INFLUENCE ON THE TEMPERATURE PROFILE
OF THE AMBIENT GAS PENETRATING IN A WALL-STABILISED ARC

Y. Cressault¹, S. Bruecat², H. Coitout², A. Gleizes³ and J.J. Gonzalez¹

¹C.P.A.T, UMR CNRS 5002, Université Paul Sabatier, 118 rte de Narbonne, F31062 Toulouse Cedex, France
²LAEPT, UMR CNRS 6069, Université Blaise Pascal, 24 av des Landais, F63177 Aubière Cedex, France

Abstract
A wall stabilised arc is studied by spectroscopic measurements. Two gases are used, pure Ar and Ar-CO₂ mixtures. In parallel a simplified 1D model is developed. In order to compare the theoretical temperature profiles with the experiments, different mixtures are used: Ar, Ar-CO₂, Ar-CO₂-air. The behaviour of the experimental temperature profiles allows to predict the presence of surrounding gas in the chamber. To check this hypothesis and to quantify the influence of air in the chamber, several homogeneous air mass fraction are used along the radius. After the corrections due to the presence of the oxygen gas a good agreement is found between experimental and theoretical results. Departures from thermal equilibrium can exist on the plasma edges, but this paper shows that the presence of external gas can also influence the results.

1. Introduction
Numerous models are developed in the literature to describe or to optimise plasma processes, to interpret the results or to validate the plasma properties and transport coefficients by comparison with experimental results. Concerning the last point, generally the agreement is very good on the plasma axis, but departures exist on the plasma edges. These differences are in general attributed to departures from thermal equilibrium. Nevertheless these differences can also be the consequences of pressure gradient or inhomogeneous plasma gas due to the penetration of the surrounding gas.

In order to estimate this phenomenon, a wall stabilised arc model is developed. The stabilisation is made by disks, with an inlet diameter equal to the experimental one φ=4mm. The current intensity can be equal to 30, 40 and 50A. The plasma gas mixture is defined by the user, and chosen for the comparison equal to 99% Ar and 1% CO₂.

In a first part the experimental set-up is given: arc chamber configuration, optical system and the data treatment. Spectroscopic measurements are made along the axis or the radius using the argon and oxygen lines.

Then the wall stabilised arc model basis are presented with the data bank, the assumptions, the boundary conditions and the equations. Finally the experimental and theoretical results are presented and compared.

2. Experimental details
The wall stabilised arc is obtained in a modified Maecker chamber [1] described in figure 1. This chamber is composed by 6 copper plates of 12 mm thick cooled with water separated by Bakelite which permits the electrical isolation and the tangential gas injection. The total chamber length is 85 mm. The two electrodes are in tungsten with 2% thorium. The arc chamber is at atmospheric pressure and the current intensity used for this study equal to 30A. The studied gas can be pure Ar or Ar-CO₂ mixtures. The experimental device is shown in figure 1. The study of the light emitted by the plasma is analysed by optical emission spectroscopy using a monochromator THR1500. The monochromator is equipped with a 2400lines/mm holographic grating with a linear dispersion of about 0.2nm/mm. A CDD with 512x512 photo-elements of 19x19μm each is coupled with the monochromator. In the chamber center, a 5mm thick quartz plate plane surface allows the observation of the radiation emitted by the arc, the geometry of the Bakelite isolators is the same than the quartz plate. The determination of the arc temperature is made by using the Boltzmann plot technique through the oxygen and the argon lines, the estimated error is around 500K. We use nine Ar I lines for the pure argon plasma with an energy spread of 2 eV and seventeen O I lines with an important energy spread of 5.5 eV for the Ar-CO₂ plasma. The electric field estimation is obtained by the measurements of the drop voltage

![Diagram](image)

between two electrodes changing the number of copper plates.

**Figure 1 : View of the arc chamber and the experimental set-up**

3. Modelling

We model a wall stabilised arc to compare the calculated temperature and electrical field with the experimental results. We use Patankar algorithm (finite volumes) in a one dimensional system. We present first the data bank, the main assumptions and equations used in the model.

*Transport coefficients*

For the model we need the thermal conductivity, the electrical conductivity and the net emission coefficient. The transport and thermodynamic properties of the pure gas components present in our system can be found in the literature: Ar [2], CO₂ [3], air [4]. Figure 2 presents the thermal conductivity of the Ar, CO₂ and air.
The net emission coefficient of the argon [2] or air gases [5] can be found in the literature. For the CO₂ new developments are made including the composition calculation and the net emission coefficient variation for different radius. The radiation is strongly absorbed in the first millimetres mainly due to the resonance lines. According to this fact, we use for the model the data for the plasma radius equal to 1mm. Figure 3 shows the net emission coefficient for the studied gases.

The thermal and electrical conductivity and the net emission coefficient of the mixtures are obtained by the use of the Wilke law [6].

**Assumptions**

The plasma is supposed in local thermodynamic equilibrium at atmospheric pressure. The flow is laminar in a steady state. According to the wall stabilised arc configuration, the convection terms are equal to zero. The electric field is considered constant along the radius of a given section.

