EXPERIMENTAL STUDY OF AN ELECTRICAL DISCHARGE AT ATMOSPHERIC PRESSURE

S. CHUON[1] and N. CERQUEIRA[1*]

[1] GREMI UMR 7344 CNRS, Orleans University, Rue Gaston Berger, 18028 Bourges, France
* nuno.cerqueira@univ-orleans.fr

ABSTRACT

This paper presents an experimental study of the electrical and thermal characteristics of an electric discharge in an Ar/CO_2 mixture by employing optical emission spectroscopy and voltage measurements. The surrounding gas temperature is measured using thermocouples.

1. INTRODUCTION

In a gas system between two electrodes, an application of an electric field can cause an electric discharge [1]. Electric discharge between two vertically electrodes occurs at a well-defined, gas-dependent combination of atmospheric pressure and the distance between those electrodes, as described by Paschen's law [2].

In this experiment, we perform a simple investigation on the electrical and thermal characteristics of a mixture of argon and carbon dioxide molecules between two vertical tungsten electrodes of distance d between them.

2. EXPERIMENTAL SET-UP

The experimental setup is a closed chamber with cylindrical geometry. We present here measurements in a cylindrical chamber (inner height: 210 mm, inner diameter: 42 mm) (see Figure 1).

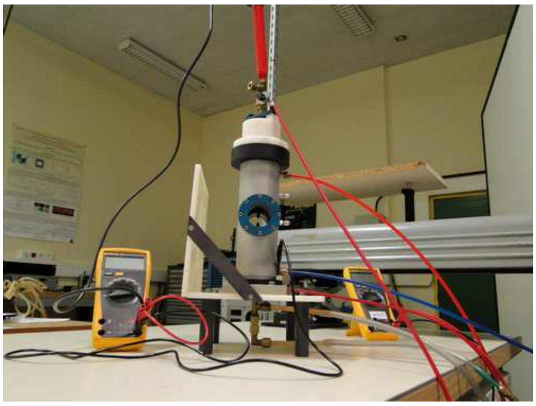

Fig. 1 Image of the experimental setup

Electrical power is delivered by a DC high voltage (10 kV) with a current intensity of 100 mA. Two optical windows on opposite sides allow us to observe the electrical discharge in the chamber (see Figure 2).

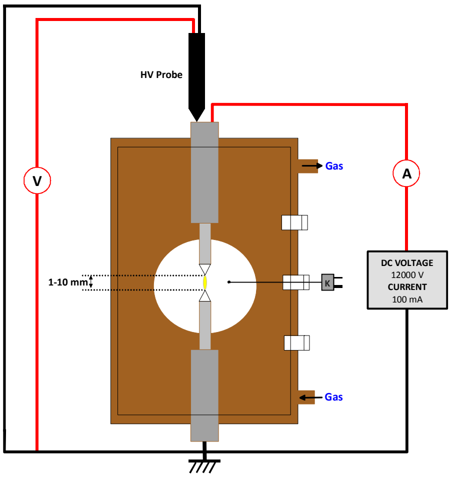

Fig. 2 Schematic diagram of experimental system

The arc burns between two vertical tungsten electrodes put in the cylindrical chamber filled with an argon/carbon dioxide mixture at atmospheric pressure [3] (see Figure 3).

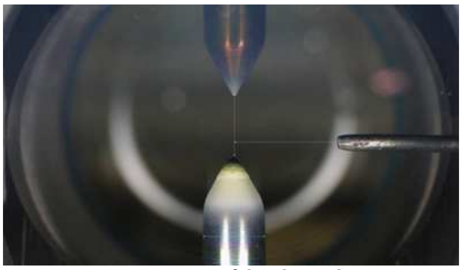

Fig. 3 Image of the electrodes

The electrical discharge is characterized by its intense emission (see Figure 4).

