Electrothermal Characterization of an AC Thermal Plasma Torch

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- **A unique, single-phase torch for gasification studies.**
- **Power supplied from the electric mains, stepped up to 6 kV.**
- **The torch uses gas flow to complement the electrical energy transfer.**
- **The output of the torch is a thermal source at or near local thermodynamic equilibrium (LTE).**
- **Electrical operation of the torch is characterized by the Volt-Ampere relation to determine the power rating of the torch and diagnosing the dynamic behavior of the plasma.**
- **Plasma current is measured by a current transformer and the voltage is via an isolated voltage divider.**
- **Optical emission spectroscopy, with the assumption of LTE, is used to determine the plasma kinetic temperature using the relative line method.**

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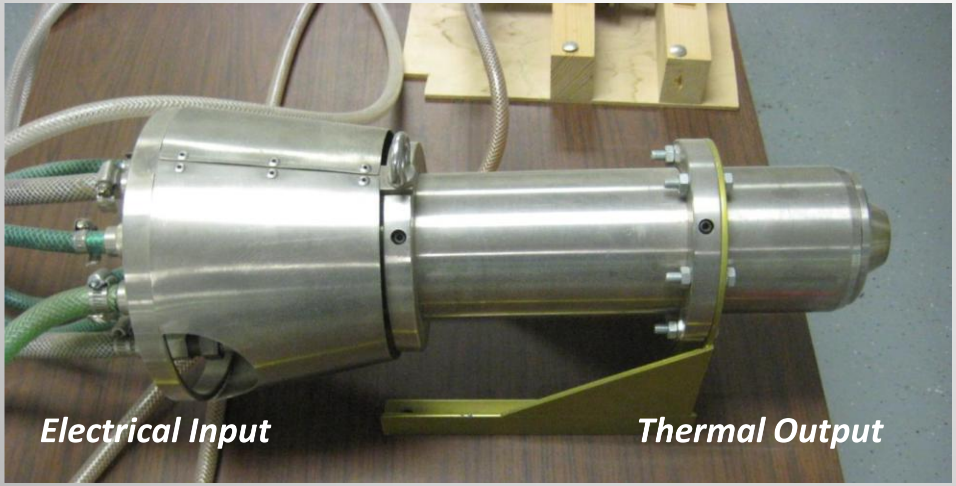
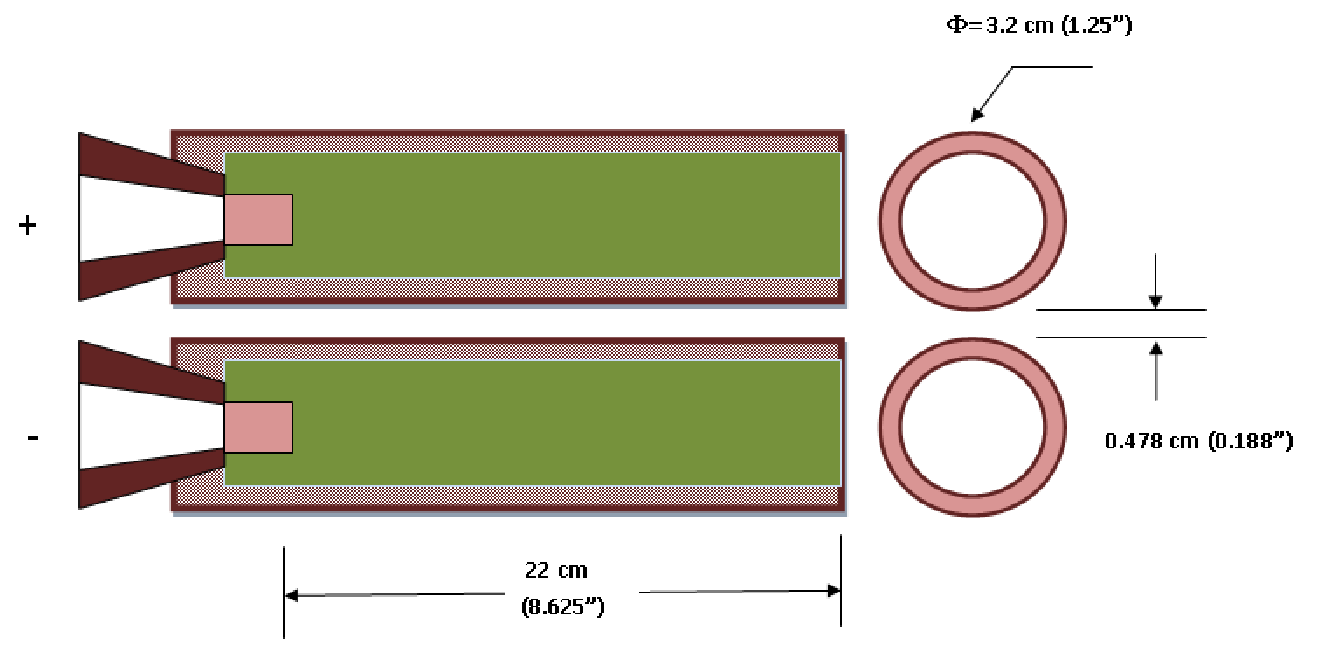
Plasma Torch and **Channels**





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Electrical Measurements

- Power supply primary side current and voltage with DVM's
  - Torch current: Pearson model 410 current transformer (0.1V/A)
  - Torch voltage: Isolated technique using 410 current transformer and resistor string in parallel with torch (4332:1)

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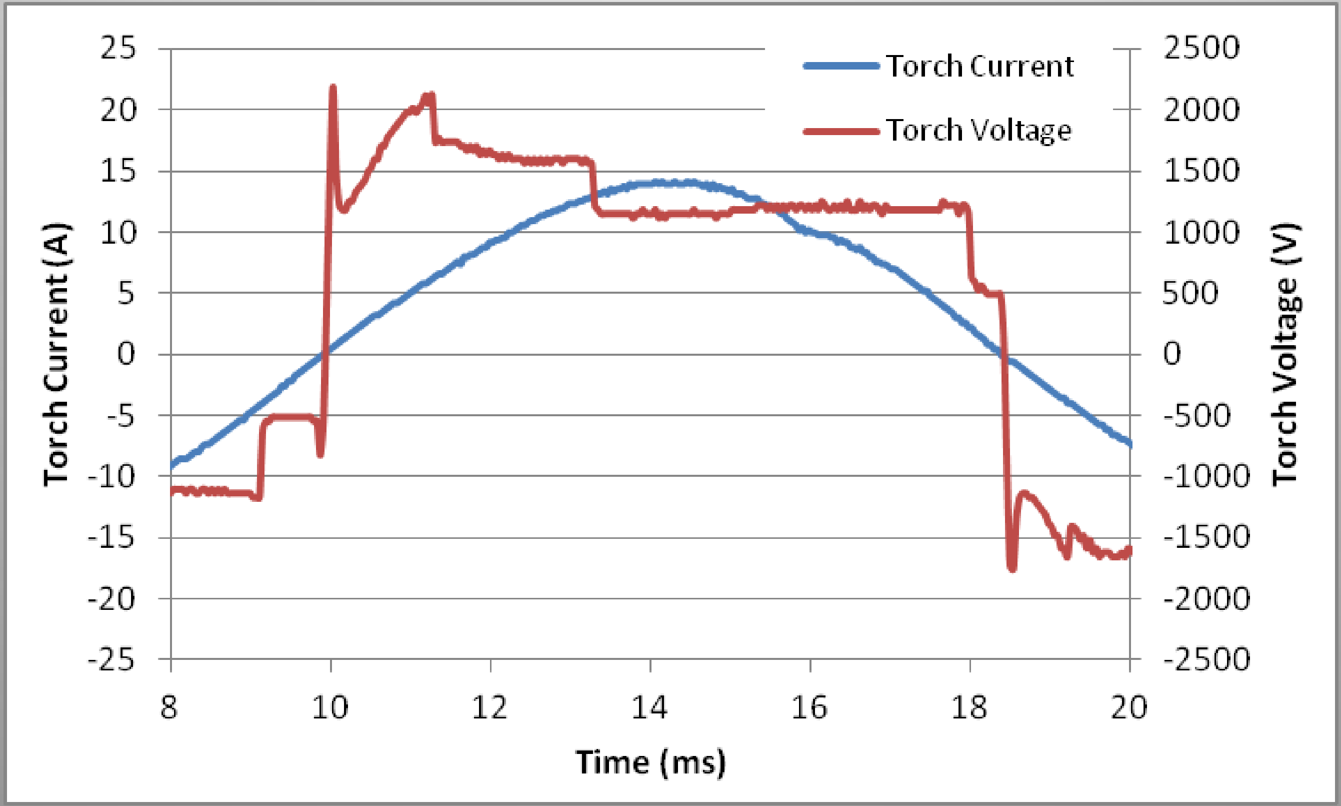
Typical Single-Cycle Torch Data

