

Section 17.0: Final Remarks and Recommendations

Over the past year, the Virginia Tech Plasma Torch has undergone hundreds of tests, which have proven its potential as a reliable and stable ignitor and flameholder for supersonic combustion. The goal of the project was to discover whether or not the torch could operate with hydrocarbon feedstocks in the attempt of integrating the torch into a supersonic combustion application and being able to run off of the main fuel supply. It has positively demonstrated its ability to do so. Experiments were conducted to catalogue the torch operational characteristics, such as arc stability, coking potential, electrode erosion rates, body temperature, plasma jet oscillation and ability to produce combustion-enhancing radicals. Arc stability tests confirmed that larger arc gaps, increased mass flowrate and operation with complex hydrocarbon gases all inhibit the formation of a stable arc. The torch experienced some coking when operating on high amplitude AC current, but DC operation showed no signs of coking whatsoever. Electrode erosion rates for ethylene, and especially propylene, were found to be significantly higher than for methane. This effect is thought to be related to the chemical complexity of these hydrocarbon feedstocks and their heat transfer characteristics. In addition, it was discovered that methane produced lower steady state torch body temperatures than argon for the same current level and volumetric flowrate. Perhaps the most interesting discovery made during the year was the detection of plasma jet oscillation. Using a high-speed digital camera and acoustic equipment, the plasma jet axial length was observed to oscillate at a frequency of approximately 180 Hz. This was later found to be caused by the three-phase, rectified DC power supplies used to power the torch. The noteworthy conclusion made from this discovery was that manipulating the input voltage could control oscillation rate and length of the plasma jet. Finally, using spectrographic equipment, combustion-enhancing radicals, C_2 , O^+ , O_2^+ , OH , CH^+ , CO^+ and N_2^+ were discovered in the plasma jet exhaust for the hydrocarbon gases tested. Tungsten, W, was also found to be present in the exhaust, indicating electrode emission.

By compiling all of the data gathered from the past year and experience collected with hydrocarbon feedstocks, the following recommendation will be made. From a missile system viewpoint, the most effective way to operate a plasma ignitor is by

running it on the main hydrocarbon fuel supply (gasified), at high power (5-6kW) and possibly with air added into the main feedstock line. Effective gas seals are a must. It was well proven during the course of this past year that complex hydrocarbons, such as onboard missile fuel, inhibit arc stability. However, high DC current (≈ 60 amps) should overcome this. DC current is recommended because of its ability to resist coking and electrode buildup in the anode constrictor. In addition, a small gap setting will lower the voltage and enhance arc stability. If plasma jet oscillation is required to assist in forming mixing eddies within the combustor, adding an AC signal at the required oscillation frequency is suggested. High current does have several drawbacks. Electrode erosion and torch operating temperatures may be high. However, using an uncooled plasma torch, it has been observed that gases with high specific heats and densities aid in keeping torch body temperatures down. The high rate of electrode erosion may also prove to be a benefit. Hot electrode particles ($\approx 3500\text{K}$) may prove to be travelling flameholders as they are injected and swept away by the fuel-air stream. A moderate flowrate, providing an internal torch pressure of about 200-300kPa, should provide sufficient cooling to keep torch body temperatures manageable, but not enough pressure as to constrict the arc and reduce stability. Finally, the high power of the torch will be required, not only for arc stability, but also to allow the arc sufficient potential to dissociate and ionize the gaseous hydrocarbon fuel. In addition, air has been proven to be an effective “seeding” gas (Harrison and Weinberg, 1971). The addition of air into the hydrocarbon feedstock could enhance the production of oxygen atoms, which have been demonstrated to be more effective than hydrogen atoms in combustion enhancement for hydrogen/air mixtures (Kato and Kimura, 1996, Mitani, 1995 and Sato et al., 1992).

In conclusion, this plasma torch device has undergone intense testing and has proven its potential for hydrocarbon feedstock operation. It has been shown to be reliable. The next step in the project development should be to integrate the torch into a fuel injector design and test the torch ignition and flameholding capability in a supersonic wind tunnel. This will verify the above claims.