EFFECTIVE DISSOCIATION TEMPERATURE FOR ESTIMATION OF ELECTRIC ARC PLASMA COMPOSITION

I.L. Babich, V.F. Boretskij, A.N. Veklich
Taras Schevchenko National University of Kiev, Radio Physics Faculty, Kiev, Ukraine
E-mail: boretskij@univ.kiev.ua

Spectroscopy investigations of the thermal multicomponent plasma of the electric arc discharge between copper electrodes in carbon dioxide flow were carried out. The technique of calculation of plasma equilibrium composition is discussed. The influence of thermal dissociation of molecular gas on the plasma state is estimated. It was assumed that the thermal dissociation of molecules of working gas play the key role in deviation from local thermodynamic equilibrium (LTE) in plasma.
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1. INTRODUCTION

A large amount of arc plasma investigation has been carried out. This is caused by wide application of electric arc discharges in different shielding gases or their mixtures in numerous industrial processes. Therefore it is important to perform investigations to have full understanding of physical processes in discharge plasma, at the electrode surface and their interaction as well as influence of environment.

In our previous investigations [1] we found that in some experimental modes the plasma state is not in local thermal equilibrium (LTE). It was shown that hydrodynamic cooling does not effect on the deviation from LTE in monoatomic. It was supposed that this effect has no influence on state of molecule gas plasma too. Therefore, it was assumed that only the thermal dissociation plays the key role in deviation from LTE. Naturally, partial LTE model must be used to describe plasma properties in such case.

The main aim of this study is an estimation of plasma composition under assumption of two temperature behavior based on experimentally obtained plasma temperature, electron density and metal content.

2. EXPERIMENTAL INVESTIGATIONS

The electric arc was ignited between copper non-cooled electrodes in a working gas flow of 6.45 slpm. The diameter of the rod electrodes was of 6 mm. All experimental investigations were carried out in average cross section of discharge gap of 8 mm at arc currents 3.5, 30, 50 and 100 A.

Monochromator coupled with CCD linear image sensor (B/W) Sony ILX526A [2] were used in investigations of spatial distribution of spectral line emission. The control of the CCD linear image sensor was realized by the IBM personal computer. The radial temperature profiles T(r) were determined by Boltzmann plot method using CuI spectral lines 427.5, 465.1, 510.5, 515.3, 521.8, 570.0, 578.2, 793.3 and 809.3 nm.

To determine the radial profile of electron density we investigated the shape of copper spectral lines 515.3 and 448.0 nm broadened by the dominating quadratic Stark effect. The measurements were carried out by techniques based on a Fabri-Perot interferometer (FPI) [3]. Unfortunately the width of these spectral lines at arc current 3.5 A is practically comparable with instrument function of FPI. Therefore, to extend the measuring range of the electron density we studied the radial distribution of absolute intensity of a spectral line CuI 465.1 nm [2].

Copper atom concentration was obtained by linear laser absorption spectroscopy technique [4].

3. RESULTS AND DISCUSSIONS

According to the previous results [1] the electric discharge plasma in CO_2 flow can be in LTE at arc current 3.5 A but not at arc current 30 A. To check these results we additionally carefully examined spectroscopic data, which were used in temperature and electron density determination.

Radial profiles of plasma temperature T(r) at different arc currents are shown in Fig. 1. We used spectroscopic data based on critical review in [5]. Distributions of electron density $N_e(r)$ obtained from the width of spectral line CuI 448.0 nm for different experimental modes are shown in Fig. 2. Shapes of spectral line CuI 515.3 nm were omitted because of influence of self-absorption.

The values of T(r) and $N_e(r)$ were used in calculation of plasma compositions (Fig. 3) by approach discussed in [1].

Copper atom concentrations in plasma obtained by optical emission spectroscopy (OES) as well as by linear laser absorption spectroscopy (LAS) techniques at arc current 3.5 A are showed in Fig. 4. As one can see the results are in good agreement which can be an additional confirmation of the assumption of the plasma state in this experimental mode.

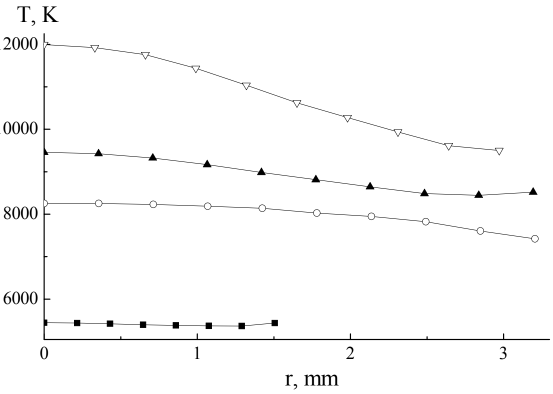

Fig. 1. Radial profiles of plasma temperature at arc currents: ■ – 3.5, ○ – 30, ▲ – 50 and ▽ –100 A

