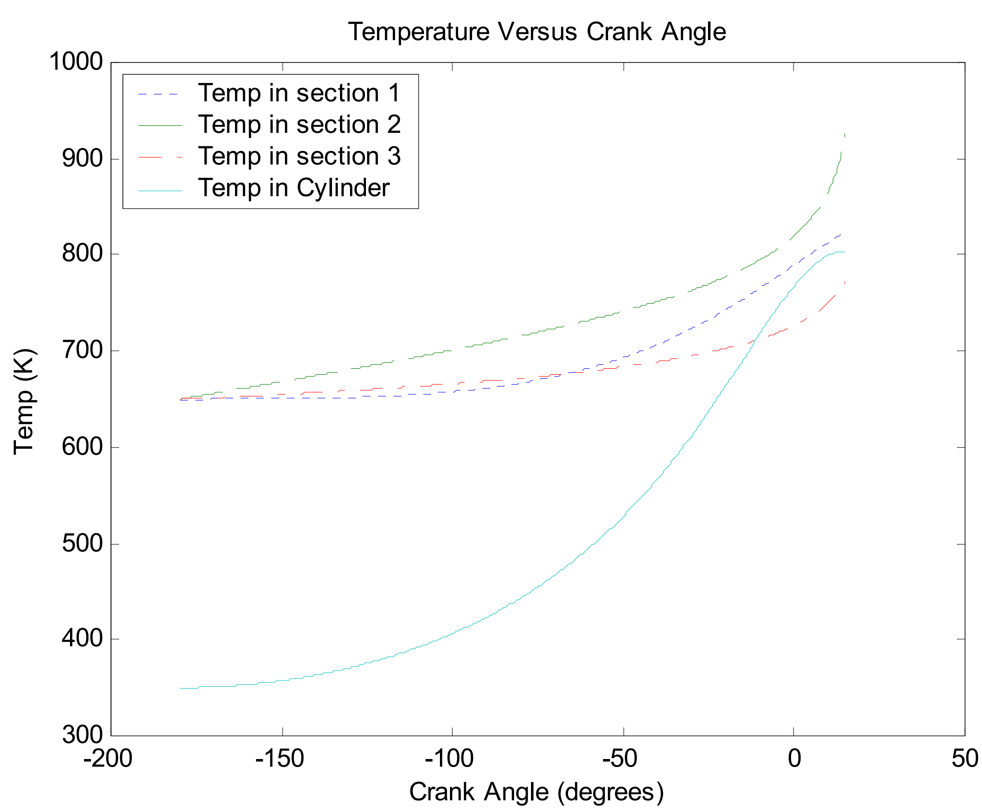

Figure 15 Temperature in each zone as a function of crank angle.

We are also able to see temperature curves in each of the zones of the model. Again, crank angle is shown on the horizontal axis and zone temperature (K) is labeled vertically. Temperatures are important for many reasons. The igniter is self-sustaining at normal run temperatures, but requires electrical heating for cold starting. Knowing the temperature of the catalyst under normal modes will help us design the heaters for cold start assist. Several changes in material are planned for in future igniter designs. Understanding the temperature in various zones will aid in material selection and reduce igniter failures. The temperature as a function of crank angle is shown in Fig. 15.

Parametric Studies

Studies varying igniter length, igniter surface temperature, and compression ratio show that varying these values can change the catalytic ignition timing. Figure 16 shows that a longer igniter advances the ignition timing. The timing is currently adjusted by varying the igniter length.