- Voltage and Current
  - Air at 9.3 cfm with a nozzle



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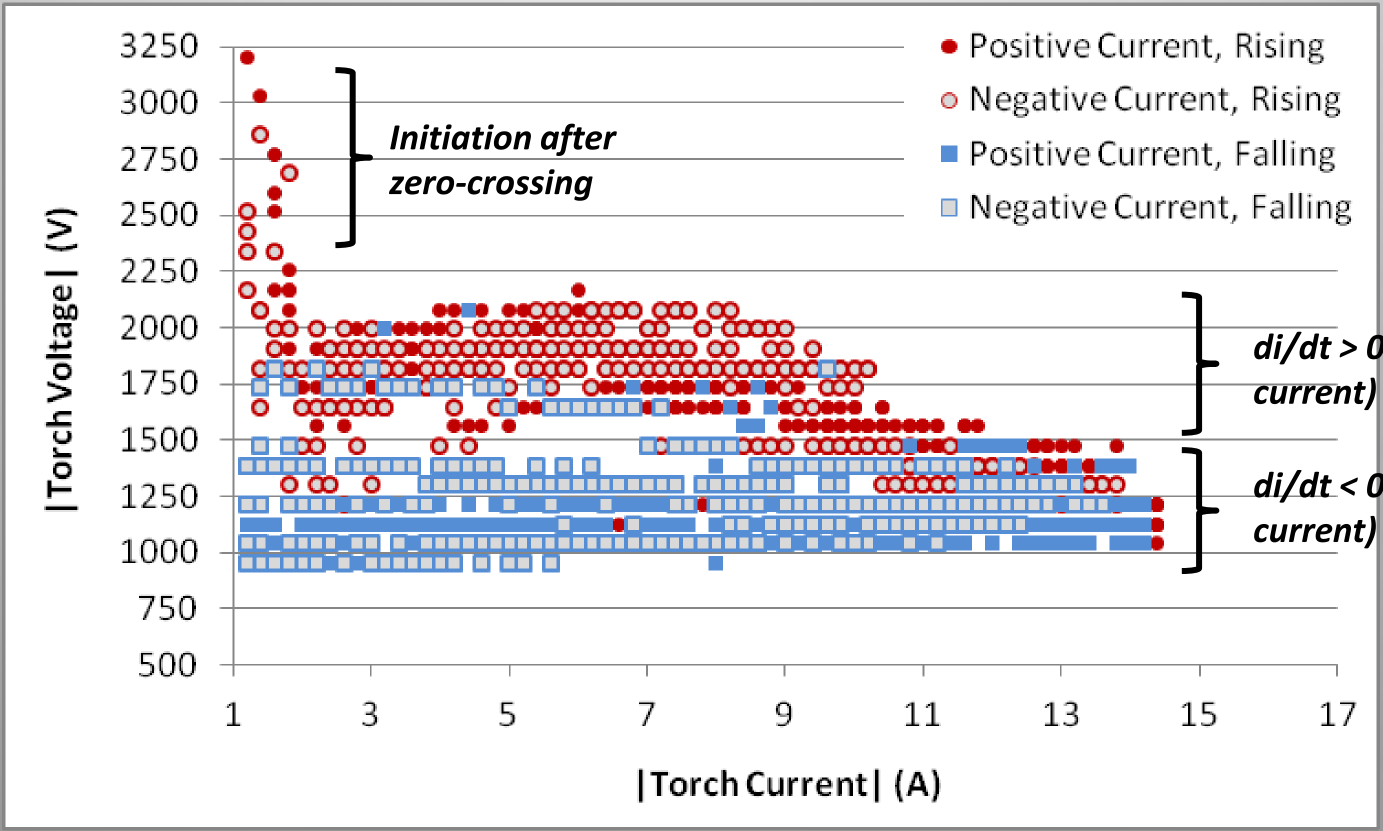
Typical Volt-Ampere Characteristic

- Highly dynamic and sensitive to di/dt
- Minimum resistance ~ 72 Ω, time-integral average ~ 172 Ω



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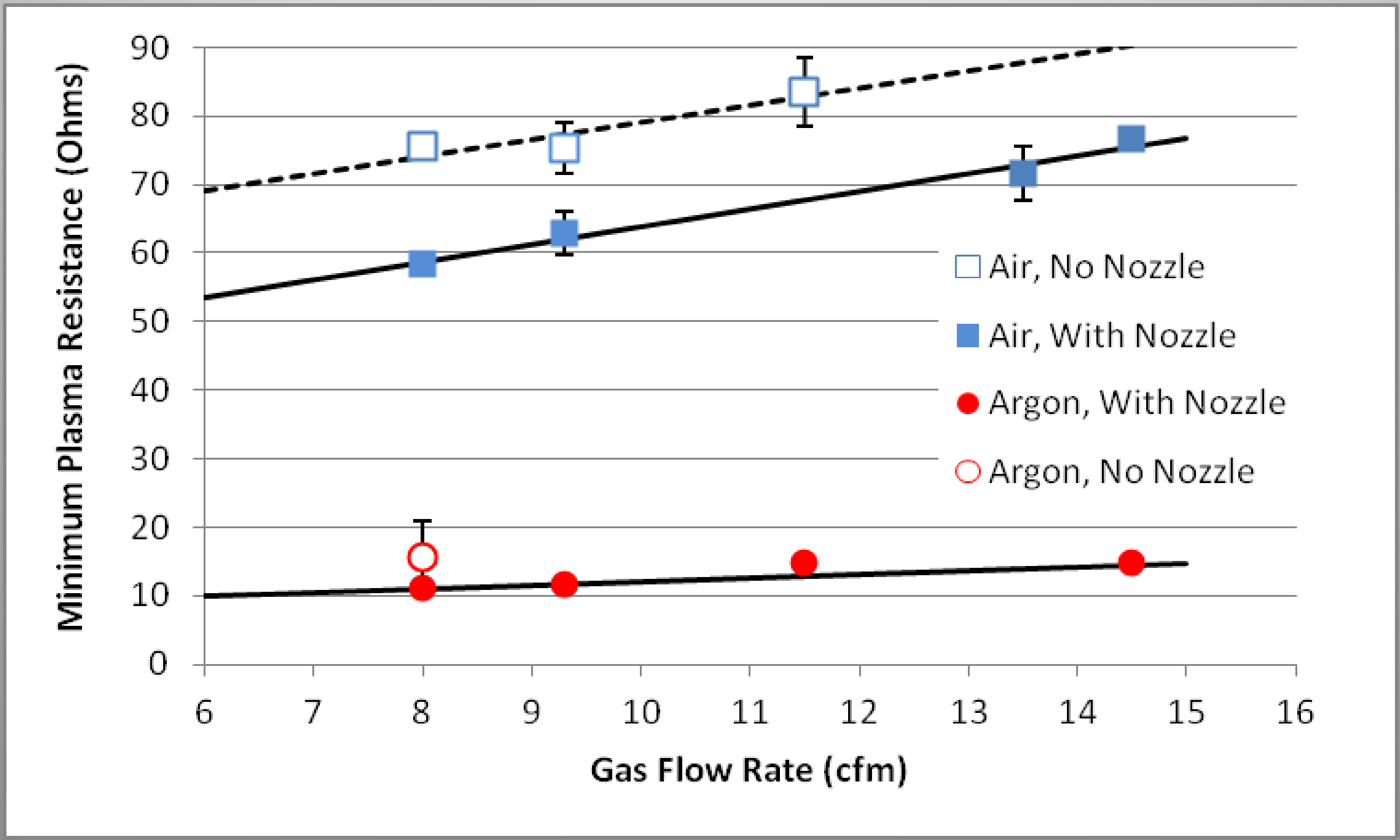
Summary of Minimum Plasma Resistance

