SPECTROSCOPIC OBSERVATION OF DIATOMIC MOLECULES IN PLASMAS GENERATED BY NON-TRANSFERRED ELECTRIC ARCS

A. MAŠLÁNI AND V. SEMBER

Institute of Plasma Physics v.v.i., Za Slovankou 3, 18200 Prague, Czech Republic
maslani@ipp.cas.cz

ABSTRACT

Two different arc plasma torches are used for production of thermal plasma jets. Emission spectra reveal presence of atomic and ionic species as well as different molecules in plasma. Temperatures obtained from molecular spectra agree well with atomic and ionic temperatures, with the exception of OH radical. It seems that excited OH molecules are formed and distributed different way than other molecules and OH rotational temperature cannot be used for evaluation of kinetic temperature in the jet axis.

1. INTRODUCTION

Plasmas produced by electric arc torches are often fully dissociated with high degree of ionization, at least in the central parts of arc columns. However, in the outer parts of arcs and in the freely expanding recombining jets, various molecules can be formed. In this work we study two different arc plasma torches by optical emission spectroscopy. First one is so-called hybrid water-argon plasma torch [1], second one is the torch operated with air as a plasma gas. Both these torches are applied mainly for plasma spraying and gasification of biomass. For these applications, the recombining free jets containing various reactive species are very important.

Hybrid water-argon torch is characterized by high input power about 100 kW. Resulting centerline temperature can be then higher than 20 000 K. Thus, produced thermal plasma contains mainly atoms, ions and electrons; only in high enough distances from the arc column, the molecules can be formed in reasonable amount.

The air torch has power almost comparable with hybrid torch; however the plasma jet is not constricted by narrow nozzle. Then also centerline temperature is much lower and molecules are observed in larger region.

This work is devoted to study of emission spectra of diatomic molecules in plasmas produced by these torches. Previously we measured spectra of OH in hybrid water-argon plasma jet located in low pressure [2, 3]; in such conditions discrete spectra of individual species are more intensive and better resolved than for atmospheric pressure operation, which is the case of this study.

2. EXPERIMENTAL SETUP

Schematic view of the hybrid water-argon torch is shown in Fig. 1. The arc is stabilized by the argon in the cathode region and by the water vortex surrounding substantial part of the arc column. The arc current at present experiment is 400 A (arc power about 110 kW) and the argon flow rate is 22 slm. Water supply system contains high amount of water, from which only small part evaporates to plasma. It is thus difficult to determine how much water goes to the arc; estimations based also on the arc modelling give values of water evaporation rate about 0.3 $g.s^{-1}$. Disc-shaped anode with thickness 20 mm, manufactured from copper, is rotating with high velocity in order to assure uniform erosion and is cooled by water. The anode is located outside of the arc chamber 2 mm from the nozzle exit in horizontal direction. The nozzle connecting arc chamber with surrounding environment has diameter 6 mm. From this description and from Fig.1 it is evident that we are able to observe not only free expanding jet, but also part of the arc between nozzle and anode.

The scheme of the air torch shows Fig. 2. This relatively simple torch is supposed to be used mainly for waste treatment and gasification of biomass. In comparison with hybrid water-argon torch, the exit nozzle is quite wide, with diameter 20 mm. Moreover, the arc itself is inside the torch body; therefore we can observe only the free jet produced by it. In this experiment, arc current 170 A is used, which gives arc power about 65 kW.

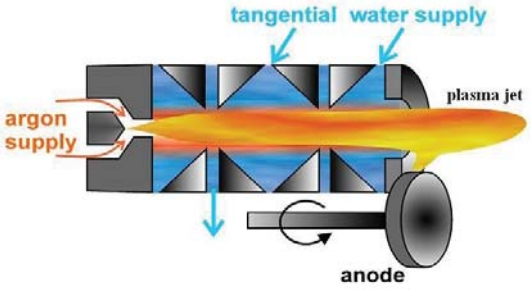

Fig. 1 Schematic view of the hybrid water-argon torch

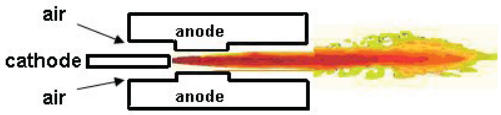

Fig. 2 Schematic view of the air torch

3. SPECTROSCOPIC MEASUREMENT

Optical emission spectroscopy measurements of diatomic molecules in the plasma jet generated by the hybrid water-argon torch reveal mainly the OH radical. In atmospheric pressure, effect of strong entrainment of ambient air into the jet causes appearance of spectrum of NH molecule. However, we do not observe other molecules containing nitrogen, namely N_2, N_2^+ or NO. Fig. 3 shows example of NH spectrum measured in this plasma jet.

