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# OVERVIEW ON STUDIES OF MARTIAN LIKE CO<sub>2</sub>-N<sub>2</sub> MIXTURE BY INDUCTIVELY COUPLED PLASMA TORCH

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## ABSTRACT

The purpose of the work is to make an overview on the results obtained through the studies on martian plasmas created by inductively coupled plasma torches (ICP). As the main advantage of the ICP torch is the absence of electrode compared to the others various test facilities, the radiative properties of this kind of plasmas are of interest to propose test cases in order to validate radiation models. ICP torches can work under various operating conditions in terms of pressure, enthalpy or flow. As a consequence, the studied plasma can be either at thermodynamical equilibrium or out of equilibrium, without problems of stability in time. The presentation concerns only the plasmas formed with a martian like CO<sub>2</sub>-N<sub>2</sub> mixture and all the parameters of test facilities will be precised.

The following paper corresponds to the first step of a global paper which will be proposed later and it reports only the oral presentation which has been done during the third International Workshop of RHTG.

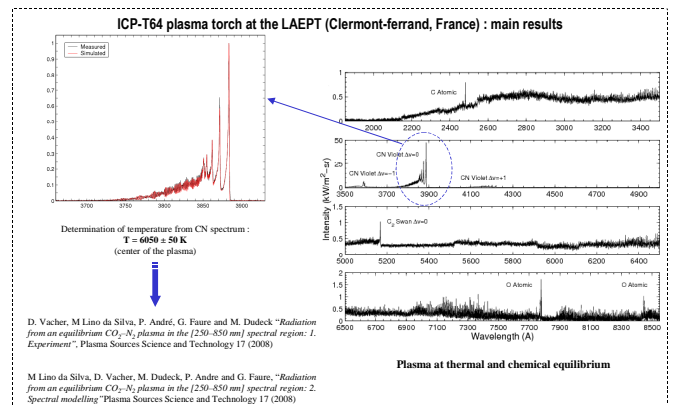
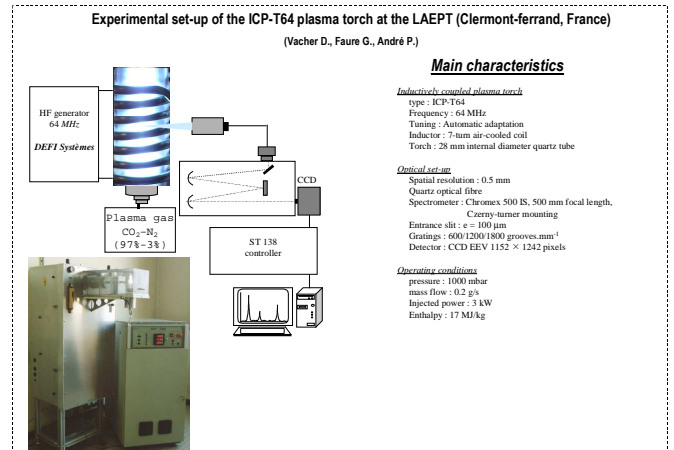
## 1. INTRODUCTION

Five laboratories have been found concerning the study of CO<sub>2</sub> or CO<sub>2</sub>-N<sub>2</sub> plasmas by inductively coupled plasma torch. The laboratories which are about to start this kind of study do not appear in this presentation.

The laboratories which have obtained results are the following :

- L.A.E.P.T. (Laboratory of Electrical Arc and Thermal Plasmas) located in Clermont-Ferrand, France;
- C.O.R.I.A. (Complexe de Recherche Interprofessionnel en Aérothermochimie) located at Rouen, France;
- I.R.S. (Institut für RaumfahrtSysteme) located at Stuttgart, Germany;
- V.K.I. (Von Karman Institute) located at Rhode Saint Genese, Belgium;
- I.P.M. (Institute for Problems of Mechanics) located at Moscow, Russia.