- Nozzle reduces the plasma torch resistance
- Nozzle extends the operation over a larger range of gas flow rates



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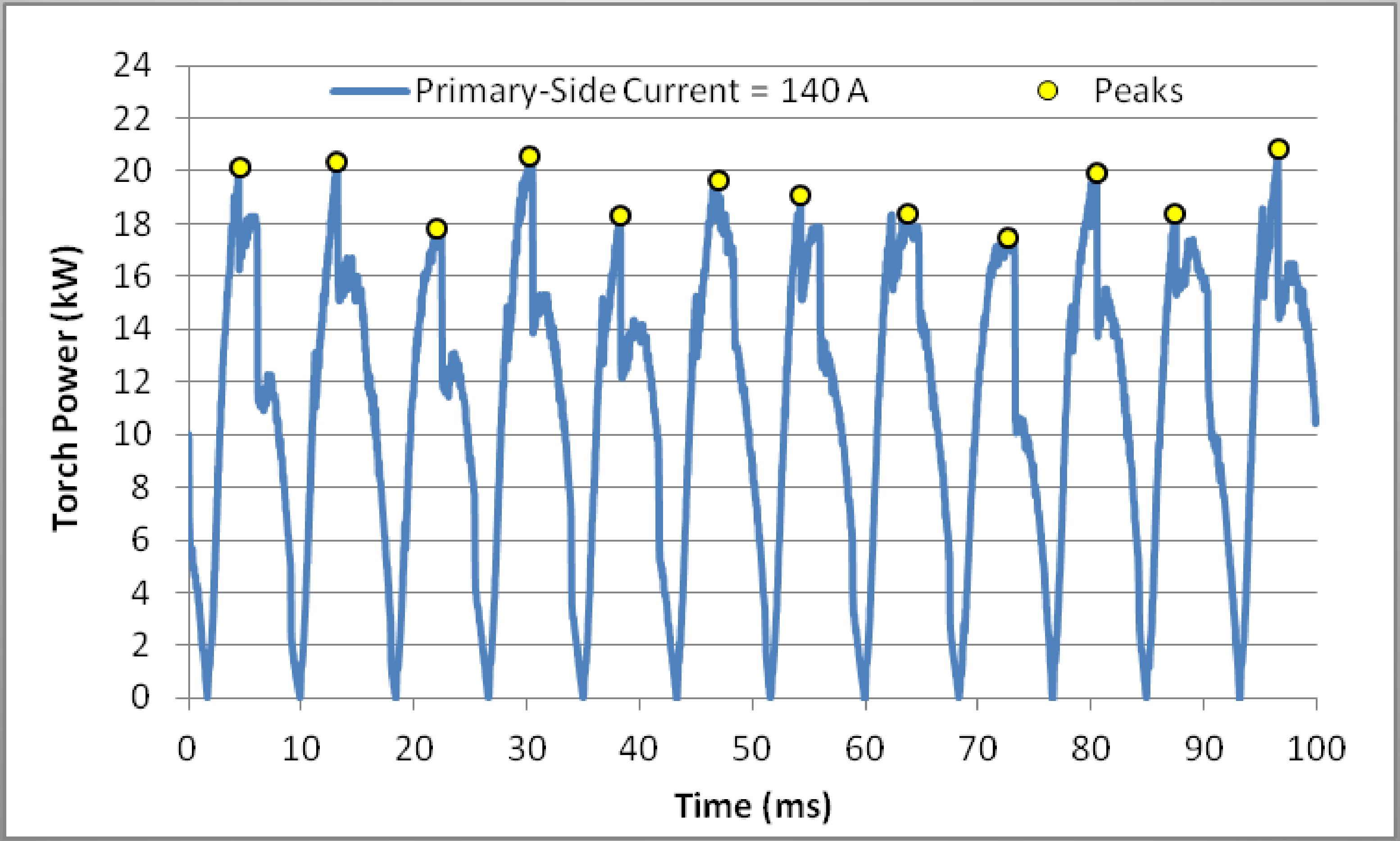
Typical Steady-State Electrical Power

- Average peak power = 19.1 kW, +/- 5.7%



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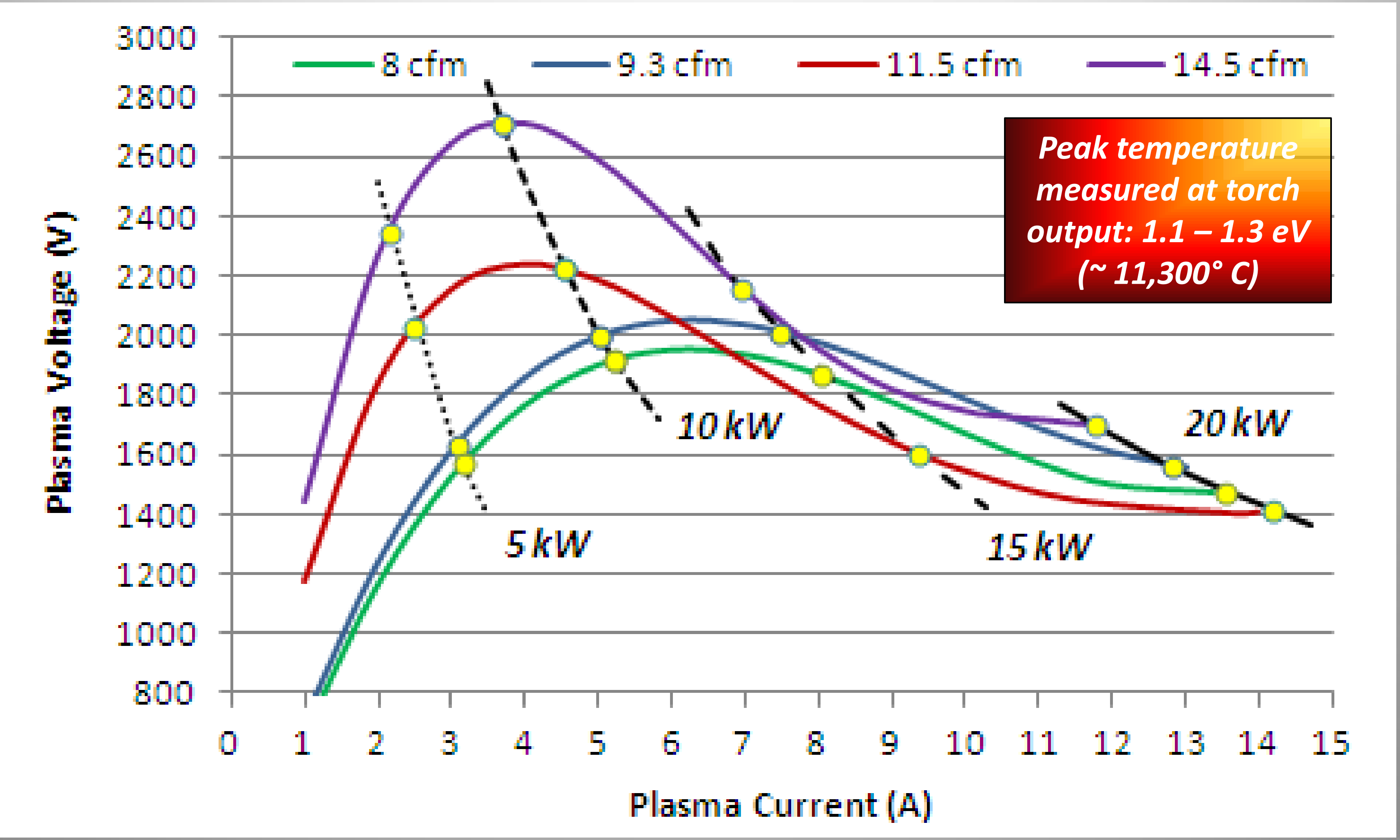
Plasma Current versus Voltage



