Section 5.0: Lab Equipment and Setup

The following section describes the equipment and arrangement used in the Virginia Tech Plasma Torch Lab to conduct tests with a plasma torch using hydrocarbon feedstocks. The lab setup can be divided into four sections: flow system, data acquisition, power supply and safety equipment. A schematic diagram of the setup is shown in Appendix A. Although the arrangement of the lab varied throughout the testing process, the setup described below is considered to be the norm. Any deviation from this setup will be listed and explained for each test sequence, if applicable.

5.1: The Flow System

The flow system is responsible for delivering the feedstock to the plasma torch at the correct flowrate. It consists of the gas storage cylinders (argon, ethylene, propylene and methane), dual-stage regulators, tubing and fittings, two mass flow meters, a dual-channel flow controller and the torch itself.

Four gases were used to test the plasma torch operation: argon, ethylene, methane and to a limited extent, propylene. The gases were stored in high-pressure gas cylinders provided by a local vendor. Flow pressure was controlled by Victor® dual-stage regulators, one of which is shown in Fig. 5.1. The regulators allow the flow pressure to be adjusted from 0-3.5 MPa. The pressure was generally set at 690-825 kPa. The regulators were custom designed for the gases listed above.

Figure 5.1: Victor® Hydrocarbon Regulator

All tubing in the flow system was made from 0.635cm (0.25in) Nycoil® tubing connected by 0.635cm (0.25in) Swagelock fittings. The particular type of Nycoil® tubing used is made from flexible nonconductive material with an operational pressure of 1.725 MPa and a burst pressure of 6.90 MPa. When both argon and a hydrocarbon gas are fed through the torch, the gases are combined using a T-fitting and then pass through 0.75 meters of the Nycoil® tubing to assure adequate mixing.

Two Sierra Series 840M mass flow meters were used to control the amount of flow to the torch. One flow meter was factory calibrated for argon and has a range of 0-20 standard liters per minute (SLPM). The second flow meter was factory calibrated for use with methane and has a range of 0-30 SLPM. When ethylene or propylene are used in place of methane, a calibration factor is needed to adjust for the different material properties of the gases. The equation used for calibration correction is as follows:

$$Q_{act}=Q_m*K$$

where Q_{act} is the actual gas flowrate, Q_m is the flowrate reading on the mass flow controller and K is a correction factor determined using data provided by Sierra Instruments. The correction factor is derived from the first law of thermodynamics applied to the sensor tube within the flow meter and is given by the following function,

$$K = \frac{N_1}{r_1 C_{p1}} \times \frac{r_2 C_{p2}}{N_2}$$

where N is a correction factor for the molecular structure of the gas (monatomic, diatomic, etc.), ρ is the density and C_p is the coefficient of specific heat. The conversion factor calculated using the above equation is for converting from the gas the flow controller is calibrated for, “2”, to the new gas, “1”. For the tests involving ethylene, K=1.20 and for propylene, K=0.564. The flow meters are shown in Fig. 5.2. The flow meter in the foreground is used to control the flowrate of argon, while the one in the background controls the hydrocarbon flowrate. Both flow meters rely on a large-diameter thermal mass flow sensor, which is virtually clog-proof. The flow meters utilized precision analog circuitry with a five-breakpoint linearizer, providing highly accurate calibration ability. Each flow meter is accurate to ±1% of full scale. The response time is generally one second to achieve ±2% of the required flowrate.

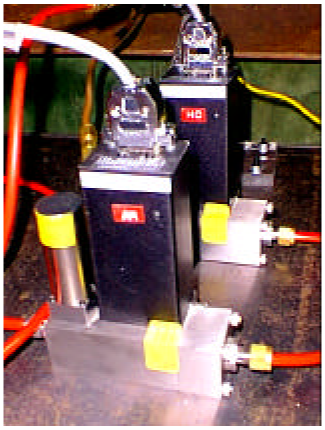

Figure 5.2: Mass Flow Meters

A 902C Dual-Channel Flow Controller, manufactured by Sierra Instruments, is used to control the two mass flow meters. It was factory calibrated to operate with the flow meters. The flow controller is shown in Fig. 5.3.

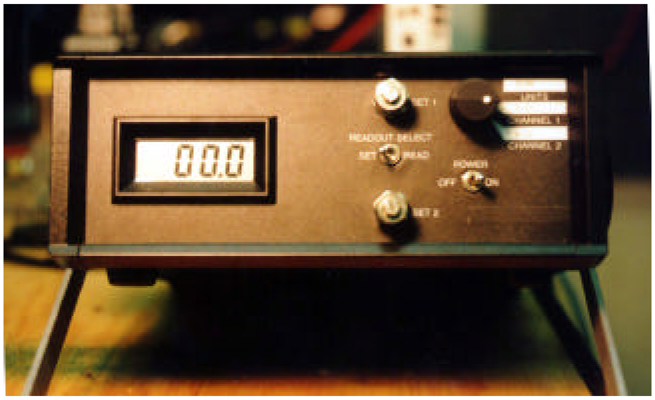

Figure 5.3: Mass Flow Meters

The face of the flow controller consists of a digital readout, readout select switch, two flow control potentiometers, rotary channel select knob and power switch. The flow control potentiometers allow the user to adjust the amount of flow through the flow meters. The readout select switch changes whether the digital readout displays actual flowrate or set flowrate for the channel selected by the rotary channel selection knob. Generally, these two numbers are identical unless there is a severe obstruction in the flow path. Control signals are sent to the flow meters using two-way parallel cables. Electrical connections on the back of the flow controller provide 0-5 volt outputs that can be used to send signals to the data acquisition system. These signals can then be converted into flow readings and displayed on the computer monitor.

