Section 12.0: Plasma Torch Operating Temperature

Experiments were conducted using a type-K thermocouple attached to the plasma torch body to collect temperature data under various conditions as the torch heated up, eventually reaching steady state. Tests were conducted using methane and argon at several different flowrates and current settings. When the Virginia Tech Plasma Torch was originally designed, it was not known at what temperature the torch would operate under design conditions. These experiments were designed to provide a guideline for future torch designs and give a better understanding of how the current plasma torch design operates. The experiments clearly showed how much time the torch requires to reach steady-state operation. In addition to the data on warm-up time, the tests provided conclusive evidence on how the feedstock type, current level and flowrate all affect the steady-state operating temperature of the plasma torch.

The plasma torch operating temperature is a critical feature of any plasma torch design. Operating temperatures will dictate material selection for various components, the design of parts that are made to expand to form seals and the rate of electrode erosion. High torch body temperatures generally require more expensive, exotic materials, that are capable of withstanding the intense heat. Most of the components in the Virginia Tech Plasma Torch are manufactured from stainless steel, tungsten, ceramics or graphite, all having relatively high tolerance to temperature. Parts that are more susceptible to temperature, such as low temperature gaskets, are placed in areas of the torch where temperatures are much lower.

12.1: Test Procedure

Four separate tests were performed using argon and methane. Current settings, flowrate and feedstock type were changed to provide an idea of how each variable affected the operating temperature of the plasma torch. The list of tests and their variable settings are summarized in Table 12.1. Temperature data was collected using a type-K thermocouple attached to the torch body using silver solder.

Table 12.1: Torch Body Temperature Tests

Test	Feedstock Type	Flowrate	Current Setting
#1	Argon	20 SLPM	27%
#2	Argon	20 SLPM	14%
#3	Methane	30 SLPM	27%
#4	Methane	20 SLPM	27%

Each test was initiated using a completely cool torch (≈300K). The torch was allowed to reach a steady-state operating temperature, upon which the test was concluded. In two instances, the tests were terminated prematurely because of high torch temperatures, electrode erosion rates and the concern that damage might be occurring within the torch body. For these two tests, exponential extrapolations of the available data are given to provide an estimated steady state operating temperature. As a comparison, Stouffer (1989), reported normal operating temperature of around 590K for argon.

12.2: Results and Discussion

The results of the four temperature tests are shown in Fig. 12.1. The feature that is most apparent is the warm-up time for the torch. In all cases, the torch reached a steady-state temperature within 14-20 minutes. Higher current settings and lower flowrates produced longer warm-up times since the torch must reach a higher operating temperature. Also, argon required a slightly longer warm-up time than methane when run at the same flowrates and current settings.

From the two argon tests it is clear that current passing through the torch plays an important role on the steady-state temperature. Both tests were conducted with argon flowrates of 20 SLPM, but the current the first argon test was at 14% (≈17A) while for the second test it was 27% (≈35A). This increase in current raised the steady state operating temperature of the torch over 300K. The rise in operating temperature is explained by simple Joule-heating (i.e. as current increases, operating temperature increases proportionally).

The two methane tests were both conducted at the same current setting, but at different flowrates. The first methane test had a flowrate of 20 SLPM while the second test had a flowrate of 30 SLPM. By increasing the flowrate 50%, the operating temperature dropped from ≈750K to ≈600K, or a decrease of about 20%. Increasing the feedstock flowrate raises the rate of convective cooling and hence lowers the operating temperature. A table of approximate final operating temperatures is provided in Table 12.2.