In the air torch, we were able to detect molecules N_2^+ and NO, which come naturally from the air. In addition, also molecules OH and CN were observed. These molecules are apparent, in spite of probably small amount of hydrogen and carbon in air. This observation is however similar to other air plasmas, for example microwave plasma torch, where spectrum of CN is reported as a result of impurities [4]. We can suppose that main source of carbon in air is carbon dioxide. Similarly, in case of OH, spectrum probably comes from the small amount of water in air. Figs. 4 and 5 show typical molecular spectra from this plasma. Both OH and CN spectra are relatively intensive, in spite their limited quantity in plasma.

Mentioned molecular spectra are measured in different parts of the plasma jets. Such a way, distribution of molecules in the regions decisive for applications can be inferred. Depending on molecule, rotational or vibrational temperatures defined by the spectra are determined. The procedure is based on comparison of experimental and simulated spectra in programs Lifbase [5] and Specair [6]. As the radial profiles of observed emission spectral intensities of atomic and ionic lines are mostly characterized by cylindrical symmetry, it is possible to apply Abel inversion and obtain local values of emission coefficients. On the other hand, for the spectra of molecules the symmetry is usually violated or completely destroyed. Therefore the molecular emissions as well as values of temperatures obtained from them are line of sight integrated and cannot be considered as the local values in given positions. We must take into account this restriction when interpreting results from molecules.

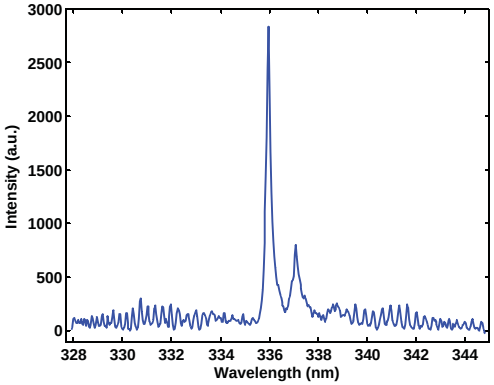

Fig. 3 Typical emission spectrum of NH (A-X) from hybrid water-argon torch

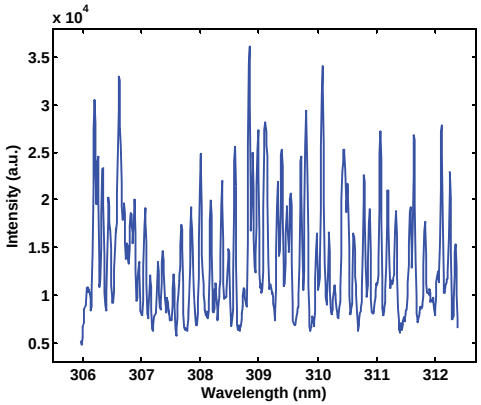

Fig. 4 Spectrum of OH (A-X) from the air torch

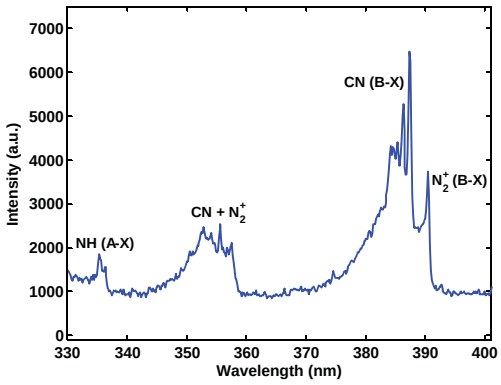

Fig. 5 Spectra of molecules in air torch. Except CN and N_2^+, also NH (A-X) can be observed, but its intensity is lower than in hybrid torch

4. RESULTS AND DISCUSSION

Temperatures obtained from different molecules in both plasma jets are summarized in Figs. 6 and 7. We present here values corresponding to the axis of the plasma jets, which is defined as the position in the radial profile where the radiation intensity has maximum. Molecules are measured also in other axial distances, not presented here; however, in cases which are shown, the signal to noise ratio and thus the accuracy of the obtained temperatures is relatively high.

Fig. 6 shows axial profile of temperatures in water-argon plasma jet. Except data from molecules OH and NH, also temperature from hydrogen atomic line H_β and argon ionic lines is included for comparison. The procedure is based on pre-calculated equilibrium composition of water-argon plasma, which gives theoretical emission coefficients of individual lines. Comparing with experimental data the temperature is obtained. Molecules are observed in colder regions of the plasma jet, NH from 40 mm and OH from 80 mm downstream. For NH, vibrational temperature defined by bands 0-0 and 1-1 can be estimated as these bands are clearly resolved and are located close to each other. However, at the temperatures exceeding 10 000 K accuracy of temperature from molecules cannot be as high as for lower temperatures. Anyway it seems that NH vibrational temperature approximately fits temperature from H_β and ArII and extends axial profile down to 100 mm. As for the OH, the most suitable and accurate is the rotational temperature obtained from band 0-0.

Axial profile of temperatures in air torch is presented in Fig. 7. We have here again rotational temperature from OH 0-0 band, which is accompanied by vibrational temperature from several CN bands and rotational temperature of N_2^+ 0-0 band. In addition, erosion of anode causes presence of copper atoms in plasma; their emission lines are used for evaluation of excitation temperature.

