CHAPTER 3

Experimental Procedures

3.1 Initial Setup

3.1.1 Engine Coolant and Air Supply

The engine's cooling system and the air's cooling system are linked as fore mentioned. The engine's cooling system places the most load on the condensing unit. It therefore was adjusted before the part of the system that cools the air. The first step was checking and making sure the water level in the engine was above the level of the cutoff valve down stream of the water circulation pump. The water level was set to 2 inches in the sight glass on the side of the water tower. If water needed to be added then it was. The water level was checked periodically. The water evaporated and or leaked off slowly over time. To start the water circulating through the heat exchanger and the engine, the pump was turned on and the bypass valve closed. Placing the compressor speed toggle switch into the low position was the next step. This turned on the condensing unit. After turning on the condensing unit, the pressure regulator controlling the amount of hot gas bypass was adjusted until the pressure in the regulator read 68 psig (Figure 2.4). Following this initial adjustment, the engine sat for about an hour. Adjusting the hot gas bypass controls the capacity of the condensing unit and ultimately the equilibrium temperature of the engine. After stabilizing for a hour, the temperature of the water and the cylinder was set at about 6° C for this experiment. To make the water temperatures warmer, increase the regulator pressure controlling the amount hot gas bypass. Increasing the pressure, opens the bypass valve. Opening the bypass valve allows more refrigerant to flow internal to the condensing unit, thus bypassing the evaporators. The evaporators in the experimental apparatus are the water and air cooling heat exchanger. Lowering the pressures decrease the temperature. Adjustment of the TX valve can also be used to control this temperature but is more time consuming. After the TX valve's was initially installed, it was adjusted and untouched for the duration of the test. Once the water cooling system was stable and set, the air cooling system was adjusted. The air and water cooling did not have to be adjusted every day unless extreme temperature changes outside took place. Going from winter to summer will decreased the condensing units capacity at the same settings. This changed the air and water temperatures produced. When the temperatures were off, the system was adjusted as needed to return the system to the designated state.

Maintaining the constant and controlled air supply was important to the repeatability of each test. The air had to be supplied at the same conditions from day to day. At the start of each day after the A/C system was turned on along with the auxiliary fan. The auxiliary fan moved air over the cooling coils and into the reservoir. The cap on the auxiliary air outlet was removed at this point to allow air to circulate through the intake system. The air flow cooled the system and allowed fresh cold air to build up in the reservoir. The cap was placed on the auxiliary air outlet only during experimental runs. The system ran in this manner until the temperature of the air in the pleneum reaches its lowest temperature and remained constant. The pleneum temperature was regulated by the manual valve that controls refrigerant flow to the cooling coils (Figure 2.4). For this experiment, the temperature of air in the reservoir was set at around 7° C. After the temperature stabilized, the air heater voltage was adjust with the variable autotransformer until the temperature measured by the intake air temperature probe reached the desired temperature. For the experiment, the air temperature was 20° C and corresponded to a setting of about 54 volts. The key was allowing enough time for the system to stabilize. The heater took around 30 minute to reach equilibrium. At this time the ice in the thermocouple reference bath was replaced (Figure 2.2).

3.1.2 Ignition System

Proper operation of the ignition system was crucial to the success of the experiment. A series of checks were performed each day while the cooling system was stabilizing. The first of such test involved visually inspecting the wires for cracks and bad connections. If any were found, they were fixed. Cracks in insulation contribute to energy loss through arcing to ground. It also increases the EMI noise that interferes with the computers. Along with the wires, the spark plug had to be kept in proper operating condition. The spark plug was cleaned every three runs with a wire brush and its gap was checked. The spark plug gap used for these experiments was 0.025 inches. The gap distance was recommended in the operation manual for the CFR engine. After all the ignition system's components and the engine's mechanical components were checked the engine was motored and the ignition turned on. With the engine was being motored, the timing was checked and set to 5° BTDC.

The high energy system relies on the stock ignition to trigger its energy release. If the power to the HEI system is on and the stock ignition is turned off, charge builds up in the HEI system. With the engine off, touching the spark plug or bridging it to ground will result in a shock. To insure the HEI's capacitor is discharged, unplug HEI system prior to turning off stock ignition and allow the engine to be motored for a few seconds.