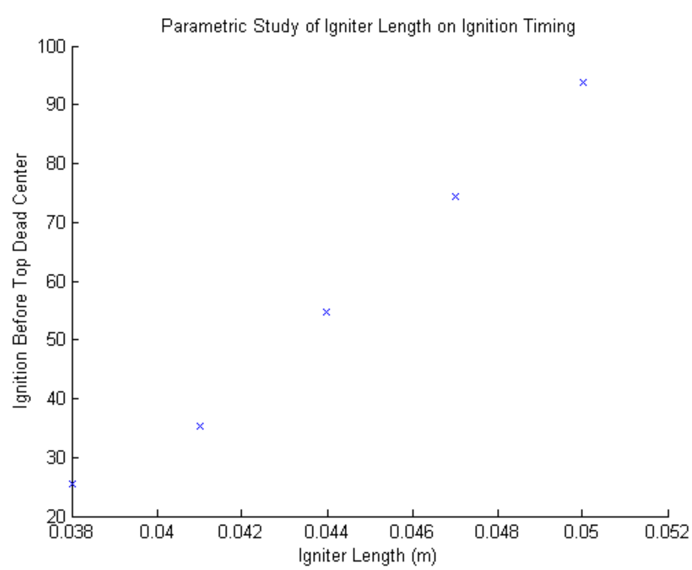

Figure 16 Parametric study of igniter length on ignition timing.

Higher igniter surface temperatures advances the ignition timing (Fig. 17). This matches the phenomena observed during engine testing. Changing the igniter surface changes the timing slower than changing the length. During engine testing we were able to fine-tune the ignition timing by varying the power to the heater coils thus changing the igniter surface temperature.

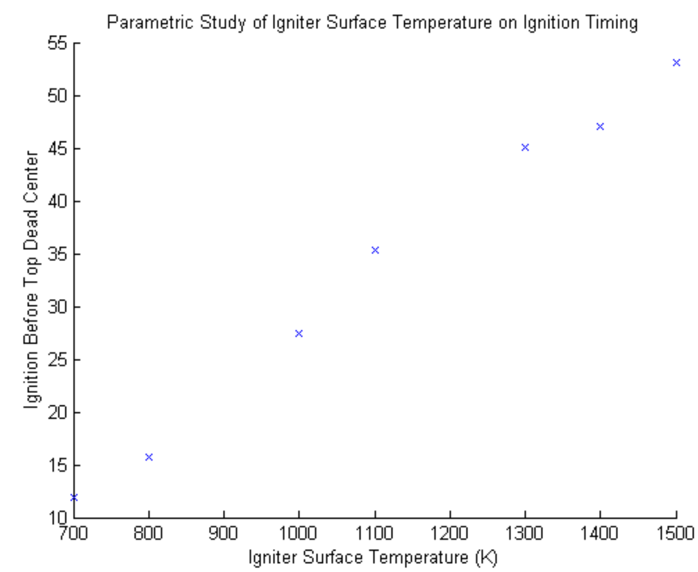

Figure 17 Parametric study of igniter surface temperature on ignition timing.

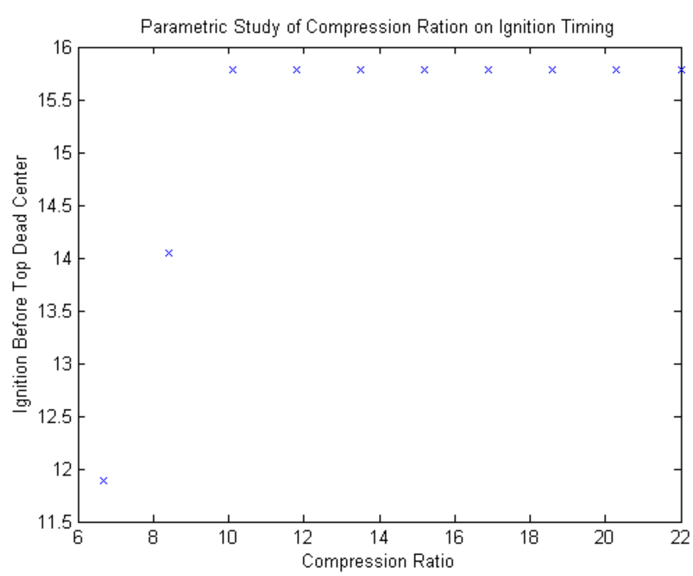

Figure 18 Parametric study of compression ratio on ignition timing.