**Boundary conditions**

We assume an axis of symmetry: \( \frac{\partial T}{\partial r} = 0 \)

On the domain edge the temperature is given: \( T_w = 300K \)
Equations

With the assumptions the system is reduce to the Elenbaas-Heller equation in a cylindrical system:

\[ \frac{1}{r} \frac{\partial}{\partial r} \left( r \kappa \frac{\partial T}{\partial r} \right) + \sigma E^2 - U = 0 \]  

(1)

Where \( \kappa \) is the total thermal conductivity, \( U \) the radiation losses, \( E \) the electric field, \( r \) the radius and \( T \) the temperature. Using the ohm’s law, the electric field can be written as

\[ E = E_r = \frac{I}{2\pi \sigma(T) \int r \, dr} \]  

(2)

Where \( \sigma \) and \( I \) are respectively the electrical conductivity and the current intensity.

4. Results

In this part we present the results obtained by the experimental measurements and by the model. For the model we use 200 grid points, this value corresponds to a good compromise between the precision and the calculation time. In this section two points are studied: the arc radius to compare the theoretical results with the experimental one, and the influence of air penetrating by the windows indeed oxygen lines are also observed in the pure argon plasma.

Pure Argon plasma

![Figure 4: Temperature profiles](image)

![Figure 5: Plate Bakelite isolators](image)

We present in the figure 4, the comparison between the experimental temperature profile and the theoretical one for a current intensity \( I=30A \) in a pure argon plasma. The stabilised arc radius is equal to 2mm. The temperatures found by the model are greater than the experimental values. The arc chamber configuration, plotted in figure 1, shows that between the copper plates, there are Bakelite isolators with a central hole (25mm) greater than the copper disk one (Figure 5). So the effective stabilised radius is not directly given by the copper plate, and in order to find the appropriate value we present in figure 6, the evolution of the theoretical axis temperature versus the copper plate radius for different current intensities. Reporting on the picture the experimental temperature \( T_{exp}=10200 \) K (I=30A) and \( T_{exp}=10800 \) (I=50A), the corresponding radius is respectively equal to 6.25mm and 6.75mm.
We plot in figure 7, the influence of the air on the axis temperature versus the radius, for I=30A using several mass fraction of the mixtures. If we report in figure 7, the effective radius extrapolated from figure 6 for the experimental axis temperature value, we found that only a homogeneous mixture of Ar-air allows to predict the same results.

![Figure 6: Theoretical axis temperature evolution versus the hole radius for 30A and 50A](image)

![Figure 7: Axial temperature versus the radius for different mixtures](image)

Using the extrapolated values of the effective radius and of the mixture, for the two current intensities 30A and 50A, we compare in table 1 the experimental and the theoretical results.

<table>
<thead>
<tr>
<th></th>
<th>% Air</th>
<th>$T_{exp}$ (K)</th>
<th>$E_{exp}$ (V/m)</th>
<th>$T_{model}$ (K)</th>
<th>$E_{model}$ (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30A</td>
<td>20</td>
<td>10200</td>
<td>772</td>
<td>9856</td>
<td>773</td>
</tr>
<tr>
<td>50A</td>
<td>50</td>
<td>10800</td>
<td>845</td>
<td>10631</td>
<td>838</td>
</tr>
</tbody>
</table>

Table 1: Comparison between model and experience

With the corrections, we can note that the agreement is good. Without air on the Ar plasma arc, and using the same geometrical parameters, the theoretical electric field is much lower: 339V/m (R=6.25 mm) and 294V/m (R=6.75 mm) respectively for 30A and 50A.

**Ar-CO$_2$ Mixture**

The same experimental system is now applied to Ar-CO$_2$ mixture with respectively 99% and 1%. The correlation found in the previous paragraph are used; estimated radius for I=30A is R=6.25mm and R=6.75mm if I=50A. The air quantity between the arc core and the wall
isolators does not depend on the nature of the gas, so for the comparison the same mass fraction is used: 80% of the Ar-CO$_2$ mixture and 20% of air. In our study we have assumed an homogenous mixture, but in reality if the surrounding gas influences the results it can only be present on the plasma edges. So the comparison will be also presented during the conference using an exponential law of air mixture along the radius. We present on the figure 8, a comparison between the experimental and the theoretical temperature profiles. We can note a satisfactory agreement on the temperatures and on the electric field results.

![Temperature profiles](image)

**Figure 8: Temperature profiles (experimental and theoretical, l=30A)**

5. Conclusion

An experimental study is performed on a wall stabilised arc using Ar and Ar-CO$_2$ mixtures. The temperature profiles and the electric field values are then compared with the theoretical ones. In order to obtain a good agreement the apparatus radius is calculated and gives results in agreement with the literature. The change on the radius allows to have a better agreement on the temperature profiles comparison but not on the electric field where big differences exist. The presence of oxygen lines suggests the presence of air in the medium, so the eventual air quantity is deduced from a theoretical diagram. Using the effective radius and the modification to take the air in account from homogeneous mixture or exponential law, the model gives results in agreement with the experimental results.

References