

INFLUENCE OF COPPER AND IRON VAPOURS ON AN ARGON TRANSFERRED ARC

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Abstract

This paper deals with the experimental and theoretical studies of the influence of copper and iron vapours on an argon plasma. Temperature and relative copper and iron concentration profiles were determined experimentally above the anode of a transferred arc burning in argon at atmospheric pressure. The working conditions were 18mm arc length, 90A current intensity and a gas flow rate at the cathode of 8 NI/mn. Then we developed a physical model of the experimental configuration. The main results were the plasma cooling caused by the presence of metal vapours. For identical conditions, the temperature profile of pure argon plasma is lower with an iron anode than with a copper anode.

INTRODUCTION

In numerous industrial applications, arc plasmas are not created in pure gases. In addition to the gas which is used to propagate the arc, a mixture of other gases and metal vapours is found. Yet, it is known that the presence of metal vapours brings about notable modification on the properties of the plasma, mainly, it raises the electrical conductivity and the radiative emission. In this work it is worth noting that depending on anode cooling conditions, we are able to obtain two very stable arc configurations corresponding near the anode to either pure argon plasma or Ar-Cu (or Ar-Fe) mixtures where copper (or iron) concentration in the mixture was stationary. This contaminated zone above the anode is of about 2 to 3mm in thickness.

I- EXPERIMENTAL STUDY

I-1 SET - UP

Details of the experimental apparatus and the spectroscopic methods we used are given in [1]. The plasma studied was generated by a transferred arc device. The cathode, with a thoriated tungsten tip was at the top. The measurements were made in the vicinity of the copper or iron anode placed at the lower end. The presence of metallic vapours arising from the erosion of the anode. The line intensities and profiles were recorded by means of a monochromator having a focal length of 1m and 1200 grooves/mm grating. At the outlet focal plane there was a 1024 intensified photodiodes array allowing analysis of radiation over the wavelength range of approximately 250nm

to $1\mu\text{m}$. The whole spectroscopic analysis was driven by a P.C. type micro-computer. The sightings being transversal, Abel's inversion is needed to access to the local values of the plasma. The calibration of emission coefficients is performed with a tungsten ribbon lamp.

I-2 METHODS FOR TEMPERATURE DETERMINATION

The emission spectroscopy methods that we developed to determine the plasma temperatures rest on the assumption of an optically thin plasma being in local thermodynamic equilibrium. In the present investigation, all the metallic lines we used were chosen because of their isolation from the neighbouring lines and their negligible self absorption. In pure argon plasma, temperatures were obtained by measuring absolute line intensities of ArI at 696.5nm and by assuming L.T.E.. In Ar-Fe mixtures, the temperature was deduced from Boltzmann's diagram by using ten neutral iron lines FeI situated at 373.48 ; 373.71 ; 375.82 ; 376.37 ; 376.71 ; 381.5 ; 382.0 ; 382.58 ; 382.78 and 383.4nm). For copper anode, temperatures in Ar-Cu mixtures were obtained by measuring the ratio between the total intensities of three lines of CuI (510.5; 515.3 and 521.8nm)[1]. Multiple measurements of the radial profiles of the arc were made in the same conditions. To increase their accuracy, statistical processing of the results was performed. The error of the spectral intensity measurements did not exceed 10% and the maximum statistical error in the temperature determination was estimated to be 5%.

I-3 DETERMINATION OF VAPOURS CONCENTRATION

By associating the temperature determination with the absolute intensity of a line of CuI or FeI, the total density of CuI or FeI atoms can be deduced from Boltzmann's law. From the equilibrium composition of the mixed Ar-Cu or Ar-Fe plasma, dependent on temperature and vapour concentration (at fixed pressure), the relative concentration of vapour in the mixture can be deduced from the value of total iron or copper densities.

I-4 RESULTS

Fig.1 gives a comparison of the measured radial temperature profiles in pure argon plasma by using a strongly cooled copper or iron anodes. These measurements were made at two positions ($z=1$ and 2mm) above the anode, for 90A current intensity, 18mm gap spacing, 8Nl/mn argon flow rate and at atmospheric pressure. This figure shows that for identical experimental conditions, the characteristics of the arc in pure argon vary with the nature of the anode.

It is interesting to point out that the use of an iron anode leads to a widening of the discharge compared to the situations using a copper one. Consequently the temperature profile of pure argon plasma is lower with an iron anode than with a copper anode. The difference between temperature profiles at $z=1\text{mm}$ is slightly greater than 1000K whereas at a position $z=2\text{mm}$, its value is about 500K. The difference between both temperature profiles at $z=1\text{mm}$ and $z=2\text{mm}$ with a copper anode is not significant whereas in the case of an iron anode the difference seems more important ($>500\text{K}$).