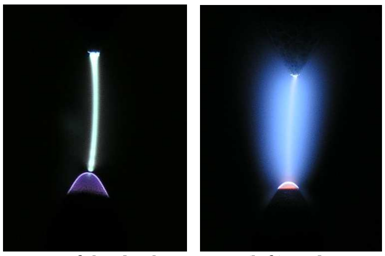

Fig. 4 Images of the discharges: Ar(left) and Ar/CO_2(right)

The distance between the two electrodes can be adjusted by displacement of the top electrode.

Before each experiment the electrodes are mechanically polished and chemically cleaned.

3. PLASMA CHEMICAL COMPOSITION

The system chosen for the study is a gaseous mixture of Ar and CO_2 [4]. We assume, in a first approach, the plasma as an ideal gases mixture at thermodynamic equilibrium with an aim of simplifying the calculation.

The equilibrium composition is calculated with the software ALEX [5], using the free enthalpy minimization method under the constraints of masse conservation and electric neutrality. If temperature and pressure are maintained constant, thermodynamic equilibrium is attained when the total Gibbs free energy is at its minimum.

In the Ar – CO_2 plasmas studied (CO_2 content from 0 to 50%) the major chemical reactions observed are (see Figure 5):

- (i) dissociation of CO_2 into CO,
- (ii) dissociation of O_2,
- (iii) dissociation of CO,
- (iv) ionization of Ar and C.

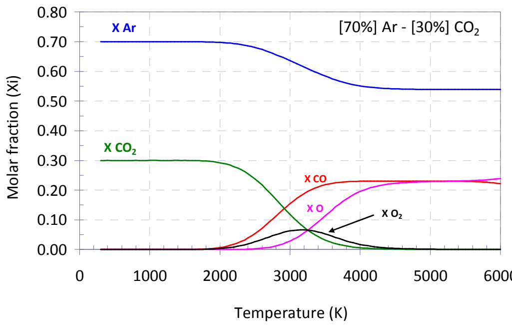

Fig. 5 Evolution of the mole fractions versus temperature

Dissociation of CO_2 in CO and O_2 is observed around 2900 K. Dissociation of O_2 begins around 3100 K.

4. EXPERIMENTAL RESULTS

In this section we present results from measurements of voltage and temperature obtained for different Ar/CO_2 gas mixtures with 2,5 L/min flow rate of gases.

The distance between the two electrodes is 5 mm and a thermocouple is put 12 mm from the axis of the electrical discharge. A high voltage probe was used for voltage measurements.

The arc current was fixed at 118 mA.

Figure 6 to 10 shows the voltage curves and temperature curves versus time.

For a gas mixture containing 6% CO_2 (see Figure 6) the mean voltage of the discharge is around 475 V and the thermocouple temperature vary from 21 to 56 °C.

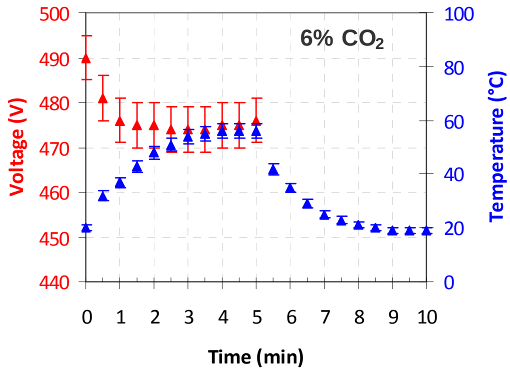

Fig. 6 Evolution of voltage and temperature versus time (6% CO_2)

For a gas mixture containing 17% CO_2 (see Figure 7) the mean voltage of the discharge is around 557 V and the thermocouple temperature vary from 17 to 51 °C.