## 2. L.A.E.P.T. (Clermont-Ferrand, France)



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3. M. Lino de Silva, *An adaptative Line-by-Line-Statistical Model for Fast and Accurate Spectral Simulations in Low-Pressure Plasmas* JQSRT, Vol. 108, n°1, pp. 106-125



3. P. Endlich, M. Auweter-Kurtz, G. Herdrich, *Mars Entry Simulation with Dust Using an Inductively Heated Generator*, Paper AIAA-2002-3237, 22<sup>nd</sup> AIAA Aerodynamic Measurement Technology and Ground Testing Conference, St. Louis, MI, USA, 24-26 June 2002

4. G. Herdrich, M. Auweter-Kurtz, P. Endlich, T. Laux, *Simulation of Atmospheric Entry Manoeuvres using the Inductively Heated Plasma Wind Tunnel PWK3*, DGLR Jahrestagung, DGLR-JT2002-254 Stuttgart, Germany, September 2002

5. G. Herdrich, M. Auweter-Kurtz, P. Endlich, T. Laux, *Simulation of Atmospheric Entry Manoeuvres using the Inductively Heated Plasma Wind Tunnel PWK3*, DGLR Jahrestagung, DGLR-JT2002-254 Stuttgart, Germany, September 2002

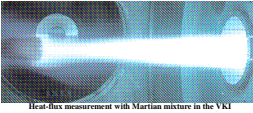
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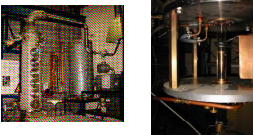
### 5. V.K.I. (Rhode Saint Genese, Belgium)

**ICP torch at the VKI (Rhode Saint Genese, Belgium)**  
(Chazol O., Carbonaro M. and al.)

|                             | Plasmatrix | Minitech           |
|-----------------------------|------------|--------------------|
| Frequency (MHz)             | 1.16       | 1.16               |
| Power (kW)                  | 1200       | 15                 |
| Operating pressure          | 1-12 mbar  | Martian atmosphere |
| Inductor                    | 3          | 2                  |
| coiled (d=4mm)              | water      | water              |
| external diameter tube (mm) | 80-140     | 250                |
| Internal diameter (mm)      | 150        | 170                |
| Flow rate                   | 0.05       | 1 g/s              |
| Embassy                     | 0.050 m/s  | 1 g/s              |



Heat-flux measurement with Martian mixture in the VKI Plasmatron



Overview of the minitech

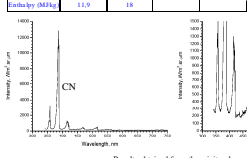
**Available instrumentation:**

- cooled pressure and heat fluxes probes
- Langmuir probes
- Laser Doppler velocimeter
- One meter emission spectrometer with CCD camera
- two color pyrometer
- Laser spectroscopy techniques (TALIF)
- (Two photon Absorption Laser Induced Fluorescence)

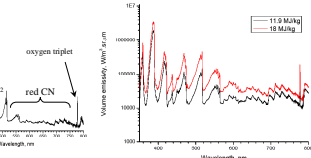
**ICP torch at the VKI (Rhode Saint Genese, Belgium)**  
(Playez M. and al.) [TRP-ESA]

|                 | test1   | test2 | test3 | test4 |
|-----------------|---|-------|-------|-------|
| Power (kW)      | 15  | 30    | 3.2   | 3.2   |
| Pressure (mbar) | 8   | 8     | 10    | 7.5   |
| Flow rate       | CO <sub>2</sub> (97%) - N <sub>2</sub> (3%) (mass flow) |       |       |       |
| Mass flow (g/s) | 8   | 8     | 0.51  | 0.51  |
| Embassy (M/s)   | 11.6  | 18    |       |       |

**Optical setup:**  
Spectrometer: Ocean Optics HR4000CG-LV-NIR;  
Wavelength interval: 200-1400 nm  
Entrance slit:  $\tau = 5 \mu\text{m}$   
Gratings: 300 grooves/mm<sup>2</sup>  
Detector: 3648-elements linear silicon CCD array