Within the sensitivity of our experiments, the determination of the concentration of metallic vapours is only limited to an area of 3mm in thickness near the anode. Fig.2 plots radial distribution of relative copper and iron concentrations for two values of z .

Copper vapours concentration is about 4 times greater than the one corresponding to iron whereas the lowering of the plasma temperature is almost identical in both cases as shown in Fig.3. One can mention that the influence of metal vapours becomes apparent through two mechanisms. First in the low temperature region, the electrical conductivity of the plasma is significantly enhanced in the area near the anode due to the presence of the metallic vapours which have a lower ionisation potential than argon. This leads to a widening of the arc's conducting channel and thus to a drop in its axis temperature [2] and along the whole radial profile. The second mechanism is an increase in the radiation emitted by the arc [3] causing an increase in energy loss, and also cooling the arc plasma.

II- NUMERICAL MODELLING

II-1 BASIS OF THE MODEL

A schematic representation of the considered arc configuration is given in [1]. It is composed of a transferred arc between a tungsten cathode and an anode of 5mm in thickness. The arc length is 18mm. Computations were carried out for an arc current of 90A. The mathematical formulation of the model was based on the following assumptions:

- two-dimensional flow, temperature, and concentration fields in an axisymetric system of coordinates.
- steady state, laminar flow conditions.
- local thermodynamic equilibrium (LTE).
- volumetric radiation energy loss.
- negligible gravity effects.

It was considered that the upper surface of the anode remained flat : no calculation was made on the variation in time of the anode surface and it was assumed that the amount of evaporated metal was sufficiently small to leave the geometrical conditions unchanged. Computation was carried out using the SIMPLE method of Patankar; the general equations are given in [4]. We solved the continuity, momentum, energy and iron mass conservation equations in the plasma. The metal vaporization rate across the interface was estimated by using the vapor pressure against temperature at the local anode interface. Vaporization was ignored in the region where the interface temperature was lower than the melting point. On the surface of the electrode, the temperature profile results on the interaction modelling plasma-anode taking into account through the transport properties the influence of metallic vapor by iterations. The heat flux to the anode was calculated using the conduction heat transfer, the electron-energy and subtracting the heat flux used for metal vaporisation .

II-2 RESULTS

This comparison was not established to discuss the influence of the different mechanisms on the anodic region, but to show under our hypothesis the repercussion on the plasma of the use of two materials of the anode.

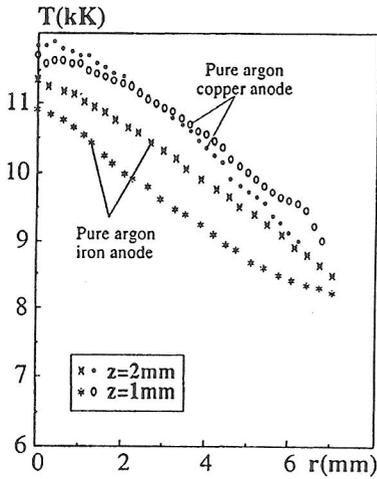


Fig. 1: Temperature profiles at $z=1$ and 2mm above the anode in pure argon

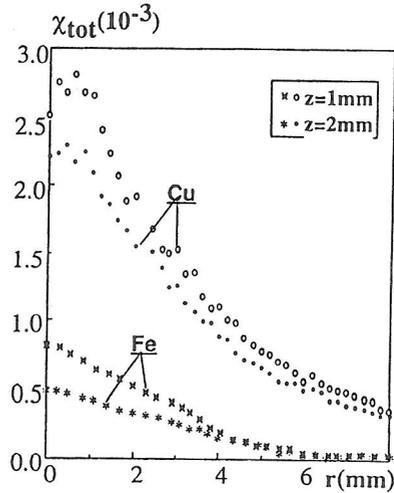


Fig. 2: Total copper and iron concentration profiles at $z=1$ and 2mm above the anode

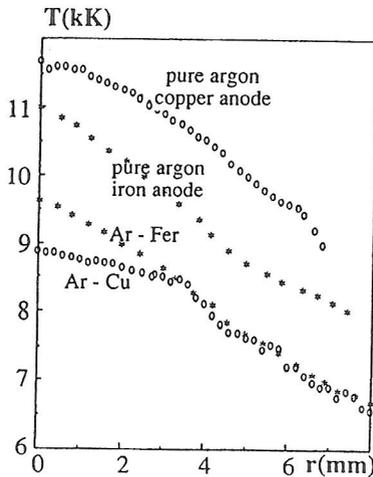


Fig. 3: Temperature profiles at $z=1\text{mm}$ in pure argon, Ar-Cu and Ar-Fe mixtures

