

The Use of Gas Mixtures in a DC Plasma Torch to Increase the Operating Voltage, while Maintaining Stability, and Application to an Inflight Reactor

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Abstract

Tests were carried out to measure the discharge voltage gradient in the discharge column by adding nitrogen to argon. The discharge voltage gradient is increased to 1.2 V/mm with a mixture of 7 per cent nitrogen and 93 per cent argon. Other parameters affecting the discharge voltage are considered.

1. Introduction

Thermochemical plasma processes generally use argon as the plasma gas. Argon enables easy ignition of the arc and good arc stability since its ionisation potential (15.755 eV) is smaller than other common gases, no dissociation occurs and is not expensive relative to other process costs. The voltage gradient (E) in the discharge column is however only of the order of 0.1 V/mm and is low compared with other gases and to achieve even moderate values of the order of 100 kW power input the arc current in pure argon is over 1000 A.

The high arc current results in higher capital cost of the power supply and torch, larger size of torch and cables and increases erosion of the torch electrodes. The sum of

the electrode fall voltage in an atmospheric pressure arc are around 15 V - 25 V so that the low voltage gradient in an argon arc (much less than 1 V/mm) and an arc length of less than 1 m the voltage drops in the electrode fall regions are a substantial part of the total voltage drop. This is a disadvantage in transferred arc processes such as an inflight reactor and in non-transferred arc process is a major limitation to increasing the power. For example recent tests using an inflight reactor made by Plasma Systems (SIP Andytical Ltd, Kent, UK) the arc voltage of an arc with nominal length of 1 m was only 40 V in argon of which only about 50 % - 60 % was developed in the arc column.

Initial development of the plasma torch in the late 1950's and early 60's used argon which was already used for TIG welding because of the ease with which the arc could be ignited and stabilised[1][2]. Subsequently other gases such as nitrogen, and standard gas mixtures used for electric arc welding were used for plasma fabrication processes. More recently air has replaced other gases for cutting while plasma torches used in spraying, metal melting and chemical synthesis (except the oxygen heater used for TiO₂ synthesis) use argon. No quantitative results are known for the effect of different gases on the voltage gradient in the discharge column.

2. Factors effecting the voltage gradient in the arc column

Several factors effect the voltage gradient in the arc column. These can be divided into two main groups:

- (1) Thermal;
- (2) Electronic and molecular.

Here the thermal factors are taken to be those what are governed by the design of the plasma device (nozzle dimension, gas flow rate etc.). Electronic and molecular processes are those what are associated with the inelastic collision properties of gases which may be modified by varying the gas mixtures.

The electronic processes are here considered as

- (a) excitation;
- (b) dissociation;
- (c) ionisation;
- (d) the electrochemical property (electropositive or electronegative);
- (e) and the gas transport properties.

The discharge voltage in the plasma arc gas is also influenced by the gas transport properties and specially the thermal conductivities, and gas flowrates. The effect on the discharge voltage caused by the different physical processes may be modelled by equivalent series resistances, which are equivalent to the effects of excitation and ionisation of atoms (R_{ei}) and the dissociation of molecules (R_{ds}) and heat losses other than by deionisation or deexcitation in the column (R_h) (Fig. 1); (where R_e is the corresponding resistance of the electrode voltage drops).

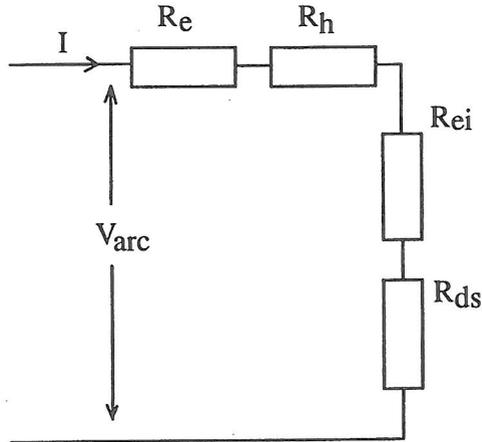


Fig. 1 Schematic diagram of the discharge voltage caused by effects of excitation, ionisation and dissociation

2.1 Ionisation and excitation potentials

Common gases used in plasma arc processes have the following first ionisation potentials given in Table 1.

Table 1 Ionisation potentials of argon, helium and nitrogen

Argon (Ar)	15.755 eV
Helium (He)	24.58 eV
Nitrogen (N)	14.53 eV

The excitation values of the gases depend on their electron configurations, ranging from a few electron volts to tens of electron volts, for example, argon has 13 eV - 13.3 eV of excitation potentials.