Higher compression ratios have more advanced timing (Fig. 18). This was also observed during engine testing. We have to change the igniter length significantly from a spark ignition conversion to a compression ignition conversion. These parametric studies are used as quantitative research. We were able to find the important parameters in the timing the catalytic ignition event.

Water content has little to no effect on the ignition timing (Fig. 19). Morton observed this during engine testing with the Yanmar. We use a 30 percent mixture of water because it cools the flame enough to significantly reduce emissions, while keeping the exhaust and other engine components hot enough that excess water evaporates.

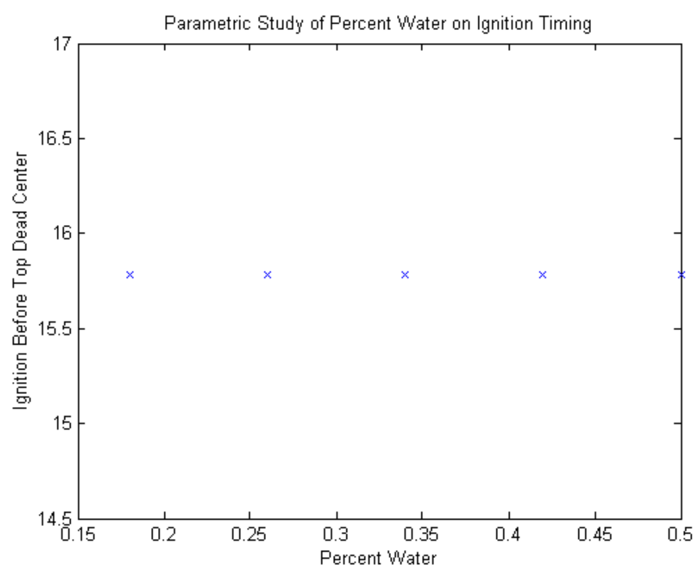

Figure 19 Parametric study of percent water on ignition timing.

The parametric studies show us which parameter best controls the timing. Igniter core length is used to roughly adjust the catalytic ignition timing. Adjusting the power to the igniters during engine operation fine-tunes the catalytic ignition timing. Adjusting the compression ratio and percent water content in the fuel does not present a viable way to adjust the ignition timing.

Diesel Platforms

Three diesel engine platforms were chosen for catalytic research. In recent years a 15-hp Yanmar diesel was acquired and converted to Aquanol. This engine was used as a feasibility study for igniting such high water content fuels in a homogeneous charge catalytic compression ignition environment. A 75-hp Volkswagen TDI industrial engine was also acquired to perform studies to measure the effect of turbo charging and EGR on catalytic timing. These two platforms are paramount for the eventual conversion of a diesel truck.

Recent Developments

The jackshafts on both the Yanmar and the TDI were modified to fit the new dynamometers. An intake manifold heater was added to the Yanmar to aid in cold starting. Another Yanmar was acquired to perform diesel baseline tests to compare with performance data on the converted Yanmar. Pressure transducers were added to each cylinder of the Yanmar for simultaneous multiple cylinder pressure monitoring. This shows us whether one cylinder is working harder than another one.

Test Plan

After the dynamometer system has been proven, baseline tests on the TDI will be performed. These tests will be intensive due to the unknown operating conditions post conversion. This will ensure that a baseline data point will be close to whatever operating conditions are chosen during fuel mapping. More extensive performance data will be collected on the Yanmar. Baseline testing on a Yanmar running on diesel and operating at the same load and speed conditions as the converted Yanmar running on Aquanol will be conducted. Durability testing is also planned for the converted Yanmar to test for corrosion and wear.

Short Term Schedule

Table 3 is a short-term schedule for testing diesel platforms.