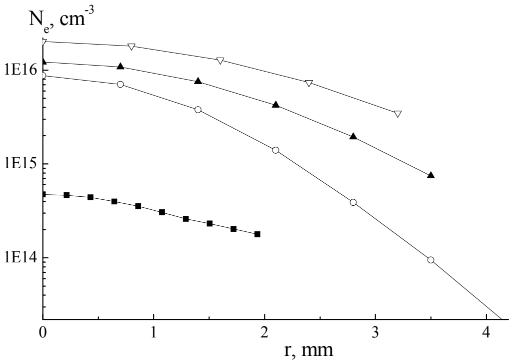

Fig. 2. Radial profiles of electron density at arc currents: ■ – 3.5, ○ – 30, ▲ – 50 and ▽ –100 A

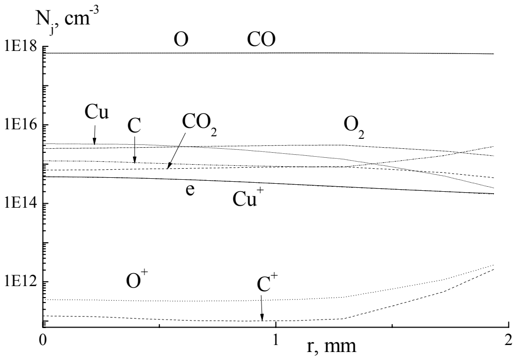

Fig. 3. Plasma composition at arc current 3.5 A

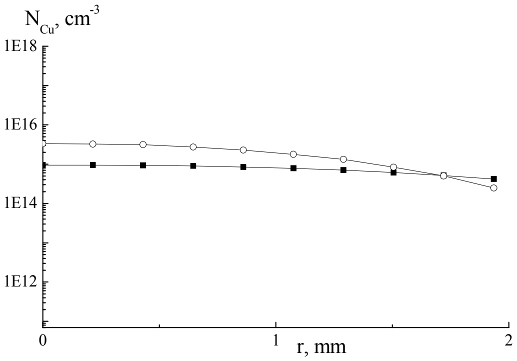

Fig. 4. Radial profiles of N_{Cu} obtained by LAS (■) and OES (○) techniques at arc current 3.5 A

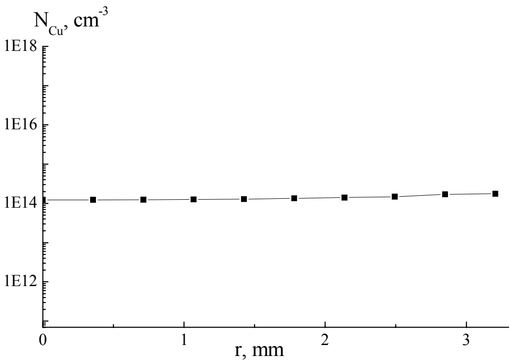

Fig. 5. Radial profiles of N_{Cu} obtained by LAS technique at arc current 30 A

Unfortunately, LTE in arc plasma at discharge current 30…100 A was not realized. Radial distribution of copper atom concentrations in plasma at arc current 30 A was obtained only by linear laser absorption spectroscopy technique (Fig. 5).

In paper [1] was assumed that the thermal dissociation play the key role in deviation from LTE in CO_2 plasma at arc current 30 A. Peculiarities of CO_2 dissociation were studied theoretically in [6]. Author showed that at temperatures kT > 0.05 D (D - dissociation energy) dissociation rate constant significantly lower than its equilibrium value. Dissociation rate constant can be estimated from the calculation of plasma composition based on experimental values of plasma temperature, electron density and copper atom concentration. In this case we assumed dissociation rate constant to be an unknown value.

In our previous papers [1, 7] two different schemes of dissociation processes were discussed. One of them is next:

$$CO_2 \Leftrightarrow C + 2O. \qquad (1)$$

The result of our calculation showed that the value of dissociation rate constant of the reaction (1) at axial point of the average cross section of the discharge is lgK ≈ 23. Equilibrium value of the dissociation rate constant for this reaction can be found in [8] where the maximum value of lgK is 6.7 for T = 10000 K. Extrapolation of lgK to obtained in our calculation value 23 leads to temperatures much higher than 10000 K. Therefore, one can conclude that reaction (1) cannot be used to interpret dissociation processes.

