THERMAL DISSOCIATION IN THERMAL PLASMA OF ELECTRIC ARC DISCHARGES IN AIR AND CARBON DIOXIDE

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Abstract

This paper deals with the spectroscopy investigation of the thermal multicomponent plasma of the free-burning electric arc in copper vapour by fast scanning techniques. The main attention is paid to the analysis of previously obtained experimental results. The condition of plasma of arc discharge between copper electrodes in air and carbon dioxide flow is widely discussed. The basic physical mechanism responsible for some realization of plasma condition in the varied modes of arc operation is suggested.

1. Introduction

The free-burning electric arcs between evaporated metal electrodes have a wide industrial application. Characteristic of such arcs is determining influence of electrode vapour on properties of arc plasma. The complex composition of the discharge plasma is caused by the plasmaformed gas mixture and metal vapour as well.

The pulsing properties in ms temporal scale due to chaos change of arc position on electrodes makes the investigation of electric arc plasma more difficult.

2. Experimental Set-up

The arc was ignited between the end surfaces of the non-cooled copper electrodes. The diameter of the rod electrodes was of 6 mm. To avoid the metal droplets appearing a pulsing mode was used: the current pulse up to 100 A was put on the "duty" weak-current discharge. The pulse interval ranged up to 30 ms. The quasi-steady mode was investigated.

Because of the discharge spatial and temporal instability the method of the single tomographic recording of the spectral line emission was used. Fast scanning of spatial distributions of radiation intensity was accomplished by an image dissector tube of electrostatic type. It allows carrying out the recording of radial distributions of nonstationary arc radiation intensity in arbitrary spatial sections simultaneously [1-4].

3. Results and Discussions

The influence of ambient gas on the radial distribution of arc plasma parameters was studied. In this case the arc discharge in the air as well as in CO2 was investigated. In the last
case copper electrodes in air atmosphere were flowed by the tangent stream of carbon dioxide. The flow of CO₂ was 1.6*10⁻⁴ kg/s.

As a spectroscopy element the copper was used, which injects into a discharge gap as a result of electrodes’ erosion.

The radial profile of temperature T(r) was determined from the ratio of local emission coefficients of spectral lines CuI 510.5 and 521.8 nm. The radial profile of electron density Nₑ(r) was calculated from the experimentally obtained appropriate distribution of the intensity of the spectral line CuI 465.1 nm [1,4].

The radial profiles T(r) and Nₑ(r) determined in the average cross section of the discharge gap lₐk = 4 and 8 mm in carbon dioxide flow and air at the discharge current 3.5, 30, 50 and 100 A are given in [5]. Obtained profiles T(r) and Nₑ(r) allow calculating radial profiles of plasma components in the assumption of the local thermodynamic equilibrium (LTE).

Let us consider initial prerequisites in case of carbon dioxide plasma.

With increasing temperature molecules of carbon dioxide dissociate: 2CO₂ ↔ C₂ + 2O₂. As dissociation energies of molecules O₂ (5.1 eV) and C₂ (6.2 eV) are rather low it is possible to assume that atoms and ions of oxygen and carbon would be present in plasma under considered conditions. The ionization potential of molecules CO₂ is reasonable (13.79 eV). The amount of such molecules is insignificant as the dissociation degree of carbon dioxide at temperature value 6000 K equals 0.986 [7]. Consequently, the amount of ions CO₂⁺ would be negligible. Thus we can consider that there are following particles in plasma: Cu, Cu⁺, C, C⁺, O, O⁺, CO₂ and electrons. Our assumption is confirmed by results of paper [8]. In the arc discharge in carbon dioxide gas in the wide temperature range authors observed spectral lines of atoms and ions C and O only. The paper [9] deals with investigations of Ar-10%CO₂ plasma. It was shown that Ar, C, O, C⁺, O⁺ and electrons are observed in plasma in the wide pressure range at temperatures above 7000 K. The presence of other particles as well as ion CO₂⁺ can be neglected.

The calculation used experimentally measured temperature and electron density profiles was carried out. It was obtained that the LTE can be realized in CO₂ plasma for both discharge gaps at the arc current 100 A only [6].

In Fig 1-2 examples of radial profiles of plasma components at the arc current 30 and 100 A are had shown. The deviation from LTE is observed in the axial plasma region at the discharge current 30 A (see Fig 1).

In a similar manner the composition calculation of air-copper plasma was carried out. Atoms and ions Cu, N, neutral and ionized molecules of nitrogen and electrons were taken into account.

In Fig 3-4 examples of radial profiles of air-copper plasma components at the arc current 30 and 100 A are shown.

It was established by additionally experimental techniques that the LTE is realized in plasma of free-burning arc in air at discharge currents 3.5 and 30 A and lₐk = 8 mm [10]. Probably equilibrium exists in the case of arc plasma at 3.5, 30 and 50 A, lₐk = 4 mm [5]. The LTE can not be realized in the axial plasma region of free-burning arc in air at discharge currents 50 and 100 A and lₐk = 8 mm as well as at discharge current 100 A and lₐk = 4 mm (for example, see Fig 4).

Thus, it is visible from the analysis of obtained results, that in dissimilar gases the equilibrium state of plasma can be realized at different currents, i.e. at different energy deposition. It is possible to speak about varied probable mechanisms of the deviation from LTE at different parameters of plasma. One of the main reasons of a nonequilibrium state of
arc discharge, on our view, is the thermal dissociation of working gas molecules [11]. The equilibrium state in this case is realized under operating of two opposite mechanisms. The VT-exchange is the first of these mechanisms. It seeks to recover the balance. The second one is the process of dissociation. It leads to the deviation from LTE. When the times of these processes become comparable there is a nonequilibrium state in plasma. In [11] the lower limit of temperatures for a diatomic molecule is determined, when the deviation from LTE start to be essential:

$$kT \sim (0.05 - 0.06) \, D,$$

where $D$ is dissociation energy. For polyatomic molecules this limit is even lower.

![Graph](image)

Fig 1.

In our case working gas is carbon dioxide (dissociation energy of a molecule is 7.56 eV) or nitrogen (accordingly, 9.76 eV). As the dissociation energies differ more, than on 2 eV, the nonequilibrium is necessary to expect in investigated gases at different energy deposition. It should be earlier realized at presence in plasma of molecules with smaller dissociation energy (CO$_2$ in our case). This effect must be occurred first of all in the high temperature axial region of the arc plasma.

The calculation results of equilibrium plasma composition, based on experimentally obtained radial profiles of temperature and the electron density, confirm the offered mechanisms of the deviation from LTE. In carbon dioxide plasma the deviation from equilibrium is realized already at currents 30 and 50 A. And in atmosphere of air the deviation from equilibrium is realized at large energy deposition (current 50 and 100 A).

The probable realization of equilibrium in carbon dioxide plasma at a current 100 A can be possible explained by full dissociation of CO$_2$ molecule.
Fig 2.

Cu d = 6 mm, $l_{ak} = 8$ mm, $l = 100$ A, CO$_2$

Fig 3.

Cu d = 6 mm, $l_{ak} = 8$ mm, $l = 30$ A, air
4. Conclusions

The analysis of the obtained results of investigation of the thermal multicomponent plasma of the free-burning electric arc between copper electrodes in air and carbon dioxide has allowed to offer the probable mechanisms of the deviation from the local thermodynamic equilibrium. The comparison of plasma characteristics of studied arcs allows assuming, that such mechanism is the thermal dissociation of molecules of working gas.

References