MODELING OF A PLASMA TORCH USED IN TECHNOLOGICAL APPLICATIONS

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ABSTRACT

Plasma torches based on electric breakdown in gases are very useful in many technological applications as welding cutting and spraying. The main item in this type of applications is the quantity of heat produced by the electrical breakdown in the gas and delivered to a work piece. To predict this amount of heat and deduce the temperature profiles a heat model based on the equations of conservation of particles momentum and energy is made. Starting at the torch nozzle and for different initial temperatures the temperature axial profiles are found to decay very fast due to the large heat dissipation to the surrounding medium. Drawing the velocity contours of the plasma beam shows a large reduction of the beam velocity after a short axial distance away from the torch nozzle. Those results can be used to adjust the torch parameters and position in order to satisfy the heat requirements on the work piece for the different technological processes.

NOMENCLATURE

- A Cross-section area
- P_i Input power
- c_p Specific heat
- Q Radiated power
- h Heat transfer coeff.
- r Radius
- I electric current
- R Universal gas const.
- k Thermal conductivity
- r Density
- M Molecular weight
- s Elect. conductivity
- m viscosity
- T Temperature
- p Pressure
- v Velocity

1. Introduction

The plasma state [1] is a very interesting medium concerning the transfer of particles and energy. Through the plasma particles we can convert large electric power into thermal heat which can be very useful in some technological applications as welding cutting and spraying. In those applications the main device used is the plasma torch. Practically to produce a certain amount of heat on a work piecethe torch parameters are adjusted in an empirical way. A model of the heat flow and the gas velocity propagation out of the torch is very important to compute in order to optimize the torch conception and operations.

2. THERMAL PLASMA PROPERTIES AND TORCH DESCRIPTION.

By thermal plasma we mean plasma ionized gases at relatively high pressure or atmospheric pressure dominated by a high collisions rate regime[2]. The electrical power is transferred to the plasma through a high pressure arc and the electrons in the arc are heated to large values. Due to the high collisions rate between the electrons and the neutral gas molecules in the plasma those molecules can acquire energy from the electrons and the gas temperature rises to very high values. Under these conditions the plasma have very attractive properties such as high temperature ranging from 3 000 °K to 50 000 °K, and high energy density ranging from 10^6 to 10^8 J/m^3,[3].

The main types of plasma discharges used in technological applications are the arc discharge [4] the glow discharge (5) the high frequency discharge (6) and the microwave discharge (7). We will treat in this work mainly the torch based on an electrical breakdown.

The plasma will be taken as a flowing gas expanding axially from the torch nozzle in the form of a high pressure arc.

The main parts of a plasma torch as shown in Figure (1) are two electrodes cathode which is usually a tungsten rod and an anode air or water cooled which form the torch nozzle.

A gas jet usually argon is injected inside and around the torch to maintain the discharge and to protect the work piece from oxidation during the different processes.

We can distinguish between two types of torches operating on transferred and non transferred mode. In transferred mode the discharge occurs between the cathode and the anode the anode is electrically related to the work piece across a certain resistance. In non transferred mode the discharge occurs only between the two electrodes the work piece is not polarized in this case.

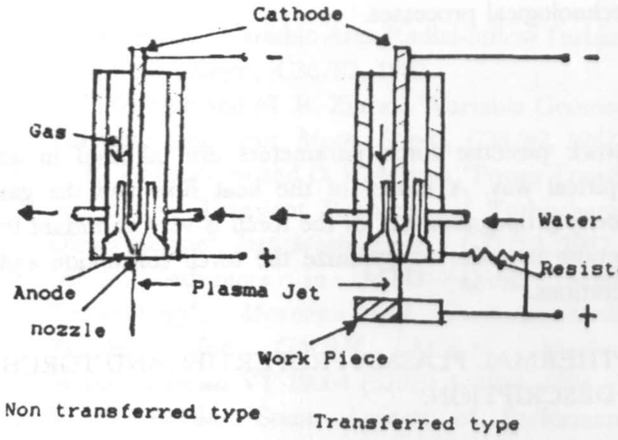

Figure 1. Sketch of a plasma torch.

3. ONE DIMENSIONAL HEAT MODEL OF THE PLASMA TORCH

The modeling of the thermal plasma and its applications in technology has acquired a large importance in the last few years [8-11]. In this work a simple model capable of predicting the one dimensional axial temperature distribution is made. The plasma is assumed to flow in the Z direction out ward of the torch as a result of the gas injection and the arc breakdown inside the torch.