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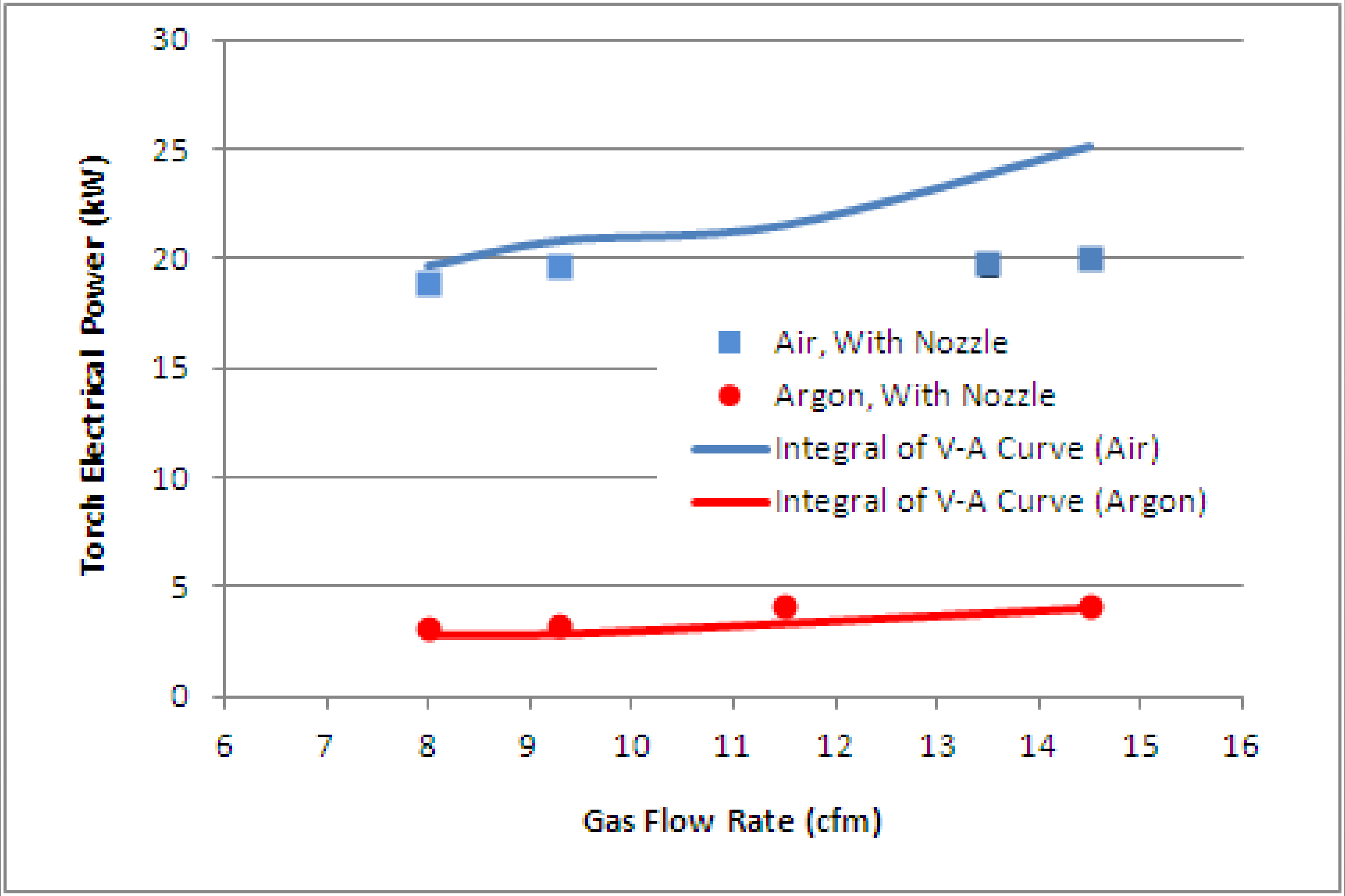
Torch power versus gas flow rate



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Optical Emission Spectral Measurements

- Spectra taken at upper and lower channels and down stream looking at the nozzle at various gas flow rates

- Two Ocean Optics HR2000 fixed grating spectrometers

- The UV-VIS HR2000 spectrometer has a range of 300 nm to 736 nm with a 600 line/mm grating blazed at 500 nm

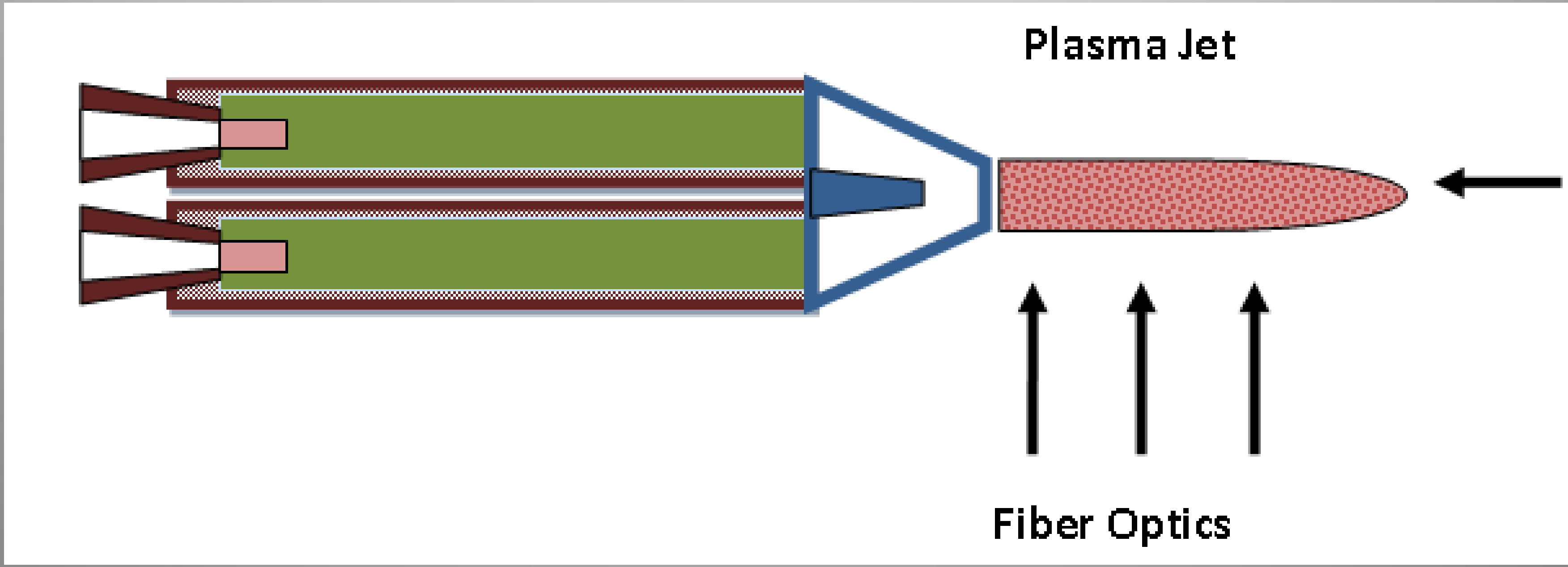
- The VIS-NIR HR2000 spectrometer has a range of 600 nm to 1025 nm with a 600 line/mm grating blazed at 750 nm