Table 3 Diesel Platform Testing Schedule

Start Date	End Date	Activity
October, 1 2001	October, 15 2001	Setup for automated BSFC runs
October, 15 2001	October, 22 2001	Baseline testing on TDI
October, 22 2001	October, 29 2001	Converted Yanmar performance testing
October, 29 2001	November, 5 2001	Baseline testing on preconverted Yanmar
November, 5 2001	December, 18 2001	Data accumulation and report writing
January, 15 2002	February, 30 2002	Durability testing on converted Yanmar
January, 15 2002	March, 25 2002	TDI conversion
March, 25 2002	May, 10 2002	TDI fuel mapping

Aquanol Van

Conversion Components

As part of a senior design project in the 1998-1999 academic year, a 1985 Ford extended van from Valley Transit Authority in Lewiston, Idaho, was donated for conversion to Aquanol fuel. The van was to be fueled with both gasoline and Aquanol, and have the ability to use both spark plugs (for gasoline) and catalytic ignition (for gasoline and Aquanol). Initially the vehicle received a basic conversion, but since then other modifications have been required.

The components in the initial conversion are outlined below. Because the original engine was involved in a fire, the engine was rebuilt, and some parts were replaced with stock components. Piston rings were total-seal gapless rings to minimize blow by into the crankcase. The vehicle was converted to programmable fuel injection to handle delivery of either gas or Aquanol fuels. Largely, newer model Ford parts were used in the fuel injection conversion. Catalytic igniters were also produced for the van.

Because of the corrosive nature of Aqueous fuels, several modifications to the fuel handling system were made. The fuel tank was coated with Teflon, and stainless filters were used. An aluminum housing high-pressure fuel pump was used to provide pressure for the fuel injectors.

Recent Modifications

After a few years of use, we identified several problems with the initial conversion. Most problems are fuel related on the Aquanol side. The Teflon lining on the fuel tank began to fail and cause blockages in the rest of the fuel system. The long-term solution is to replace the tank with a material that does not react with water or ethanol, most likely a polyethylene tank. As a short-term solution, the filters are checked and replaced frequently.

The aluminum-housed fuel pump was corrosion resistant, but eventually the Aquanol did produce some steel corrosion and the pump seized. An agriculture pump with similar pressure and flow rates and that is meant to work with harsh chemicals was located. A rubber diaphragm, and nylon casing should ensure that this pump lasts much longer. Our primary concern is that it may not be designed for constant duty, as in the vehicle application. It appears to be working well, but the vehicle needs to log more miles before we determine the pump's reliability.

Other parts of the fuel system have had problems. The fuel injectors and fuel rail had some steel parts that began to rust as the particles clogged the fuel injector tips. The fuel rail has been replaced with stainless steel. Some stainless steel fuel injectors made for methanol and other alcohols have been located and will be installed.

The remainder of the fuel system needs additional modifications. Fuel tubing should be replaced with stainless or aluminum hard line to reduce corrosion. Also, a simple method for draining return lines when switching must be identified. A diverter valve on the return line would keep the fuel in the recirculation loop from contaminating the other fuel during a tank switch.

The exhaust system is starting to leak due to rust problems. The system will be replaced with stainless tubing and muffler. Catalytic converters will be installed close to the engine, and emissions data will be gathered with and without them. While the current exhaust setup is dual tip, the new system will be run to a single exhaust tip for ease of emissions gathering.

The van is largely a public demonstration vehicle, so aesthetic enhancements help promote awareness of our research. A number of large vinyl decals were added to enhance the exterior of the van. New wheels give it a nicer appearance.

The van was displayed in July 2000 at the Idaho Department of Water Resources (IDWR) energy fair in Coeur d'Alene, Idaho. The van ran on Aquanol fuel and helped promote public to promote awareness of alternative fuel technology. IDWR hosted an Ethanol workshop in Boise in the winter of 2000 where the van was displayed and used to give rides to interested parties. In both events, features on the Aquanol van were broadcast on local TV stations.