3.1.3 Fuel Injection System

The EFI system's integrity, like all the other systems, was checked every day. On initial instillation the injector timing was set to 10° ATDC on the intake stroke. To set the injector timing an oscilloscope was connected to the output of the transistor in the infrared trigger circuit (Figure 2.10). The trigger circuit was powered up and flywheel rotated by hand until the output voltage of the transistor went half way from high to low voltage. To adjust the timing of the trigger signal, the timing wheel on the IR trigger was rotated to allow the arm to pass between the emitter and detector at the correct time. The actual timing in degrees was read off of the markings on the flywheel. The fuel injector timing was set to fire the injector as the intake valve opens. The intake valve has a duration of 240° of crankshaft rotation or 120° of camshaft rotation. The longest pulsewidth used was 30 ms. It corresponds to 81° of camshaft rotation. The injector timing was chosen to minimize wetting of the port by injecting at the open valve.

The fuel pressure was set to 50 psig at the beginning of the day and checked if the valve was altered. The fuel pump usually took a second or two to reach 50 psig. Because the fuel system has no means to measure the amount of fuel in the gas tank, the ability of the fuel pump to supply the 50 psig fuel pressure was used to judge when more fuel was needed. If the pressure took longer than 5 seconds to reach 50 psig or did not reach 50 psig for the same valve setting, the fuel level in the tank was low and more fuel was added.

Batteries were used to power the signal processing circuits to help isolate the circuit from background noise. They had to be checked every couple of weeks. When the batteries voltage fell, the circuits would behave strangely. The op-amps needed a negative and positive voltage to function properly. In the circuits, there was more draw on the batteries supplying the negative power. These batteries died faster and caused the circuits integrity to deteriorate slowly making it hard to detect initially. A constant check of the voltages prevented this from happening after the first experience. A drift in the positive voltage supplied to the op-amp in the fuel injector driver circuit (Figure 2.11) affects the amount of current available to open and close the fuel injector. The positive voltage supplied to the op-amp should not fall below 15 volts. An unexpected drop in power here will cause the injector to open slower. The power transistor was powered by a DC power supply. The power supply is set at 20 volts.

3.1.4 Gas Analyzer Calibration

The OTC five gas analyzer was used for analyzing exhaust gas content. Its calibration procedure was controlled by its computer. The instruction manual specified calibration of the analyzer on a monthly basis. For the experiment it was calibrated a minimum of once a week. Depending on the need, it was calibrated more frequently. The need for calibration was determined by reading the sample gas provided with the analyzer. If any of the analyzers readings differed from the known concentrations by more than the listed uncertainty associated with that analyzer then the calibration option was chosen on the computer screen. Since calibration is controlled by the computer all that needed to be done was connecting the sample gas line to the supply when the computer prompted. The concentrations of the sample gas are listed in Table 3.1.

Table 3.1 - Sample Gas Concentrations

Sample Gas	Concentration
CO	1.01%
CO_2	5.99%
HC (propane)	297 ppm
NO_x	996 ppm

The gas analyzer was re zero-ed between every run. In most cases the zeroing process was automatic. The analyzer zeroed every 15 minutes when cold and every 2 hours when fully warmed. It also zeroed itself if more than 20 minutes passes between successive samples. The usual time for zeroing occurred at the start of the next test run.   After waiting an hour for the engine to cool off between runs, the computer went to its zeroing routine for about 3 minutes then started reading the concentrations of the exhaust gas sample.

The sampling frequency of the analyzer was set to 1 second. The computer has enough memory to save for about 558 samples of the 7 parameters measured. This equals about 9 minutes at this sample rate. Increasing the sample interval to 2.14 sec increases the time span to about 20 minutes. The stored data was down loaded to a text file through the terminal interface on the gas analyzer.

The Rosemount Analytical Hydrocarbon Analyzer (FID) was used to compare the levels of HC read by the OTC analyzer with the total hydrocarbon count in the exhaust sample based on gasoline have a molecular formula of $C_{8.26}H_{15.5}$. On the day before that the comparison test was run, the analyzer was turned on and the internal temperature allowed to heat up and stabilize. Once the temperature was stable, the hydrogen flame was ignited. To ignite the flame, the fuel supply was turned on and set at a pressure of 40 psig at the gas bottle’s regulator. The FID analyzer’s internal fuel regulator was set to 25 psig. The fuel gas used was a 40% hydrogen and 60% nitrogen. In similar fashion, the compressed air bottle was turned on and its regulator set at 25 psig. The air regulator in the analyzer was set at 5 psig for starting. With the fuel and air on, the Purge/Ignite switch was held in purge position for about a minute, then the switch was placed on ignite. If the "Flame On" light stayed lit then the flame was burning. If it went out the system was purged again and ignited. Once the flame was lit the air pressures was increased to 15 psig slowly. Bringing the pressure up too fast or too soon will extinguish the flame, but it re-lights easily.