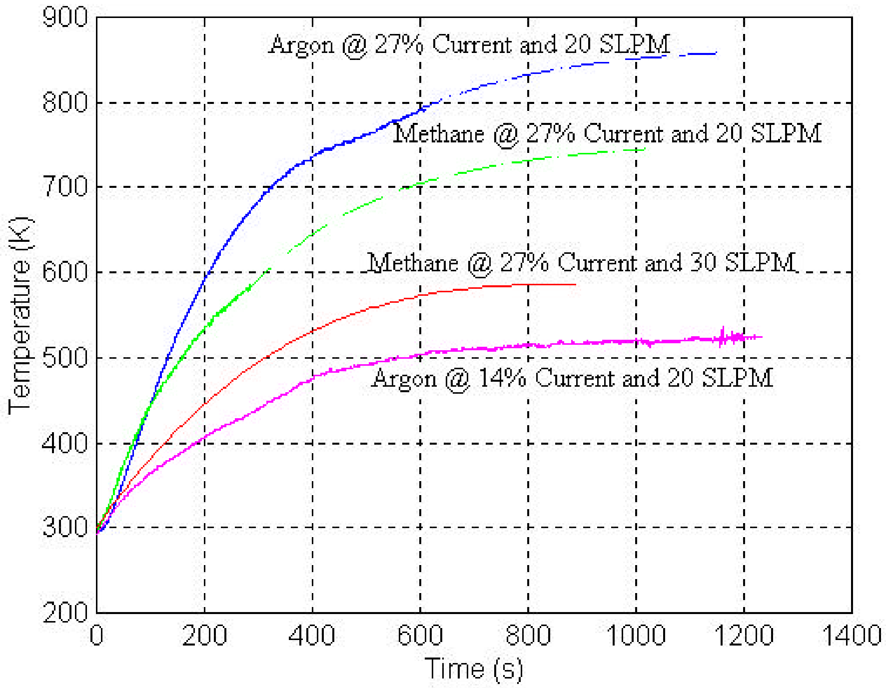

Figure 12.1: Torch Body Temperature Test Results

Table 12.2: Plasma Torch Steady-State Operating Temperatures

Test Conditions	**Final Operating Temperature**
Argon @ 20 SLPM and 27% current	≈870K
Argon @ 20 SLPM and 14% current	≈530K
Methane @ 20 SLPM and 27% current	≈750K
Methane @ 30 SLPM and 27% current	≈600K

One interesting, perhaps nonintuitive, result from the body temperature tests was that for the same current and flowrate, the plasma torch operating on methane had a lower steady-state temperature than when the torch operated on argon. Methane absorbs more energy from the arc because it dissociates and ionizes as it passes through the arc, while argon only ionizes. Gases with more complex molecules (such as propylene and ethylene compared to methane) are predicted to produce lower torch temperatures, because of their greater specific heats and heat transfer capabilities. Gases with higher specific heats will absorb more energy from the arc and also provide more effective cooling of the torch components as the gases pass over them. Of course, cooling ability also depends on other properties such as gas density, viscosity and velocity. Gases that have been tested in the Virginia Tech Plasma Torch in the past have been H_2, N_2, Ar (Stouffer, 1989) and most recently, methane, ethylene and propylene. Their specific heats, densities and chemical formulas are shown in Table 12.3.

Table 12.3: Specific Heats, Densities and Chemical Formulas of Torch Feedstocks

Feedstock	**Chemical Formula**	**Density @ STP (kg/m^3)**	**C_p @ STP (kJ/kg K)**
Argon	Ar	1.6548	0.5203
Hydrogen	H_2	0.0834	14.2091
Nitrogen	N_2	1.1692	1.0416
Methane	CH_4	0.6759	2.2537
Ethylene	C_2H_4	1.1692	1.5482
Propylene	C_3H_6	1.7699	1.4837

Note that the values listed in Table 12.3 are for STP. The actual gas temperature within the torch body is not known. These values were presented to provide a general guide, not a point from which to design. Upon first inspection of Table 12.3, it would seem that hydrogen would produce the lowest operating torch temperature because of its high C_p. However, hydrogen has an extremely low density, being almost 15 times less dense than ethylene. Of the six gases listed in Table 12.3, ethylene and propylene would probably be the best choices for cool torch operation because of their large specific heats and densities. Generally, it seems that more complex hydrocarbons should produce lower torch operating temperatures. Unfortunately, using more complex hydrocarbons as feedstocks also severely reduces electrode life because of the narrow arc column and high heat flux to the anode.

12.3: Recommendations and Final Remarks

Cooler torch operation will increase the electrode life and minimize damage to torch components. Also, torch body temperatures are important to consider when integrating the torch into an engine design where some components may be effected by excessive heat. The torch operating temperature is a function of the current passing through the torch and the specific heat and density of the feedstock being used. For the same current and flow settings, methane produced lower state-state torch temperatures than argon. Increasing the chemical complexity of the feedstock is predicted to reduce the operating temperature of the torch, but also will increase the rate of electrode erosion. Increased current settings and reduced flowrates both produced higher torch temperatures as expected. For each torch temperature test, the torch reached steady-state temperature within 14-20 minutes of ignition. These tests provided helpful information on how the current torch operates as well guidelines for future torch designs.