At steady state the one dimension equations of conservation of mass momentum and energy are written as:

$$\frac{d}{dz}(A\rho v) = 0 \quad (1)$$

$$\frac{d}{dz}[A(p + \frac{1}{2}\rho v^2)] = 0 \quad (2)$$

$$c_p \frac{d}{dz}(A\rho v T) = \frac{d}{dz}(kA\frac{dT}{dz})$$

$$hA(T - T_s) + AP_i - AQ_r \quad (3)$$

To those three well known fundamental equations one can add the equation of state:

$$p = \rho \frac{RT}{M} \quad (4)$$

Eqs. 1-3 are solved numerically after substituting with Eq.4. In Eq. 3 the convective heat transfer coefficient h is derived from the empirical formula:

$$Nu = \frac{hD_p}{k} = 2.0 + 0.6\ Re^{1/2} Pr^{1/3} \quad (5)$$

Where D_p is the particle diameter Nu is the Nusselt number Re is the Reynolds number and Pr is the Prandtl number. The convective heat transfer occurs between the plasma temperature T and the surrounding air temperature T_s. The radiated power Q_r is calculated using the black body radiation assumption:

$$Q_r = \sigma \epsilon T^4 \quad (6)$$

Where σ is the Stefan-Boltzmann constant and ϵ is the emissivity. The input power P_i is calculated from the breakdown current I as:

$$P_i = \frac{I^2}{\sigma_{el}(\pi r^2)} \quad (7)$$

Where r is the plasma beam radius. The electric conductivity for an Argon gas is given by:

$$\sigma_{el} = 2.26\ 10^6 \exp(-\frac{6.21\ 10^4}{T})\ (\Omega m)^{-1} \quad (8)$$

Eq. 8 is valid for T < 8000 °K.

For the numerical calculations the gas used is argon with the following parameters:

Gas flow rate = 1.10^{-4} m^3 / Sec

Gas initial velocity = 120 m / Sec

Gas pressure = 1 atm

Torch nozzle = 3 10^{-3} m

The result of the calculations is shown in Figure (2). For different initial temperatures corresponding to different discharge currents the axial distribution of the gas temperature out-ward of the torch decreases very sharply.

After few centimeters all the curves tend to a certain equilibrium temperature determined by the convective cooling and the radiation to the surrounding medium the conduction term is negligible and the input power is considered only inside the torch no power is added in the plasma beam. The exact determination of the temperature gradient can help to know the position at which the work piece should be placed with respect to the torch in order to obtain a desired temperature on it for a specific use.

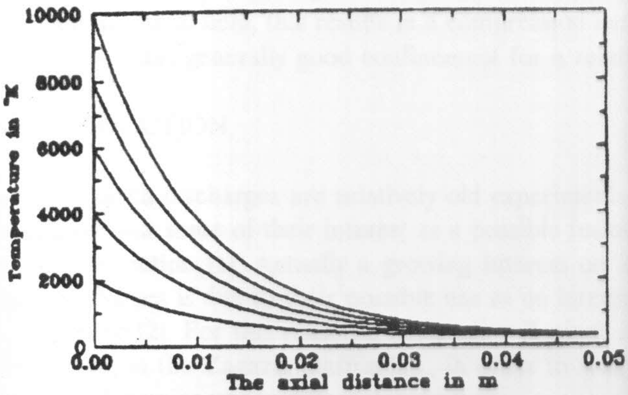

Figure 2. Axial temperature profiles, for differnt initial temperatures at the torch nozzle.

The velocity distribution along the plasma beam is a very important parameter concerning the applications of plasma torches in Figure (3) the axial distribution of the velocity is drawn for the same gas parameters cited previously. The gas expands axially out of the nozzle with decreasing velocity. The values of the temperature and velocity gradients computed in Figures (2) and (3) are comparable to some experimental measurements obtained for similar conditions [12-13].

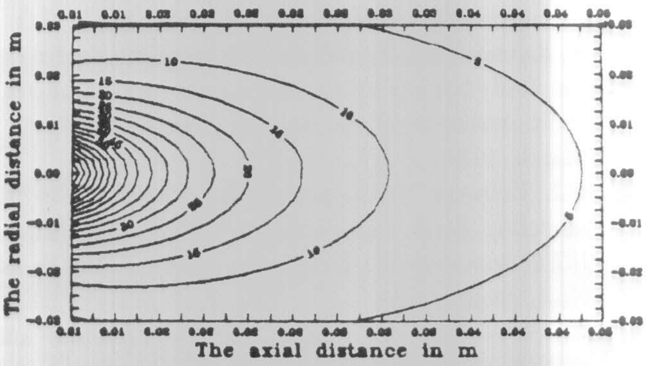

Figure 3. Axial velocity contours out-ward of a plasma torch.

4. CONCLUSION

The applications of the thermal plasma in the technology have got a large importance in the last few years due to the performances achieved by such methods over the conventional ones. An effort should be made in the future to make a self consistent model inside and outside the torch this will be very helpful in the conception of new types of plasma torches.

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