Contrib. Plasma Phys. **43**, No. 2, 73 – 77 (2003) / **DOI** 10.1002/ctpp.200310008

Study of uniformity of plasmas produced in a wall-stabilized arc

I. Książek* [1] and **E. Pawelec** [1]

[1] Plasma Division, Institute of Physics, Opole University, ul. Oleska 48, PL 45 - 052 Opole, Poland

Received 12 December 2001, revised 2 January 2003, accepted 13 January 2003
Published online 6 May 2003

Key words Arc discharge, plasma radiation, plasma temperature.
PACS 52.80.Mg,52.25.-b

In this contribution the plasma of an arc discharge in a mixture of helium and argon is studied. The gas mixture is introduced uniformly along the arc column between each of the stabilizing plates. From the measured lateral distribution of radiation (HeI, HI, ArI, ArII, NI, FI line intensity and width measurements), after Abel inversion, the radial temperature distributions were obtained at various positions of the arc column. Beside the expected radial temperature gradients, a distinct temperature gradient along the arc column was found.

1 Introduction

Wall–stabilized arcs are widely used as sources of light, emitted by excited atoms and ions. As the spectroscopic studies of this light can reveal many interesting features of those species, the wall-stabilized arc is widely used for measuring the atomic and ionic constants [1], [2], [3]. These experiments are usually performed assuming stability and homogeneity of the plasma in such a source. In plasmas containing one element only these assumptions are usually fulfilled (including in most cases also the assumption of local thermal equilibrium), but in the case of multi-element-plasmas the analysis is more difficult. This consideration is most relevant in plasmas containing a large amount of helium, because of its low mass, high ionization potential, long diffusion lengths in plasmas and the long-lived metastable states. These properties of helium result in strong demixing effects and departure from thermal equilibrium of helium-based plasmas [4], [5], [6].

In this work we analyse the spatial uniformity of the helium – argon arc, by determining the temperatures derived by different methods.

2 Experimental setup

The experiment was performed using the cascade arc consisting of eleven copper segments of 6 mm width, separated by 1.5 mm thick teflon rings (Fig. 1). The diameter of the discharge channel was 4 mm. The thoriated tungsten electrodes were attached to the boundary segments.

The mixture of argon and helium (argon of about 10% mass) was injected by 2 mm diameter inlets alongside the whole plasma channel. The arc current was 40A.

The light emitted from the plasma channel was registrated in side-on direction. The teflon spacers were slotted to allow the registration of the light between nine cascade arc segments - from the third to the tenth. The plasma was imaged onto the entrance slit of the PGS-2 spectrometer applying the spherical mirror ($f = 730\mathrm{mm}$) and registered by an Optical Multichannel Analyzer (OMA 4). The CCD matrix of the OMA was divided vertically to form 64 tracks for measuring the spatial distribution of the plasma radiation. The Abel inversion procedure was applied to derive the radial distributions of emission coefficients of the atomic and ionic lines from the measured light intensity distributions (integrated over the line of sight). The width of one track corresponded to 0.09 mm

* Corresponding author: e-mail: iksiaz@uni.opole.pl

 0863-1042/03/0205-0073 $ 17.50+.50/0

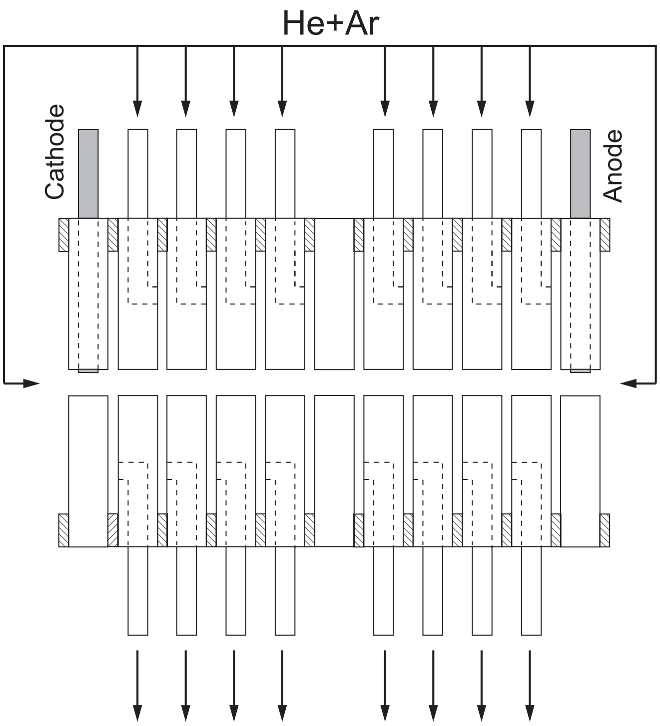


Fig. 1 Arc setup.

distance across the arc channel. The observed plasma diameter was larger than the channel of the segments (4 mm) due to the plasma expansion in the region between the copper segments.