2.2 Thermal conductivity

The thermal conductivity of the gas affects the heat transfer from the discharge column. Cooling causes constriction of the discharge column and decreases the column diameter and increases the discharge voltage until equilibrium between power input and heat loss is achieved, but this can lead to a reduction of arc stability. It is difficult to relate variation in thermal conductivities to the voltage gradient except in a qualitative way, however it has been reported that argon with H₂ (< 15%) increased the discharge voltage due to the high thermal conductivity of hydrogen[2].

2.3 Electronegativity

The electronegativity of a gas is a measure of the ability of a molecule to attract electrons to itself. This can be used as a way of increasing the discharge voltage by limiting the number of the free electrons in a discharge by attaching them to gas molecules. This will lead to the formation of negative ions which are much heavier than the electrons and these negative ions are not accelerated to high velocity, do not significantly contribute to ionising the gas further and do not release electrons. Sulphur hexafluoride (SF₆), oxygen and the halogens are example of electronegative gases.

3. The characteristic of the discharge voltage gradient and the current

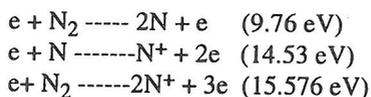
The range of gas mixtures was restricted by the need to satisfy the criteria for both a stable discharge and a high discharge voltage. The discharge length was fixed at 25 mm in the following tests. The sum of the voltage falls at the anode and the cathode was measured to be 9 V.

3.1 Argon

Fig. 2 shows the discharge voltage gradient and the discharge current in argon.

3.2. Argon - Nitrogen

Nitrogen is a molecule gas with lower density than argon. Some of the ionisation processes are



The discharge voltage and the current in the argon - nitrogen mixtures is shown in Fig. 2. The rate of the increase of the discharge voltage at high concentration of nitrogen (50 %) is not as large as low concentrations of nitrogen (7 %). This is due to the slow rate of the ionisation of nitrogen atoms and dissociation of nitrogen molecules. The discharge becomes unstable and harder to strike with further increase in the concentration of nitrogen above 50 %.

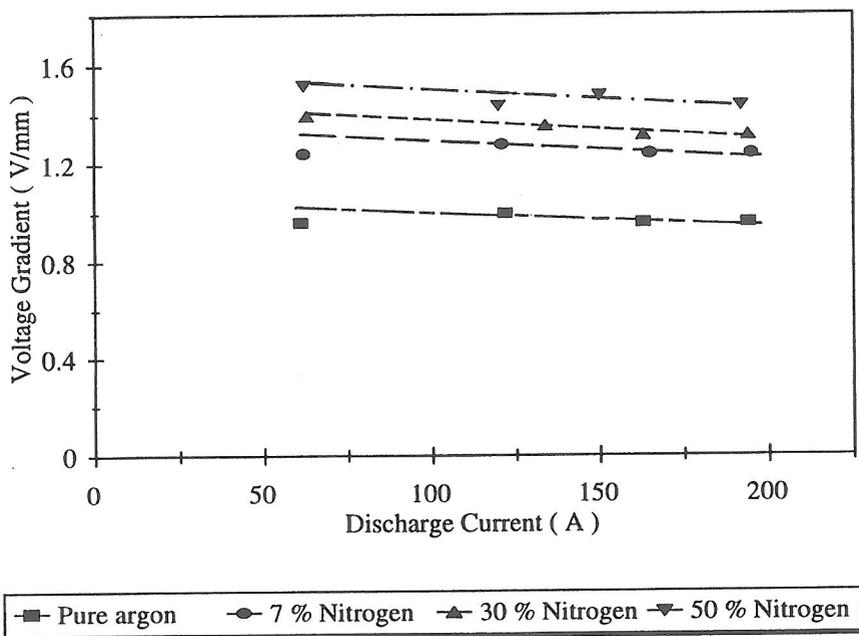


Fig. 2 The variation of the discharge voltage gradient and the discharge current in the discharge column

4. Discussion

The results show that the discharge voltage in a transferred plasma torch can be increased by adding nitrogen to argon. The discharge voltage is 8 V higher in argon with

only 7 % nitrogen and the corresponding voltage gradient is 1.2 V/mm. The optimum mixture of argon - nitrogen is about 93 per cent of argon and 7 per cent of nitrogen to maintain the stability of the arc and high discharge voltage and economy.

These results are potentially useful in high power plasma applications. Further research is in progress to investigate the effect of electronegative gases such as SF₆ and the influence of the other parameters such as thermal conductivity of the added gas.

5. Reference

- [1] M. M. Schwartz, Modern Metal Joining Techniques, p143-150, John Wiley, New York (1969)
- [2] L. Griffing, Section 3, Part B, Welding Handbook(sixth edition), p54.20, American Welding Society, New York(1971)