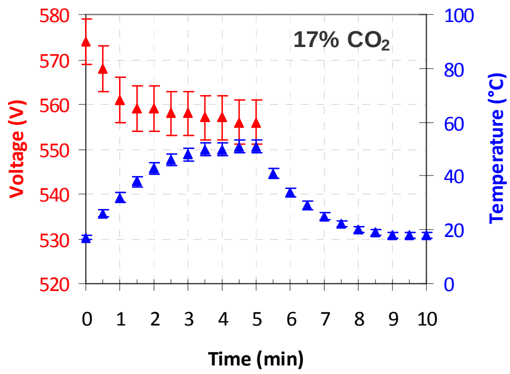

Fig. 7 Evolution of voltage and temperature versus time (17% CO_2)

For a gas mixture containing 30% CO_2 (see Figure 8) the mean voltage of the discharge is around 605 V and the thermocouple temperature vary from 19 to 52 °C.

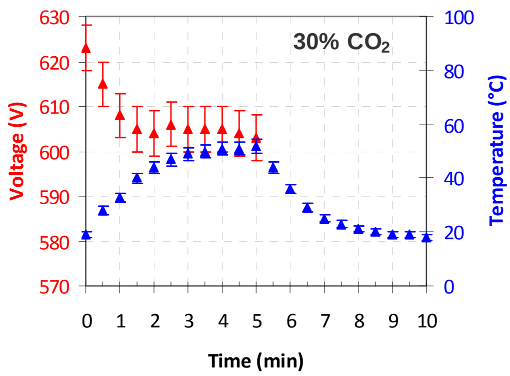

Fig. 8 Evolution of voltage and temperature versus time (30% CO_2)

For a gas mixture containing 41% CO_2 (see Figure 9) the mean voltage of the discharge is around 680 V and the thermocouple temperature vary from 20 to 59 °C.

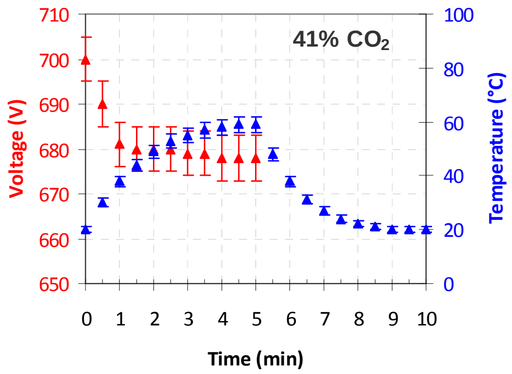

Fig. 9 Evolution of voltage and temperature versus time (41% CO_2)

For a gas mixture containing 51% CO_2 (see Figure 9) the mean voltage of the discharge is around 750 V and the thermocouple temperature vary from 20 to 67 °C.

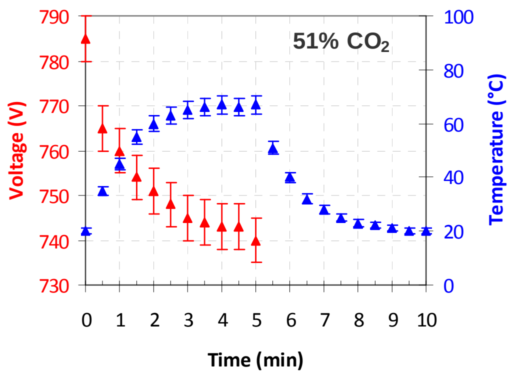

Fig. 10 Evolution of voltage and temperature versus time (51% CO_2)

5. OPTICAL EMISSION SPECTROSCOPY

Molecular spectra can be used in temperature measurements when atomic spectra are not strong enough to give significant information.

The UV OH band spectra [6] and the spectrums of the Swan band of C_2 have been used to measure the gas temperatures in the range of 2000-8000 K.

The spectroscopic diagnostic of the electrical discharge was made at atmospheric pressure using the experimental set-up shown in Figure 11.

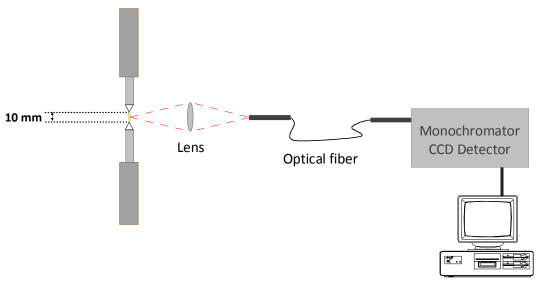

Fig. 11 Experimental set-up for spectroscopic diagnostic

The experimental spectrums of the Swan band of C_2 molecule have been recorded for different gas mixtures.