The arc was mounted on a translation table, so it was possible to move it in the direction perpendicular to the axis of the optical set-up (Figure 2). In this way it was possible to measure the arc radiation emerging between two subsequent stabilizing segments. On the basis of our measurement a three–dimensional map of the emission coefficients of different atomic and ionic lines was obtained. The emission of the arc was registered in several spectral regions, chosen to include lines of atomic and ionic argon, atomic helium and lines expected from traces of hydrogen, nitrogen and fluorine. The impurities got into the plasma in various ways. Both the working gases (helium and argon) contained some amount of hydrogen. The fluorine originates from the heated teflon spacers [8]. Since the flow of the working gases was rather weak, nitrogen came into the discharge channel by back diffusion through the gas outlets, from the surrounding atmosphere. The most prominent lines registered during the measurements were:

Element	Spectral line wavelength [nm]	Excitation energy [eV]
Helium	I 667.815	23.07
Argon	I 696.543	13.33
Argon	I 703.025	14.84
Argon	II 686.354	19.55
Hydrogen	I 656.2 (H_α)	12.09
Nitrogen	I 744.230	11.0
Fluorine	I 685.603	14.51

The above lines were used to determine the plasma temperature applying different methods.

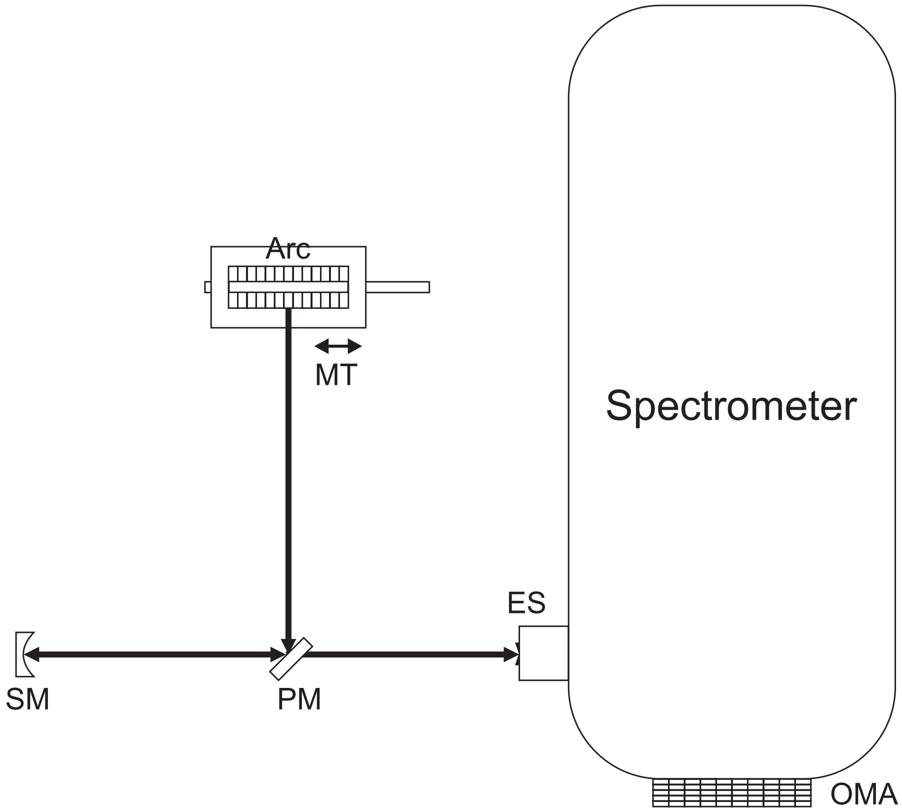


Fig. 2 Optical setup (SM – spherical mirror, PM – plane mirror, OMA – optical multichannel analyzer, ES – entrance slit of the spectrometer, MT – motion table below the arc).

3 Methods of temperature determination

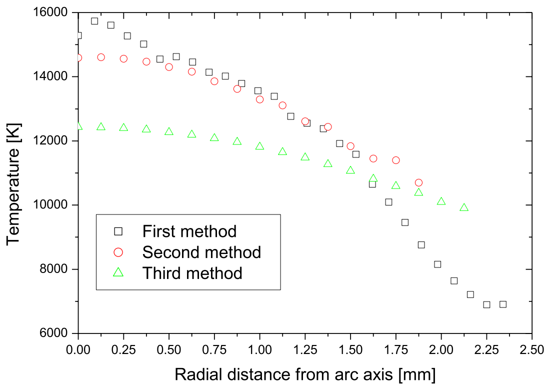
Three methods of temperature determinations were used for the plasma diagnostics.