- Spectrometers are power calibrated using Ocean Optics LS-1-CAL lamp

- Collected spectral data were analyzed using PeakFit spectra package to determine the emission, and/or absorption lines

Optical Emission Spectral Measurements

Spectra taken at upper and lower channels and down stream looking at the nozzle at various gas flow rates between 8 to 17.5 cfm



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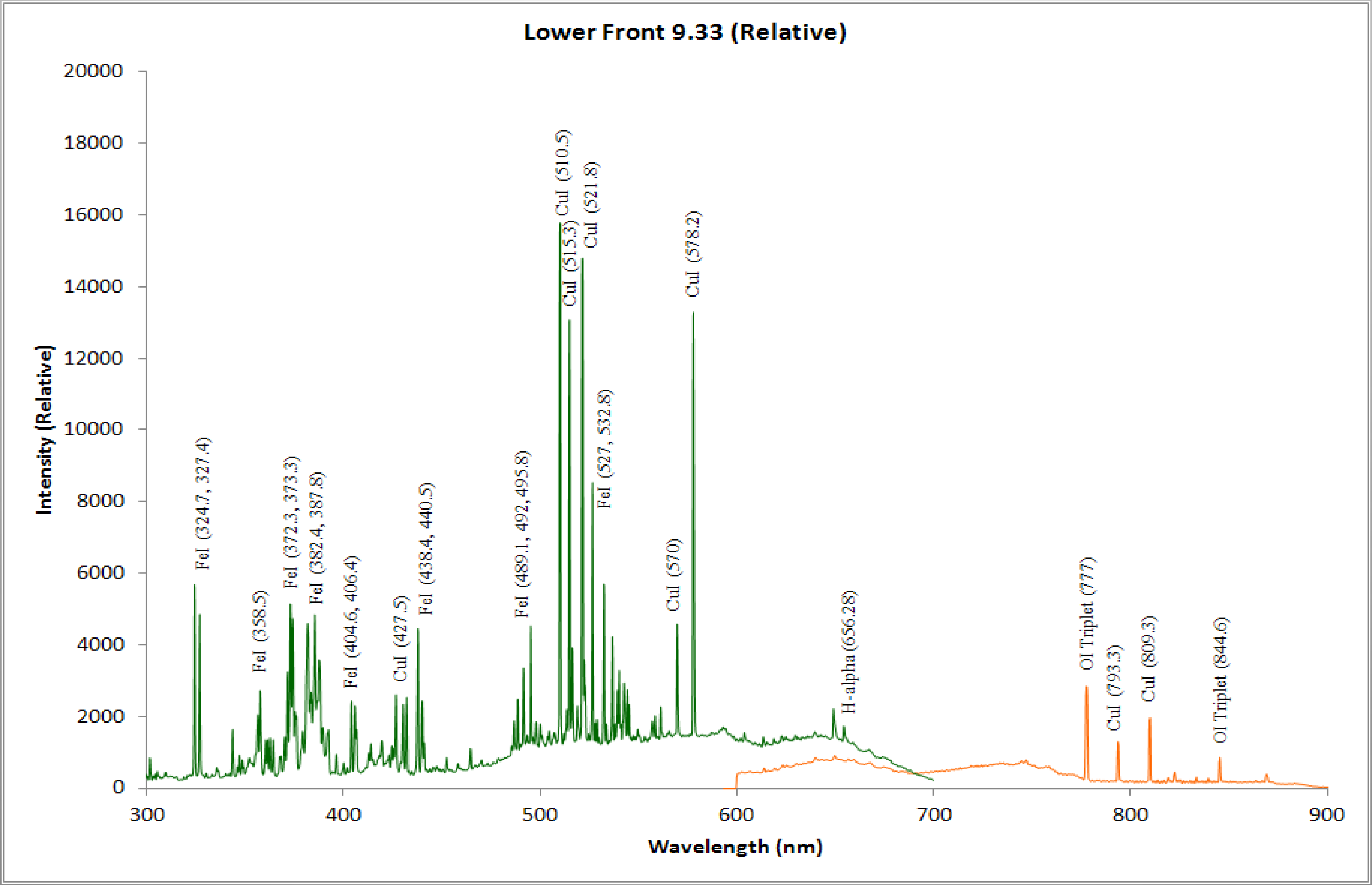
Spectra taken at the lower front of the torch with **Air** as the working gas at 9.33cfm flow rate



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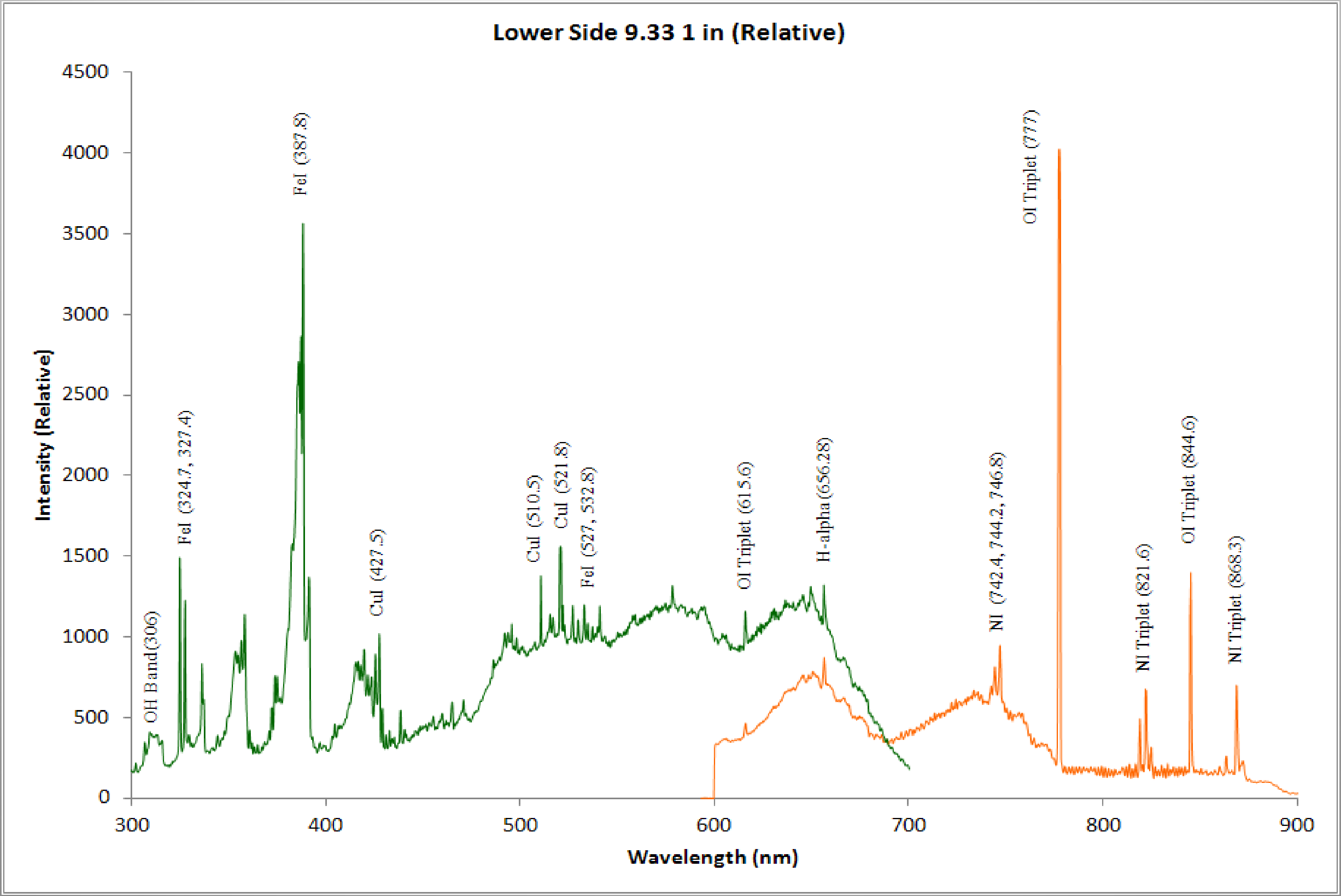
Spectra taken at the lower front of the torch 1-inch from the exit with Air as the working gas at 9.33cfm flow rate