In the first part, the boundary temperature used for the cooling of the anode on the lower part was chosen to obtain a pure argon plasma. We have plotted in Fig. 4 the temperature field corresponding to iron and copper anodes. In the core of the arc, temperatures were found to be higher with a copper than with an iron anode. Quantitatively the same establishment was observed on the experimental results with a difference of about 1000K on the temperature of the axis at $z=1\text{mm}$. Nevertheless, on the modelling, the temperature profiles using a copper anode at $z=1$ and 2mm don't converge to the same value. The temperature at $z=1\text{mm}$ is only greater for an arc radius of 2.5mm . In the anode we only solve the energy conservation equation. Thus, the difference observed on the temperature profile can be explained by the specific thermic conductivity of the two materials.

In the second part we used a value for the cooling of the anode leading to the experimental concentration values for the iron anode. The same boundaries conditions were reported on the copper anode. The temperature of the lower part of the anode is 2200K for a radius less than 1cm and 1000K for the other boundary conditions. The effect of the metal vapour was taken into account through the transport and radiative properties of the plasma. The difference between the melting and the boiling points of the two materials can justify the different vapor proportions.

In Fig. 5 the temperature profiles were obtained at $z=1\text{mm}$ for a pure argon plasma and with a slight cooling leading to the experimental concentration field of copper and iron. In pure argon, the copper anode leads to higher temperature for a radius less than 2.5mm . Then, the temperatures converge to the same values. The difference on the axis temperature given by the two materials anode is about 1000K at $z=1\text{mm}$. Contrary to the experimental observations, the temperature is higher in Ar-Cu mixtures than in Ar-Fe mixtures. At distance $z=2\text{mm}$ from the anode, the pure argon plasma presents a behaviour close to the experimental profiles at $z=1\text{mm}$ as shown in Fig. 6.

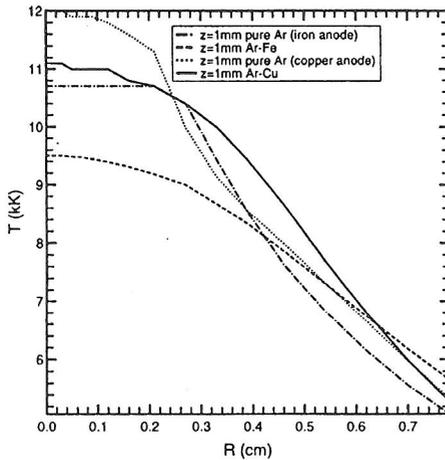


Fig. 4: Temperature profiles at $z=1\text{mm}$ above the anode

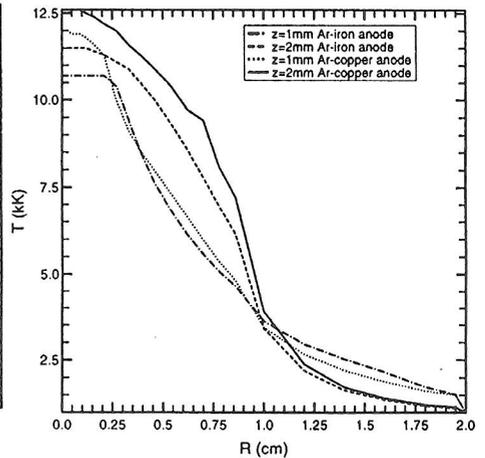


Fig. 5: Comparison iron anode-copper anode on the temperature profiles

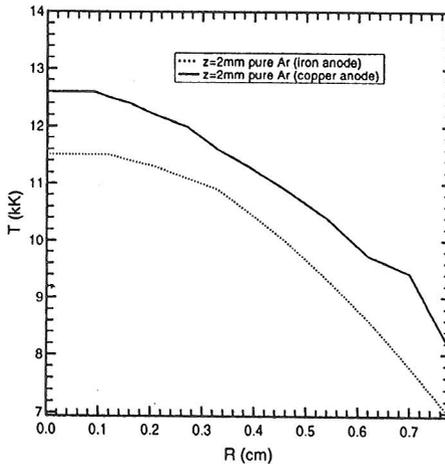


Fig. 6: Temperature profiles at $z=2\text{mm}$ in pure argon

II-3 CONCLUSION

We have coupled a modelling of a transferred arc with that of plasma-anode energy transfer. The presence of metallic vapours (copper or iron) was carried out by a boundary temperature simulating the cooling of the anode. The modelling of the interaction takes into account the vapours through the thermophysical properties. In spite of the approximations, this model allowed us to point out the importance of the nature of the anode on the arc characteristics. This quantitative comparison confirms the main experimental observation and peculiarly the fact that for identical conditions the values of temperature along the whole radial profile are higher in the copper.

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