Emission intensities of C_2 Swan system steeply dropped with the increase of carbon dioxide gas addition.

Rotational temperatures have been determined by comparison between experimental and calculated spectra.

This method is described in [7].

For a gas mixture containing 0% CO_2 (see Figure 12) the rotational temperature obtained is around 2300 ± 500 K.

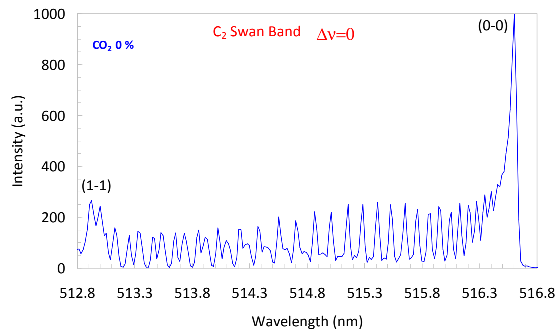

Fig. 12 Experimental spectra of C_2 Swan band (0 % CO_2)

For a gas mixture containing 5% CO_2 (see Figure 13) the rotational temperature obtained is around 4500 ± 500 K.

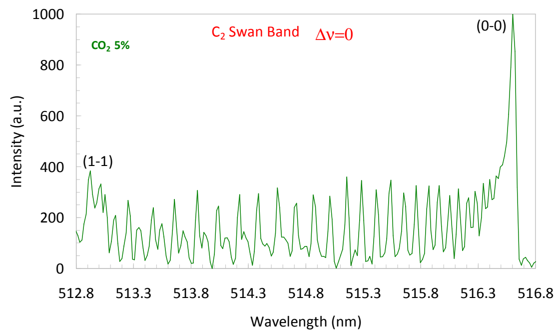

Fig. 13 Experimental spectra of C_2 Swan band (5 % CO_2)

For a gas mixture containing 10% CO_2 (see Figure 14) the rotational temperature obtained is around 3500 ± 500 K.

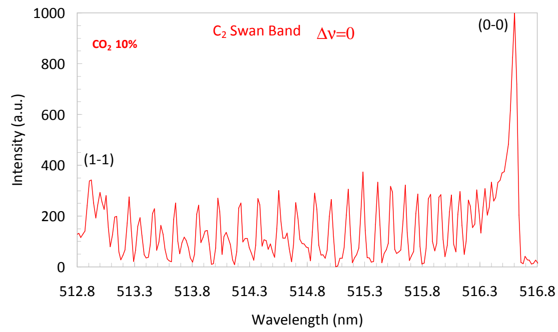

Fig. 14 Experimental spectra of C_2 Swan band (10 % CO_2)

The emission of OH band has been also used to measure the gas temperature (see Figure 15 to 17). Two peaks in the UV OH band (G_0 and G_1) can be used to calculate the gas temperature after normalizing with the reference peak near 309 nm (G_{ref}).

The ratios of G_0/G_{ref} and G_1/G_{ref} are shown to be sensitive to the gas temperature.

This method is described in [8].

For a gas mixture containing 0% CO_2 (see Figure 15) the rotational temperature obtained with the UV OH band is around 2275 ± 200 K.

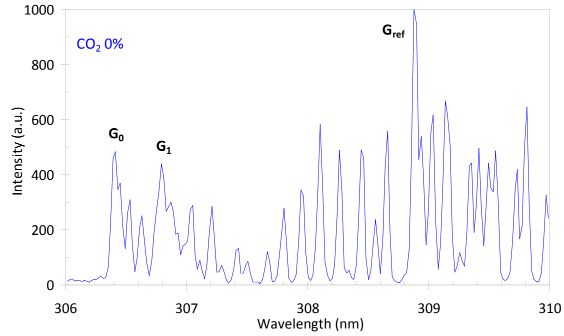

Fig. 15 Experimental emission spectrum of OH band (0 % CO_2)

For a gas mixture containing 5% CO_2 (see Figure 16) the rotational temperature obtained with the UV OH band is around 3025 ± 200 K.