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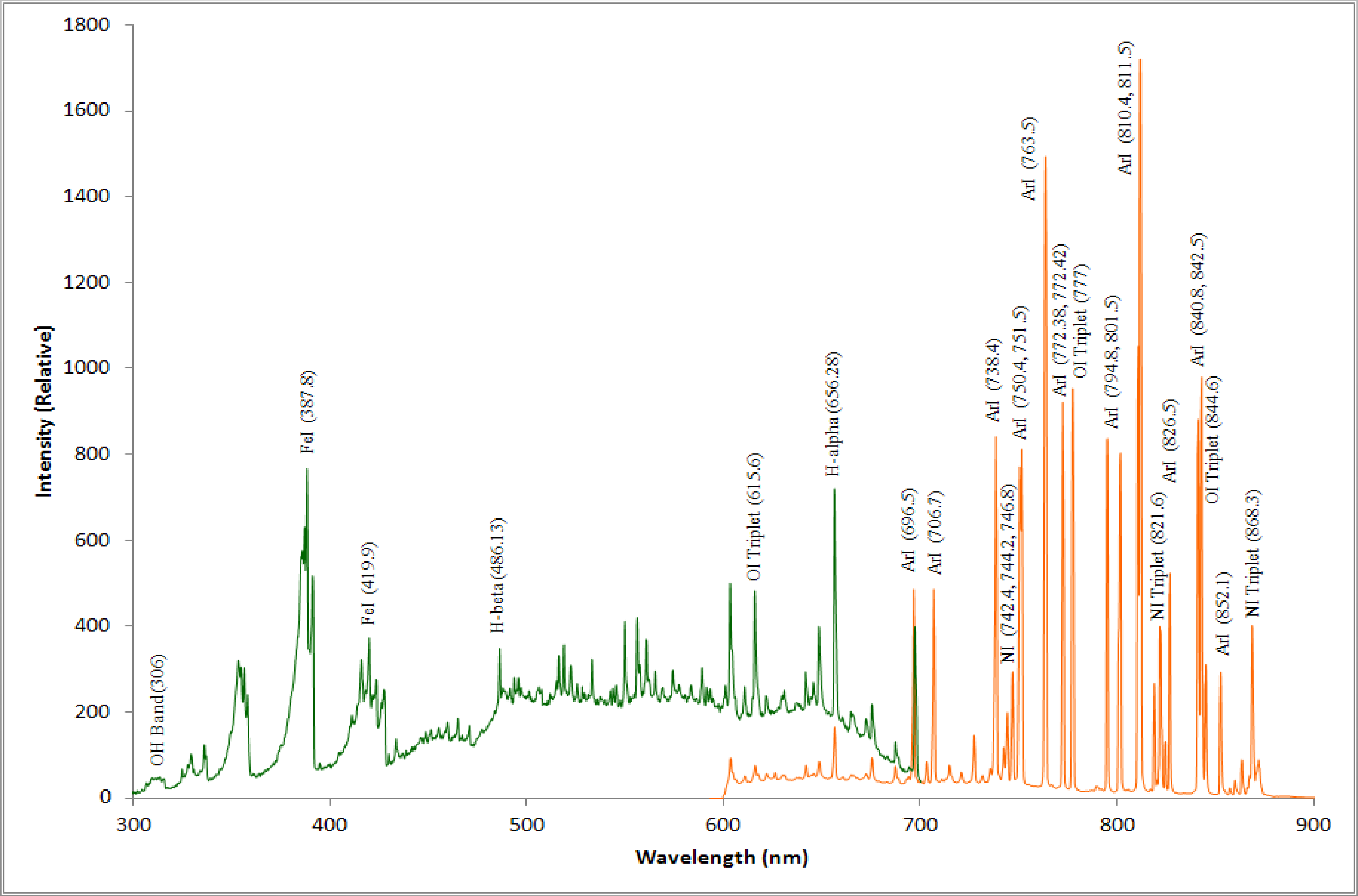
Spectra taken at the lower front of the torch with Argon as the working gas at 9.33cfm flow rate



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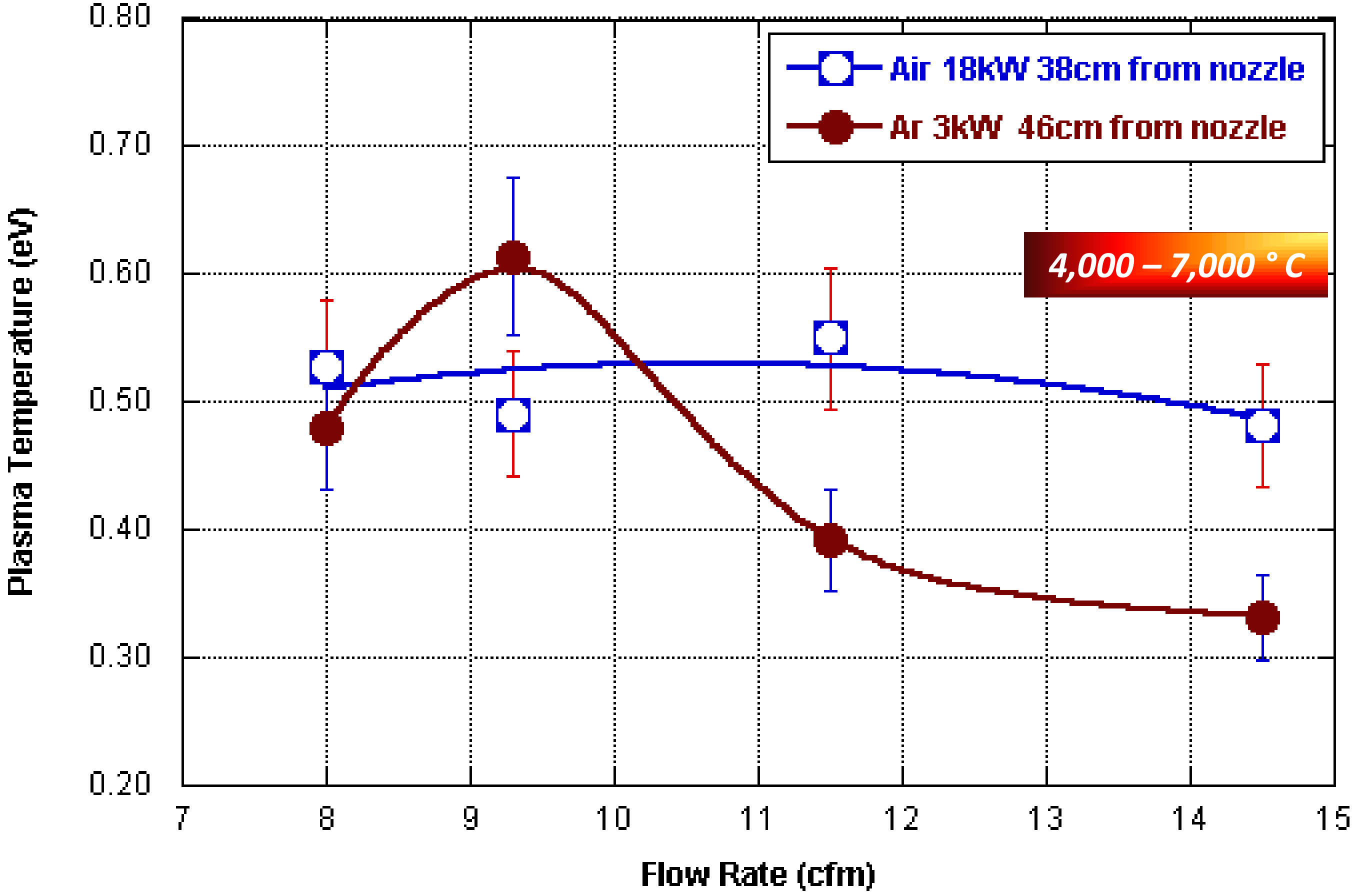