Few remarks can be added to presented axial profiles. In case of both torches we have relatively well defined temperatures from atoms and ions, which should correspond to kinetic temperature of thermal plasmas in the axis of the plasma jets. Moreover, Abel inversion is possible to perform in order to obtain local values of emission coefficients and temperatures. As for temperatures from molecules, we can distinguish two cases: firstly, NH, N_2^+ and CN give temperatures which seem to be in good agreement with temperatures from atoms and ions. Second case is the rotational temperature of OH, which is substantially lower than other temperatures. In addition, this temperature is more or less constant along the axial profile, about 4 000 K for water-argon jet and about 3 500 K for air jet. This observation can be interpreted from the point of view of way of formation of different species. While NH, N_2^+ and CN are probably formed and thermalized in the central part of plasma jet, OH can be produced dominantly in the outer parts of the jets from the available water molecules. Indeed, production of OH from water or from H_2O^+ and H_3O^+ is the most important mechanism in atmospheric pressure plasmas [7]. This explanation is supported by the fact that similar behaviour is observed for air jet as well as for water-argon jet.

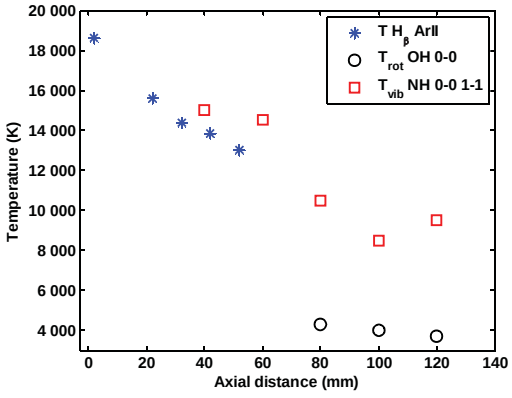

Fig. 6 Axial profiles of temperatures for water-argon plasma jet

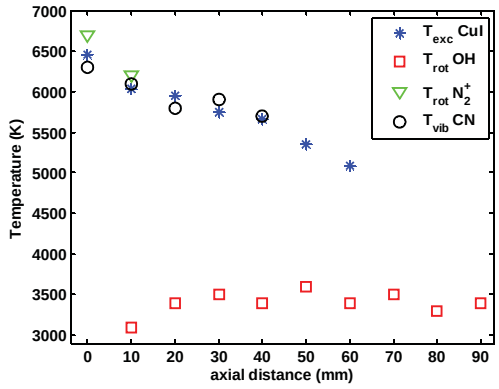

Fig. 7 Axial profiles of temperatures for air plasma jet

5. CONCLUSION

Various molecules are observed in recombining plasma jets produced by high power arc plasma torches. Rotational temperatures of OH radical have similar profiles for both plasma jets with substantially different plasma composition. However, these temperatures apparently do not represent kinetic temperatures in the axis of the jet, which are obtained from atoms, ions and other molecules.

Acknowledgement

This work was supported by the PPP project between National Science Council (NSC) of Taiwan and Academy of Sciences of the Czech Republic (AS CR) with the title "Modeling and Diagnostics of Non-Equilibrium Thermal Plasma Flow"

REFERENCES

[1] M. Hrabovský, V. Kopecký, V. Sember, T. Kavka, O. Chumak and M. Konrád, Properties of Hybrid Water/Gas DC Arc Plasma Torch, IEEE Transactions on Plasma Science, Vol. 34, no. 4, 1566-1575, 2006.

[2] A. Mašláni and V. Sember, Rotational distribution of OH molecules in supersonic thermal plasma jet, Journal of High Temperature Material Processes, Vol. 13, issue 2, p. 205 – 215, 2009

[3] A. Mašláni and V. Sember, Measurement of OH emission spectra in water-argon thermal plasma generated by the DC plasma torch, Proceedings of 31st ICPIG, July 14-19, Granada, Spain, 2013

[4] Z. Machala, M. Janda, K. Hensel, I. Jedlovský, L. Leštinská, V. Foltin, V. Martišovitš and M. Morvová, Emission spectroscopy of atmospheric pressure plasmas for bio-medical and environmental applications, Journal of Molecular Spectroscopy, **243**, 194-201, 2007.

[5] J. Luque and D. R. Crosley, *LIFBASE: Database and Spectral Simulation*, Program (Version 1.5), SRI International Report MP 99-009, 1999

[6] C. Laux, *Radiation and Nonequilibrium Collisional-Radiative Models*, von Karman Institute Lecture Series 2002-07, Physico-Chemical Modeling of High Enthalpy and Plasma Flows, eds. D. Fletcher, J.-M. Charbonnier, G.S.R. Sarma, and T. Magin, Rhode-Saint-Genèse, Belgium, 2002

[7] P. Bruggeman and D. C. Schram, On OH production in water containing atmospheric pressure plasmas, Plasma Sources Sci. Technol. **19**, 045025, 2010