

Preliminary Study of an Arcjet Plasma Torch for Gasification and Material Processing Applications

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Abstract: The roadmap for a preliminary study of a moderate-power (5-50 kW) arcjet plasma torch, using analytical and numerical tools, following an extensive literature review, is presented. The final aim of this study is the implementation of a prototype torch that will be characterized experimentally. Possible applications include gasification, waste disposal and material processing.

Nomenclature

c	=	vacuum light speed
E	=	electric field
k	=	thermal conductivity
r	=	radial coordinate
$R(T)$	=	rate of energy loss through electromagnetic radiation as a function of temperature
T	=	temperature
σ	=	electrical conductivity
σ_{SB}	=	Stefan-Boltzmann constant

I. Introduction

THE technology transfer from aerospace to terrestrial applications, and vice versa, has a long and fecund history, dating back to the birth of aviation at the beginning of the twentieth century. Among more recent examples,

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arcjets for space propulsion, in particular, share most of their basic physics with plasma torches for industrial, technological applications (such as gasification, waste disposal and material processing), and with devices used in high-enthalpy wind tunnels¹.

The rapid economic growth and industrial development that Brazil has been experiencing in recent years has created a demand for new, advanced technologies to satisfy the increasing energy needs. Plasma gasification, in particular, has been deemed attractive, for its capacity to process various materials, such as biomass, waste and petroleum coke efficiently and with minimum pollutant emissions, thus conforming to the increased levels of environmental awareness.

In this paper, the roadmap is presented for a preliminary study of an arcjet plasma torch. After an extensive review of the abundant literature existing on fundamentals, experimental results and practical issues of plasma torch technology¹, analytical and numerical tools will be used to reach the level of understanding of the fundamental operation processes where a preliminary design can be developed. The final aim of this study is the implementation of a prototype moderate-power (5-50 kW) cylindrical torch that will be characterized experimentally. If sufficient funding from governmental and private, industrial sources is obtained, this technology will then be developed further, to the level where it can be employed in practical applications. These could include material processing, the clean-up of the products of operational, conventional gasification plants, complete plasma gasification for energy generation and waste disposal, and various other processes.

The initial prototype could be installed on the grounds of the new PISAC (Park for the Innovation and Sustainability of the Built Environment), which will be built on the UnB (University of Brasilia) Gama Campus in collaboration with the UK BRE (Building Research Establishment).

II. Numerical Simulations: Preliminary Results

We are developing a two-dimensional, axisymmetric numerical model of the device, involving the integration of the equations for the conservation of charge, mass, momentum and energy, as well as magnetic field equations. We intend to calculate electric and thermal conductivities from statistical mechanics and to utilize for the equation of state an approximation more precise than the ideal gas equation².

A. One-Dimensional Model

As a preliminary step, we have developed a one-dimensional simulation of the discharge, using an approximation of the energy equation known as the Elenbaas-Heller equation³, but without the usual assumption of negligible radiation losses:

$$\frac{1}{r} \frac{d}{dr} \left(rk(T) \frac{dT}{dr} \right) = R(T) - \sigma(T) E^2 \quad (1)$$

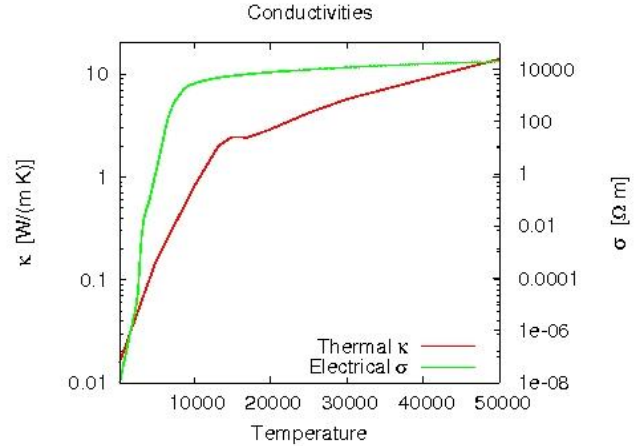


Figure 1. Thermal and electrical conductivities as a function of temperature.

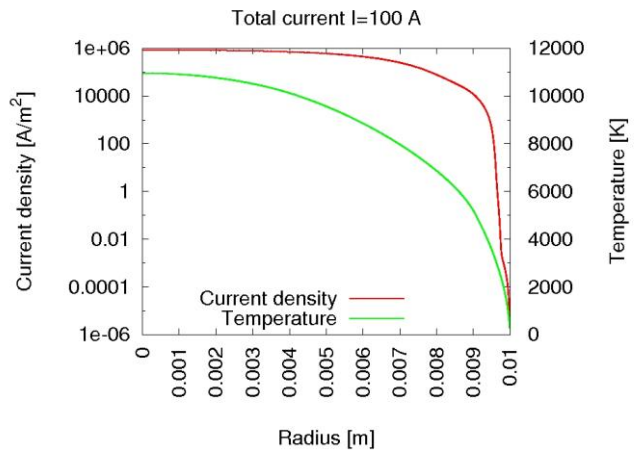


Figure 2. Temperature and current density as a function of radius.

In Eq. (1) T is the temperature, r the radial coordinate, $k(T)$ the thermal conductivity, $R(T)$ the rate of energy loss through electromagnetic radiation as a function of temperature, $\sigma(T)$ the electrical conductivity and E the electric field. This simulation models an infinite, axisymmetric tube of argon plasma. In it, we used tabulated results for argon electrical and thermal conductivities (Fig. 1) and calculated the rate of energy loss per unit volume through the electromagnetic radiation energy density:

$$R(T) = \frac{4\sigma_{SB}T^4}{c} \quad (2)$$

In Eq. (2) σ_{SB} is the Stefan-Boltzmann constant and c is the vacuum light speed. Preliminary results for the radial distributions of temperature and current density are shown in Figure 2. These results are in good qualitative agreement with typical ones for this type of discharge.

III. Conclusion

Plasma gasification has been deemed increasingly attractive, for its capacity to process various materials, such as biomass, waste and petroleum coke efficiently and with minimum pollutant emissions, thus conforming to the increased levels of environmental awareness. After a preliminary study, a plasma torch prototype will be developed and tested, in order to characterize its operation and explore possible applications.

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