Plasma temperature measured down-bore from the nozzle as a function of the gas flow rate and at 38cm/18kW for air and 46cm/3kW for Argon

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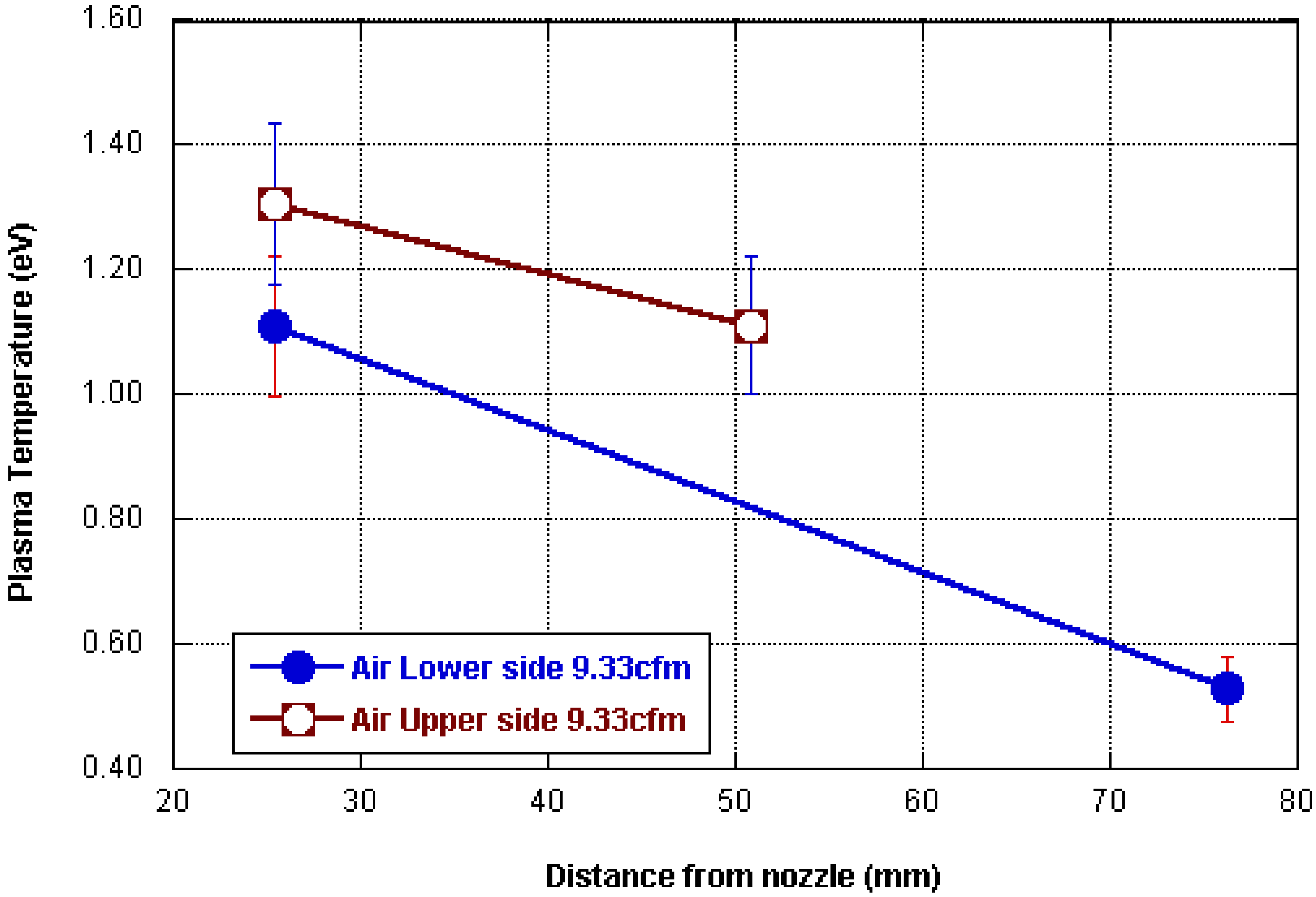

Plasma temperature calculated form H_α lines on the upper and lower sides of the torch as a function of the distance from the torch side for Air with the torch operating at 19kW

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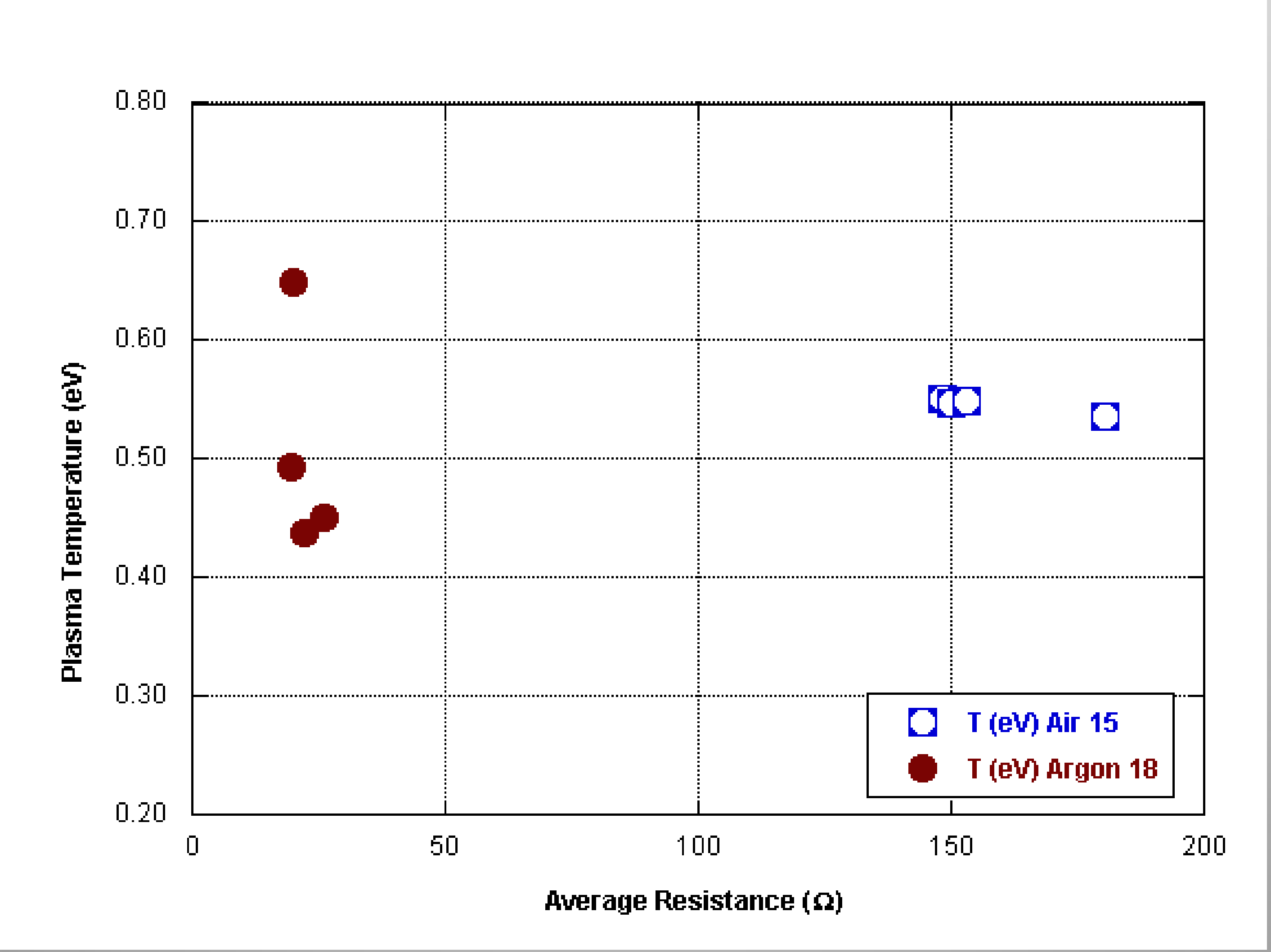