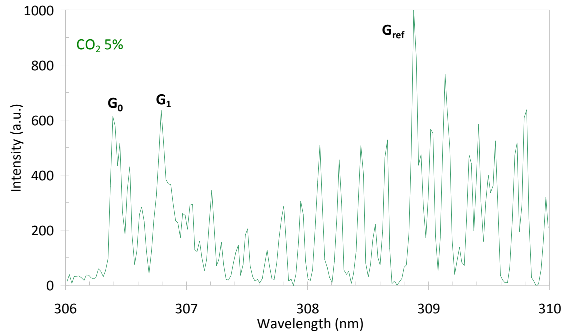

Fig. 16 Experimental emission spectrum of OH band (5 % CO_2)

For a gas mixture containing 10% CO_2 (see Figure 17) the rotational temperature obtained with the UV OH band is around 3075 ± 200 K

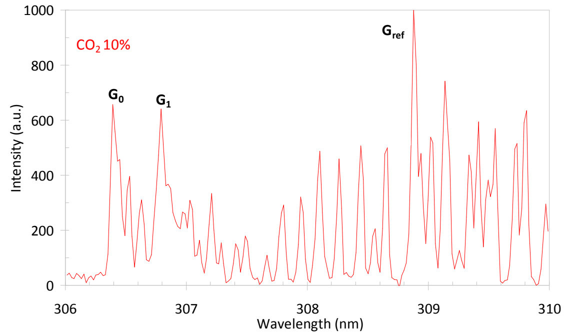

Fig. 17 Experimental emission spectrum of OH band (10 % CO_2)

6. CONCLUSION

We investigated the influence of CO_2 concentration in Ar / CO_2 electrical arc discharge by usage of a combination of optical emission spectroscopy and electrical characterization.

The emissions spectra of OH band and C_2 Swan band have been used to measure the gas temperature in the plasma.

The results obtained by OH spectrum and C_2 spectrum are in good agreement.

REFERENCES

[1] N. St J Braithwaite, “Introduction to gas discharges”, Plasma Sources Science and Technology, vol **9**, pp 517-527, 2000.

[2] C. Torres, P. G. Reyes, F. Castillo and H. Martinez, “Paschen law for argon glow discharge”, Journal of Physics: Conference Series, vol **370**, 2012

[3] N. Cerqueira, K. Kesseng and C. de Izarra, “Temperatures in an Ar-CO_2 arc plasma”, High Temperatures Material Processes, vol **12**, n°1, pp 81-90, 2008.

[4] Nishimura Y. and Takenouchi T., “Decomposition of carbon dioxide in an induction-coupled argon plasma jet” Industrial and Engineering Chemistry Fundamentals, vol. **15**, n° 4, pp 266-269, 1976.

[5] Sanon A. and Baronnet J.M., “Modélisation des propriétés thermodynamiques et des coefficients de transport des plasmas thermiques” Code de calcul ALEX, Les plasmas dans l'industrie (collection Electra, Dopee), 1991.

[6] G.H. Dieke and H.M. Crosswhite, “The ultraviolet bands of OH”, Journal of Quantitative Spectroscopy and Radiative Transfer, vol **2**, pp 97-199, 1961.

[7] S. Pellerin, K. Musiol, O. Motret, B. Pokrzywka and J. Chapelle, “Application of the (0,0) Swan Band spectrum for temperature measurements”, Journal of Physics D: Applied Physics, vol **29**, n°11, pp 2850-2865, 1996.

[8] C. de Izarra, “UV OH spectrum used as a molecular pyrometer”, Journal of Physics D: Applied Physics, vol. **33**, pp 1697-1704, 2000.