5.2: The Data Acquisition System

The data acquisition (DAQ) system was assembled to collect and process the data taken during the testing series. The actual computer components consist of an IBM 486PC, a National Instruments™ AT-MIO-16E-10 multifunction analog and digital I/O data acquisition card, LabVIEW 4.0 software and three analog signal-conditioning modules. The three signal conditioning modules are a ±50mV, a ±10V and a Type K thermocouple input, each with a ±5V output. Visual data of the plasma jet was taken using digital and standard motion cameras, a Model 82-020 Series 0.5 Meter Ebert Scanning spectrometer and a Burle 1P28B Photomultiplier tube (PMT) in a housing. Current, voltage, pressure and temperature data were collected using a current shunt, a voltage dividing circuit, a Genisco Tech 0-100psig pressure transducer with a Measurements Group 2310 signal conditioning amplifier; a backup analog pressure gage; and a type K torch body thermocouple, respectively. For the majority of the tests, the thermocouple, current shunt and power supply voltage were connected to the analog signal conditioning modules. This provided signal filtration and isolation of the DAQ card and PC from any unanticipated surges in the power supply system. The pressure transducer and flow meter outputs are pre-conditioned, and therefore, run directly into the DAQ card through the use of a CB50 connector block (Fig. 5.4).

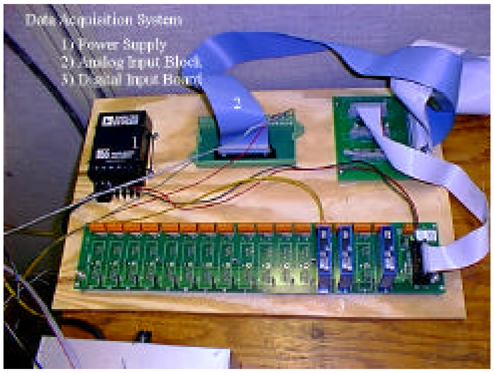

Figure 5.4: Data Acquisition Hardware

The Burle PMT (highlighted in Fig. 5.5 by the arrow), was attached to the exit slit on the spectrometer. When acquiring spectrographic data, the output voltage from the PMT is connected to one of the signal conditioning modules. Normally, the three modules are used to collect voltage, temperature and current data, but for spectrographic tests the voltage module was used instead to read the PMT voltage.

Figure 5.5: Ebert Spectrometer with Burle PMT

The wavelength counter on the spectrometer is synchronized with a counter in the LabVIEW program (a data acquisition and processing program provided by National Instruments) in order to correlate the PMT voltage with the appropriate wavelength. The wavelength counter and the other spectrometer controls are shown in Fig. 5.6

Figure 5.6: Spectrometer Controls

From left to right, there is a scan direction control knob, an end of scan indicator light, a fuse, the wavelength counter, a manual scan and shifter control and a HI-LO shift selector.

As a check of the DAQ system, the analog pressure gage and a hand-held multi-meter were used to verify that the DAQ readings displayed on the computer monitor were correct. This verification of the DAQ system was performed prior to each test series to insure that the data collected during those test runs were accurate. Also, for the first few tests of the project, a video camera was used as a form of data collection and validation. Replay of the tape at low speed helped to qualitatively evaluate the torch operation in a slower time scale. Problems, which occurred too fast for the eye to see, were easily evaluated on the replay and could later be corrected. An example of this was when arcing occurred in the back of the torch. The arcs were noticed on film and an insulator was designed to correct the problem.

5.3: The Power System

The power system is used to generate and deliver sufficient power to ignite and sustain the plasma torch. It consists of four welding units connected in series and one high frequency starter box. This configuration provides an open circuit voltage of approximately 270 volts. The plasma torch can be run in either DC or high frequency mode due to the available power and flexibility of the system.

Two of the four welding units are shown in Fig. 5.7. Each one is a Miller Electric Constant Current, DC, SR-150-32. They have an open circuit voltage of approximately 67 volts and can produce 5-150 amps. Most tests were conducted at 40 amps or below, with the norm being around 30 amps. For future reference, current settings (0-100%) are reported when actual current was not recorded. (Ex. 10%=15A, 20%=30A, …) Each unit is equipped with a high frequency starter. High frequency starters induce a rapidly oscillating voltage signal to break down the voltage gap. Initiating an arc across a gap requires a much larger voltage than maintaining the arc, which is why the high frequency starter is needed. Once the arc is in initiated, the starter shuts itself off and the welder returns to DC mode. These starters were used in early tests to ignite the torch, but they proved to be problematic because of the great intensity of the high frequency signal produced, so an external high frequency starter box with variable intensity setting was obtained to alleviate the problem.