- Boltzmann plot for the Ar I lines (696.5 and 703.0 nm),
- Saha–Eggert law and Boltzmann factors for Ar I (696.5 nm) and Ar II (two lines, 686.3 and 664.3 nm) with N_e taken from H_α broadening measurements, using the theoretical data of [9],
- solving the following set of equations with the temperature and particle densities taken as calculated parameters:
  - Boltzmann factors linking the measured emission coefficients of H I, He I, Ar I, F I and N I lines with the corresponding atomic densities
  - Saha equations for calculating the ion densities for above mentioned elements
  - quasineutrality to determine N_e from the ion densities
  - Dalton's law for all of the above mentioned species.

The first method of temperature determination is based on only one assumption - Boltzmann equilibrium for the excited argon levels. The second method include also the assumption of ionisation equilibrium between argon atoms and single ionized ions (including ground state). Electron density, used for the calculation of the Saha coefficient, is derived from the measurement of the FWHM of the H_α line. This calculation is based only on the assumption of the Maxwellian distribution of particle velocities ([9]), especially of the electrons, colliding with the hydrogen atoms. The third method is based on all above mentioned equilibria and equations for all the plasma components.

At the electron densities and the total gas pressure of our experiment, the assumption of LTE is not justified. The departure concerns mainly the ground state of the atoms, the population of whose is larger than resulting from the Saha law and Boltzmann factors. It can be described by the so-called overpopulation factor [7]. In our case the greatest overpopulation factor is associated with helium, because of the large energy gap between the ground and the first excited level and metastability of the lowest excited level. In the case of argon the overpopulation factor is expected to be about one order of magnitude smaller than in helium, so it can be neglected. Thus we consider, that the temperatures derived from first two methods, should be more reliable than the result of the third method, where the helium lines were used for diagnostic purposes.

As it can be seen in Fig 3. the temperature derived from first and second method give nearly the same results. For the second method the Saha-Eggert factors were calculated twice, pairing the Ar I line with both the ionic lines, but the differences between the results were negligible, so only one of those results is presented here. The third method gives definitely different results. In this figure, the radial distributions of temperature in the intersegment space near the middle of the arc are shown. The radial distributions suggest, that the "LTE" temperature is probably not describing the plasma parameters very well (especially in the off-axis regions), but the comparison between it and the excitation/ionization temperature derived from Boltzmann and Saha equations shows, that close to the arc axis the same trend and in most plasma regions also similar gradients (Figure 3 - right) are observed.



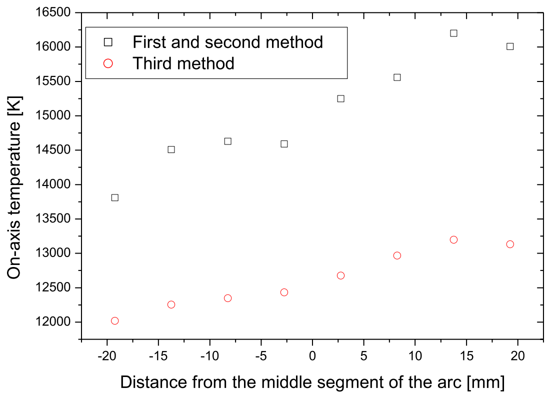


Fig. 3 Comparison between temperature values obtained from different diagnostic techniques, left – radial temperature distributions, right – axial distributions.

In Figure 4 the full contour map of the temperature distribution is given, with the contour step of 500K, to show the regions of higher and lower temperature gradients.

4 Results of the analysis

Figure 5 shows the radial and axial temperature distributions with the superimposed 5% uncertainty. It can be seen, that the plasma is radially homogenous for a cylinder of a 1 mm diameter, centered on the plasma axis. Along the axis the discrepancies are larger – the difference between the temperatures on the opposite ends of the axis is of the order of 10%.

The above shown results suggest, that the radial temperature distribution is (as assumed) "flat" in the region around the arc axis. They show also, that the discrepancies in the plasma parameters along the plasma channel cannot be neglected in the case of a helium-based arc. Those inhomogeneities have to be taken into account in the case of measurements performed in the end–on geometry.