Plasma temperature down-bore from the nozzle versus resistance obtained from I-V data for Air (18kW at 38cm) and Argon (3kW at 46cm)

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Temperature Evaluation form Simple Plasma Resistivity Model

- Plasma temperature down-bore is the boundary layer temperature
- Plasma is weakly nonideal, however, the ideal Spitzer model is satisfactory with correction to the Coulomb logarithm (such plasmas are in the $\ell n\Lambda \approx 5-6$
- For the torch configuration the plasma temperature can be calculated form the resistivity (calculated form the measured from the current-voltage data)

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Torch channel length = 22cm

Torch diameter = 3.2cm

Model equation for temperature:

$$T_{(eV)} = \left(\frac{71.06 \times 10^{-3}}{R_{(\Omega)}} \right)^{2/3}$$

$R_{(\Omega)}$ is plasma resistance from electrical measurements

There is good correlation between the temperature obtained from spectroscopy and the temperature calculated from resistivity

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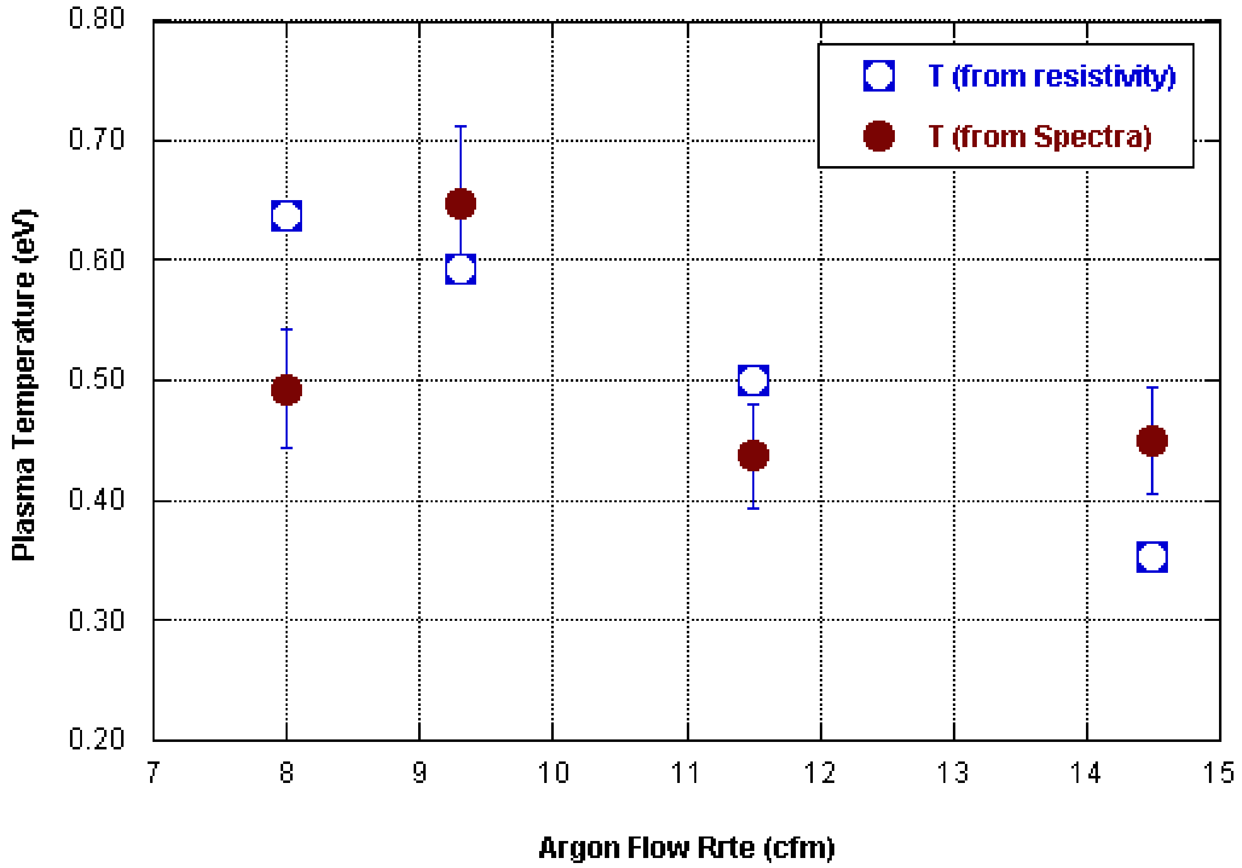

Plasma temperature for Argon torch down-bore from the nozzle (3kW at 46cm) versus gas flow rate as calculated form optical emission spectra and from the resistivity model

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ETFLOW Code Run for Plasma Torch

- **ETFLOW code is an electrothermal (ET) plasma code that can run in ablative, non-ablative and combustion regimes*, it runs in pulsed mode, however extension of pulse length is available in the code**.**

- **Code results indicates 0.4eV plasma temperature at the channel exit, which correlates to temperatures obtained from spectroscopy and from resistivity model. Exit Total number density is ~ 1.5 x $10^{24}/m^3$**

*Winfrey et al., *IEEE Trans. Plasma Science*, Vol.40, No.3, pp.843-852, 2012

**"Winfrey et al. J. *Fusion Energy*, DOI 10.1007/s10894-012-9578-5, 2012,

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Summary

- Unique, dual-channel, high-voltage single phase plasma torch was characterized
- Argon torch can operate at 3kW considerably lower than Air torch (18kW)
- Volt-Ampere characteristic indicates plasma is stable up to 10 kW, marginally stable up to 15 kW, and unstable above 15 kW.
- Minimum plasma resistance ~ 70 Ω.
- Use of a nozzle extends operating regime over a wider range of gas flow rates

- Spectral data indicates plasma temperature in the range of 0.4-0.6eV downstream, which correlates well to temperature from resistivity model (slightly nonideal).
- Initial code results showed about 0.4eV plasma temperature downstream.
- Further experiments and modeling are planned to determine torch optimized operational parameters.

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