Test Plan

The vehicle has been running in Sandpoint, Idaho, for the last few years, making testing and modification difficult at best. Just recently, we brought the van moved back to Moscow in order to prepare for chassis dynamometer testing. Our plan is to first conduct baseline tests with gasoline and spark plugs. The van will then be tested with the catalytic igniters and Aquanol fuel.

Prior to conducting dynamometer testing, we will gather roll down data. For this data we purchased a non-contact speed sensor and mobile data acquisition system. Previous data gathered with rolling wheel contact sensors provided poor resolution and inaccurate calculations of important the road load parameters. The new sensor has over 100 times the resolution of our previous sensor and, combined with a mobile laptop and USB data acquisition board, should provide us with much better results for road load modeling.

Once the roll down tests are completed, the speed vs. time data will be analyzed with a program written to extract the road load parameters. In particular, the coefficient of drag and coefficient of rolling resistance are pulled from curve fits to the data. With those and other vehicle parameters, such as weight and frontal area, we have enough to correctly model the vans road load. For a given speed, this model will predict the necessary power requirements.

When road load modeling is complete, software written as part of a previous NIATT Master's student research will be used to approximate the instantaneous power requirements for various points of a FTP city cycle. Certain parts of the cycle are at steady state speeds, while others are acceleration between two speeds. About 20 points from the cycle will be used to approximate FTP cycle emissions for this vehicle. Some of these points will be steady and collected on the chassis dyno, while dynamic points will be approximated by setting power levels to calculated values necessary for that acceleration level. Likewise, the same modeling will be done for the FTP highway driving cycle, and points for testing will be selected.

Once points of operation (speed and power) are identified by modeling, the van will be taken to the chassis dyno for testing. Emissions and fuel consumption will be recorded for each data point, and extrapolated to give an approximation of the vehicle performance under the standard FTP test conditions. The tests will be run with gasoline and Aquanol to compare the results of conversion. The testing will be done with and without the catalytic converters to test their effectiveness at reducing emissions with both fuels. If time and money permit, the van will be taken to a test facility that can do actual FTP runs. We plan to take a baseline in gasoline and spark plugs and complete a second run with Aquanol and catalytic igniters.

Short Term Schedule

The fall of 2001 will be the first time we have had the converted van sufficiently ready to do significant testing and modifications. Table 3 outlines the short-term plan for the following months. Because the cost associated with having a lab perform FTP tests, it is important to maximize our time there. Making sure the vehicle is in a reliable and robust state and having adequate experience collecting data on our chassis dyno are both critical to ensuring good results from the FTP testing.

Table 3 Preliminary Schedule to Prepare Aquanol Van for FTP Testing

Start Date	End Date	Activity
October 1, 2001	October 15	Maintenance and drivability on gasoline and spark plugs
October 15	October 20	Roll down tests and data analysis
October 20	October 31	New exhaust system installed, and new igniters built
November 1	November 15	New fuel tank installed. Stainless fuel lines fabricated
November 15	November 25	Fuel injectors installed, and dyno test points identified
November 25	December 10	Setup mobile data acquisition and FTIR for dyno tests
December 10	December 31	Optimize fuel map, prepare for chassis dyno testing
January 1, 2002	January 15, 2002	Dyno testing with gasoline and spark plugs
January 15	January 31	Setup Aquanol and igniters, and new fuel mapping.
February 1	February 15	Chassis dyno testing with Aquanol and Igniters
February 15	February 28	Preparations for FTP testing
March 1	March 7	FTP testing in Napa, CA

The data gathered over the next few months will yield two strong data points comparing emissions, performance, and fuel consumption of diesel and gasoline to Aquanol conversions. Previous results show promise of large reductions in NO_x, Hydrocarbons (HC's), and Carbon Monoxide (CO), but the proposed testing will give us quantifiable comparisons of actual improvements.

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