After allowing the flame to burn for an hour or until readout stabilizes on the 10 ppm scale, the analyzer was ready for calibration. The calibration gas used was 10300 ppm CH_4 and the zero gas was nitrogen. The analyzer was first zeroed on the 1000 ppm scale, using Nitrogen as the sample gas. The FID analyzer counts carbon atoms so assuming gasoline is $C_{8.26}H_{15.5}$, 10300 ppm CH_4 is equal to 1247 ppm $C_{8.26}H_{15.5}$. The upscale calibration using CH_4 was set to equal 75% of full-scale.

3.2 Test Procedure

The focus of the experiment was discovering the effects and benefits of increased ignition energy on hydrocarbon emissions during the cold start phase of the engine. All the test were run using the same Air/Fuel ratio versus time algorithm. The test included several runs at the three increasing ignition energies (stock, stock + 0.387J, and stock + 1.187J). Each run was conducted using the same technique.

To run each test from start to finish took about 15 minutes. To reset the setup for the next test requires an hour. Forgetting to flip a switch results in an hour of time wasted re-cooling the engine. After forgetting to carry out key steps in the procedure a few times, a time table was created to help organize the procedure into a efficient process. The time table started with telling the OTC analyzer to begin reading the exhaust concentrations. The gas analyzer as mentioned earlier would zero itself. This took about 3 minutes. The LABTECH data acquisition was started next. LABTECH took temperature data. The computer running LABTECH required about 3 minutes also before it was ready to take the first temperature measurements.

In this 3 minute span, the EFI system was readied. This involved connecting the batteries and turning on the power supply as well as pulling up the appropriate FORTRAN program to control the injectors. The program counted 3 minute from when the “On” switch was thrown and the engine started to be motored. At the 3 minute mark the fuel injection map was started. The actual map and the program is show in the Figure 4.16 and Appendix B respectively. Once the program was executed, it asked for a file name to save “cycles until start” data in. It also asked for the run length. A run length of 12 minutes was entered. Upon pressing enter the program waits for the injection trigger signal. At this point the engine is not being motored so the program just waits. After setting up the program, the switch used to indicate first engine fire is placed in -9 volts position. By this time 3 minutes had elapsed. The gas analyzer was showing concentrations of room air and LABTECH was showing engine temperatures.

At this point, the engine was ready to be motored up to 18° C. Before the “On” switch was thrown, the water bypass valve was inspected to make sure it was closed. It took the engine approximately 3 minutes to reach 18° C from 6° C when being motored with the cooling system pump on and the bypass valve closed. This 3 minute time was measured and used in the EFI control program. The stopwatch and the electric motor driving the engine were started simultaneously. The stopwatch was used to ensure the fuel pump, the ignition, the record function on the analyzer, and the exhaust flow to the analyzer were all turned on at the same time from run to run.

After starting, the auxiliary outlet was capped. At 1 minute 30 seconds, the exhaust flow to the analyzer was open. The actual timing when opening exhaust flow was not crucial but allowed the analyzer plenty of time to read the residual level of HC in the sample line. At 2 minute and 30 seconds, the fuel pump was turn on. At the 2 minute 45 seconds, the ignition energy was set by adjusting the HEI power supply and turned on. At 2 minute 55 seconds, the record button was pressed on the OTC analyzer. This started the analyzer saving exhaust concentration. Starting the recordings 5 seconds ahead allowed the residual HC concentration level to be recorded so the reading could be corrected. All focus was then turn to the “cycle until start” switch. When the first firing of the engine was heard the switch was flipped to the +9 volt position. The computer controlling the EFI reads the voltage from that switch and save it to the file name designated.

Once the engine starts firing the water pump was turned and the by-pass valve opened. The engine was allowed to heat up. When the cylinder temperature reached 90 the water pump was turned on. The water pump was then turned off and on as needed to maintain a operating temperature of about 90° C. When the computer reached the 12 minute mark it stopped supplying fuel and the engine returned to being motored. At this point the Analyzer had also stopped taking data and the power to the EFI circuits was turned off. The fuel pump and the ignition where turned off next and the auxiliary outlet cap removed. The motor was turn off last. When the engine stopped spinning, the flywheel was turn so that the piston was located at TDC during the cooling period. The stopwatch was then reset and started to count out the hour needed to cool the engine. All the data was now down loaded between runs.