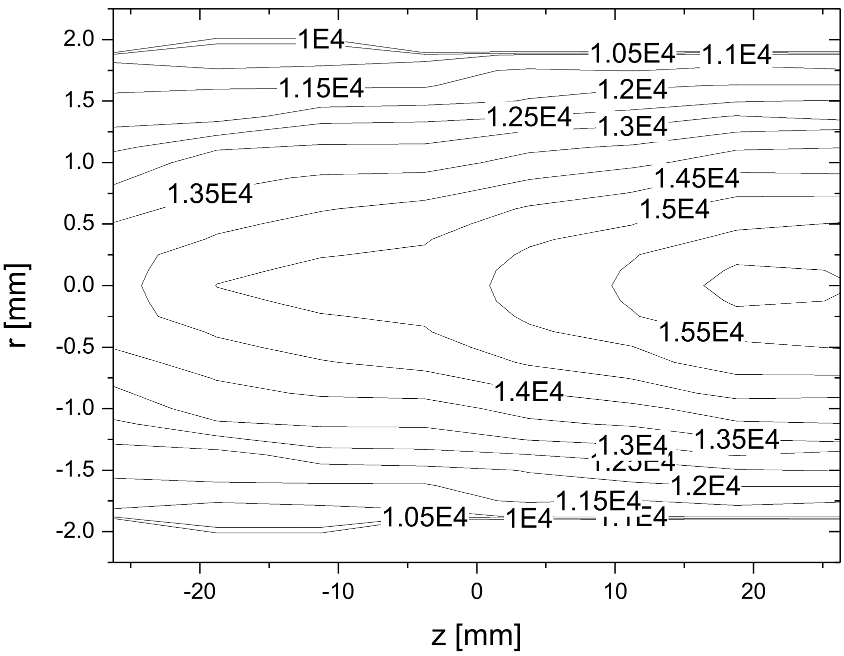


Fig. 4 Temperature distribution - contour map

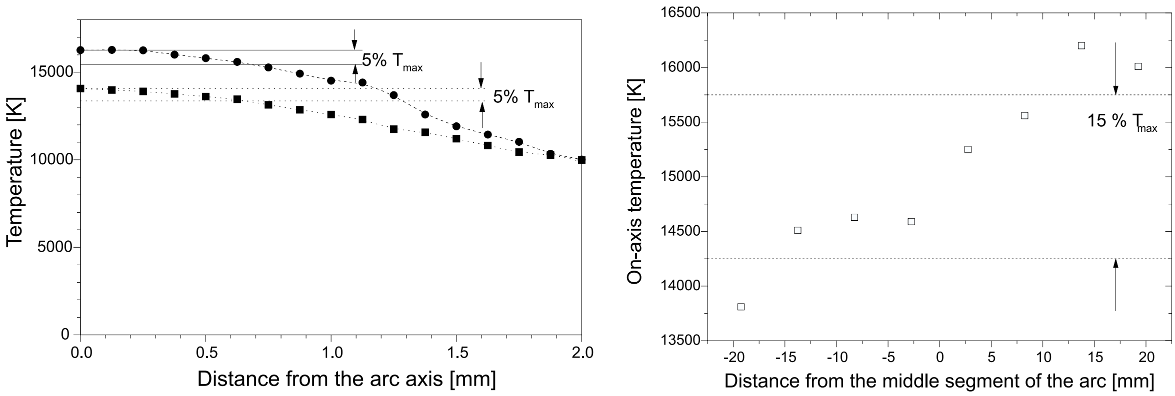


Fig. 5 Temperature distributions with the "homogenous" regions marked, left – radial temperature distributions for two different arc regions, right – axial distribution.

References

[1] J. Musielok, W.L. Wiese, G. Veres, Phys. Rev. **A 51**, 3588 (1995).
[2] V. Helbig, K.-P. Nick, J. Phys. **B 14**, 3573 (1981).
[3] A.T.M. Wilbers, G.M.W. Kroesen, C.J. Timmermans, J. Quant. Spectrosc. Radiat. Transf. **45**, 1 (1991).
[4] A.B. Murphy, Phys. Rev. **E 55**, 7473 (1997).
[5] J. Uhlenbush, E. Fisher, J. Hackmann, Z. Phys. **238**, 404 (1970).
[6] J. Uhlenbush, E. Fisher, Proc. IEEE **59**, 578.
[7] J.A.M. van der Mullen , Physics Reports **191** Numbers 2 & 3, 110 (1990).
[8] J. Musielok, E. Pawelec, U. Griesman, W.L. Wiese, Phys. Rev. **A 60**, 947 (1999).
[9] W. Olchawa, PhD Thesis (Opole – Toruń 1997).