The second scheme of dissociation that we used previously is:

$$CO_2 \Leftrightarrow CO + ½O_2, \qquad (2)$$

$$CO \Leftrightarrow C + O, \qquad (3)$$

$$O_2 \Leftrightarrow 2O. \qquad (4)$$

Two of these reactions (2-3) can be responsible for deviation from LTE in plasma. The third of them (4) can be assumed equilibrium because of quite low relaxation time of dissociation [9].

Further analysis was divided into three approaches:
1. calculation of dissociation rate constant for reaction (2), reaction (3) was assumed equilibrium;
2. calculation of dissociation rate constant for reaction (3), reaction (2) was assumed equilibrium;
3. calculation of effective dissociation temperature which is the same for both non-equilibrium reactions (2-3).

The calculated dissociation rate constants were compared with their equilibrium values to estimate effective dissociation temperatures (Fig. 6).

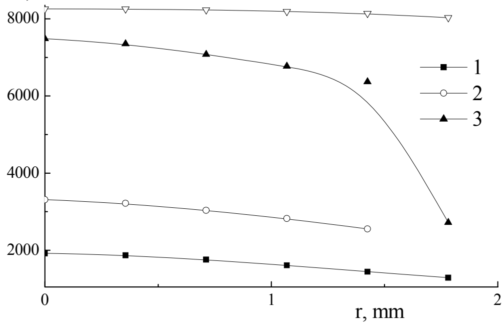

Fig. 6. Plasma temperature (▽) and effective dissociation temperatures obtained by different approaches

Concentration of CO_2 and CO molecules calculated by approaches 1-3 are shown in Fig. 7, 8. The results of the approaches 1-2 lead to very extreme difference between temperatures (see Fig. 6). Approach 3 gives more plausible values of effective dissociation temperatures and CO_2 and CO concentration. Therefore, one can conclude that dissociation of both reactions (2-3) is not equilibrium.

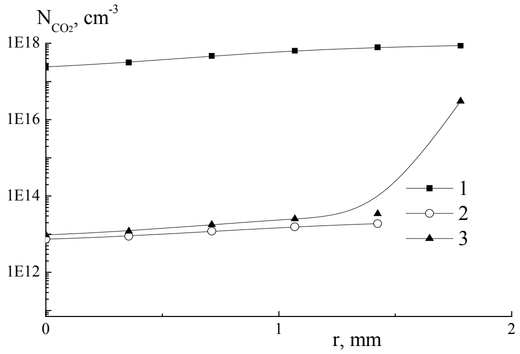

Fig. 7. CO_2 concentration obtained by different approaches

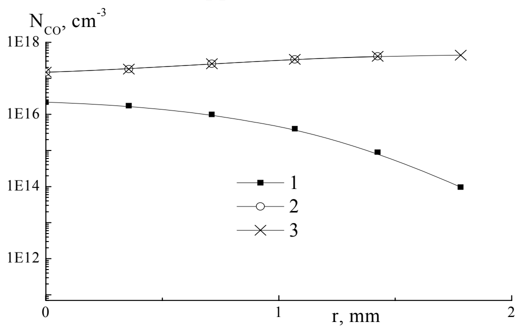

Fig. 8. CO concentration obtained by different approaches

CONCLUSIONS

The assumptions of plasma state were confirmed using approved set of spectroscopic data. It was shown that reaction where carbon dioxide molecule dissociates into atoms of oxygen and carbon cannot be used to interpret dissociation processes. It was found that dissociation of both reactions (2-3) is not equilibrium.

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ЭФФЕКТИВНАЯ ТЕМПЕРАТУРА ДИССОЦИАЦИИ В РАСЧЕТАХ СОСТАВА ПЛАЗМЫ ЭЛЕКТРОДУГОВОГО РАЗРЯДА

И.Л. Бабич, В.Ф. Борецкий, А.Н. Веклич

Спектроскопическими методами исследована термическая многокомпонентная плазма электродугового разряда между медными электродами в потоке углекислого газа. Обсуждается методика расчета равновесного состава плазмы. Оценено влияние термической диссоциации молекулярного газа на состояние плазмы. Предполагается, что термическая диссоциация молекул рабочего газа является основным механизмом отклонения от локального термодинамического равновесия в плазме.

ЕФЕКТИВНА ТЕМПЕРАТУРА ДИСОЦІАЦІЇ В РОЗРАХУНКАХ СКЛАДУ ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ

І.Л. Бабіч, В.В. Борецький А.М. Веклич

Спектроскопічними методами досліджено термічну багатокомпонентну плазму електродугового розряду між мідними електродами у потоці вуглекислого газу. Обговорюється методика розрахунку рівноважного складу плазми. Оцінено вплив термічної дисоціації молекулярного газу на стан плазми. Припускається, що термічна дисоціація молекул робочого газу є основним механізмом відхилення від локальної термодинамічної рівноваги в плазмі.