Figure 5.7: Plasma Torch Power Supplies

The external high frequency starter box used in all but the initial tests is shown in Fig. 5.8. The Miller Electric HF-251D-1 is equipped with a high frequency intensity selection knob (0-100%), remote switch and start/continuous selection switch. All tests requiring the use of continuous high frequency current were conducted at intensity levels of 5% or below and run on continuous high frequency. DC tests were started by applying a burst of high frequency to the plasma torch and then turning off the HF-251D-1.

Figure 5.8: High Frequency Starter Box

5.4: Safety Equipment

When conducting any test resulting in plasma or flame generation it is necessary that safety equipment be kept close by. Measures were taken to ensure the safety of those in the immediate area when the plasma torch was in operation. Any form of arc generates large amounts of UV, which must be shielded to prevent eye and skin damage. A 1.27cm thick transparent Lexan® sheet was placed in between the plasma torch test cell and the control room. This sheet had three purposes. First, it needed to be transparent to allow a clear view of the plasma torch operation. It also provided a moderate amount of UV protection. Most importantly, the Lexan® sheet provided superior blast protection to that of standard glass or Plexiglas® due to its high resistance to shattering. Also, when looking directly at the plasma torch while it was in operation, a welding shield with a tint level of 12.0 was used.

The test cell itself also had safety measures built into it. The main portion of the test cell was built from a 25.4 cm OD x 0.953 cm thick steel pipe and located on the outside of the building. It had a 90° elbow with a one-meter extension to force the exhaust gases up above head level. It was also equipped with a rain hood. A fire resistant fabric, used to keep out weather and block any light that might alter spectroscopic readings, enclosed the rest of the test cell. This fabric was also shielded from the torch by a sheet of aluminum, painted flat-black to reduce reflection. A picture of the plasma torch in the test cell is shown in Fig. 5.9.

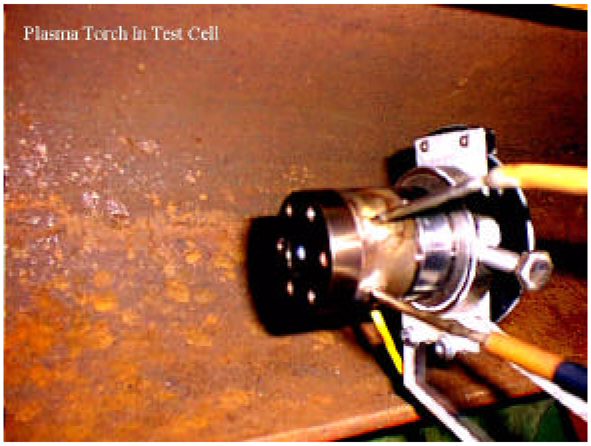

Figure 5.9: Plasma Torch in Test Cell

5.5: Plasma Torch Setup

Unless a test required a specific torch modification, such as arc gap adjustment, the plasma torch was set up identically for each test. First, the electrodes were replaced if they showed sufficient wear to be inadequate for the current test series. Electrode wear was evaluated qualitatively, simply by looking at the shape and amount of electrode loss. Gas seals and thread sealants were replaced every time the torch was disassembled to ensure quality operation.

Gap adjustment was made by the use of the plasma torch micrometer drive and a multimeter. The multimeter was connected across the anode and cathode to check for continuity. The cathode was forced to make contact with the anode by adjusting the micrometer drive until the multimeter showed no electrical resistance between the anode and cathode. The cathode was then backed out until continuity was broken. From this point, the cathode was backed out an additional 0.178mm (100° on the micrometer drive) as prescribed by Stouffer (1989). Once the gap adjustment was made, the torch was bolted onto a Plexiglas® stand in the test cell used to electrically isolate the torch from lab equipment. The torch body thermocouple, inlet gas and pressure lines were then connected. With the power off, electrical connections were made by the use of jumper cables. One cable was attached to the pressure line (anode) and the other to a steel ring, specially designed for this type of power connection.

From this point, the feedstock was set and run at the desired flowrate and then the power supplies were turned on. Plasma torch ignition was initiated by a burst of high frequency current from the starter box. The starter box was then turned off and the torch was allowed to run only on DC. For tests requiring the collection of voltage and current data, the voltage and current leads were connected to the data acquisition system after the high frequency starter was turned off. Plasma torch power levels ranged from 1.0-4.0 kW for methane, ethylene and propylene. Methane and ethylene had average power levels around 2.2 kW, with the average of propylene being several hundred watts higher. Argon consistently operated below 1.0 kW, and could be run as low as 130 W.