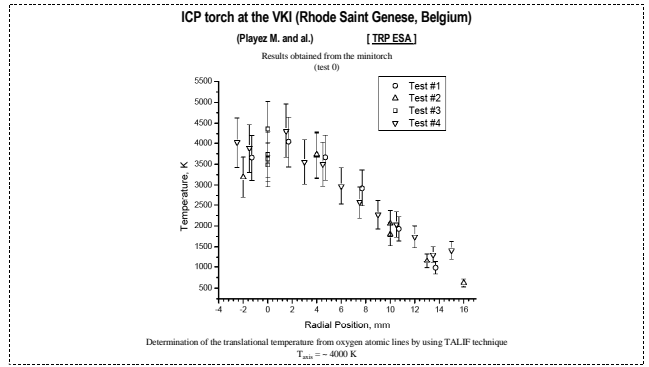


Results obtained from the minitech (test 1)



Results obtained from the plasmatron (test 1-2)

**Difficulty of interpretation - fluctuations of the jet**



### REFERENCES

The informations are given by M. Playez.

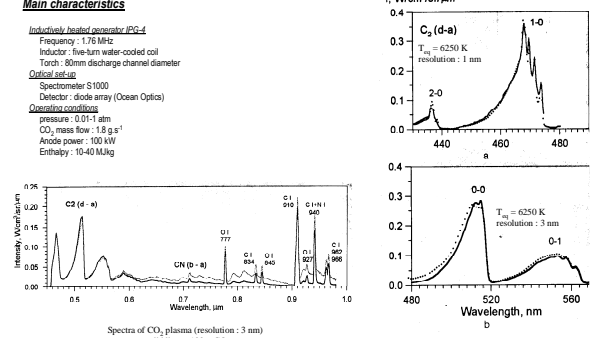
### 6. I.P.M. (Moscow, Russia)

**ICP torch at the IPM (Moscow, Russia)**  
(Baronets P.N., Bykova N.G. and al.)

**Main characteristics**  
Inductively heated generator IIG-4  
Frequency: 1.16 MHz  
Inductor: five-turn water-cooled coil  
Torch: 80mm discharge channel diameter

**Optical setup**  
Spectrometer: S1000  
Detector: diode array (Ocean Optics)

**Operating conditions**  
pressure: 0.05-1 atm  
CO<sub>2</sub> mass flow: 1.8 g/s<sup>1</sup>  
Anode power: 100 kW  
Embassy: 10-40 M/s

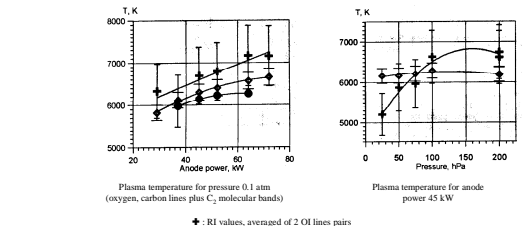


Spectra of CO<sub>2</sub> plasma (resolution: 3 nm)  
- solid lines: 100% CO<sub>2</sub>  
- dotted line: CO<sub>2</sub> + 3% N<sub>2</sub> + (0-10%) Ar

Correlation of C<sub>2</sub> Swan system band head.  
dotted line: experimental spectrum  
solid line: calculated spectrum

**ICP torch at the IPM (Moscow, Russia)**  
(Baronets P.N., Bykova N.G. and al., 1998)

Plasma temperature measurements by optical methods

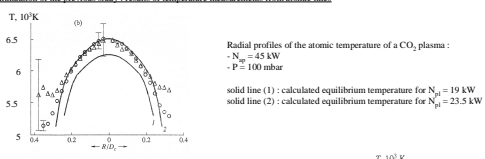


Plasma temperature for pressure 0.1 atm (oxygen, carbon lines plus C<sub>2</sub> molecular bands)

- RI values, averaged of 2 OI lines pairs
- AI values, averaged over three oxygen and four carbon lines
- Values from C<sub>2</sub> molecular bands

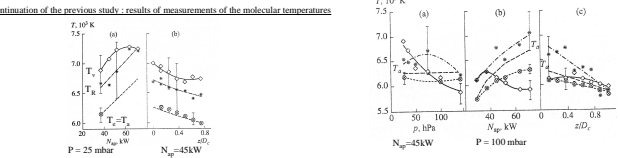
**ICP torch at the IPM (Moscow, Russia)**  
(Bykova N.G., Kuznetsova L.A., 2004)

Continuation of the previous study - results of temperature measurements from atomic lines

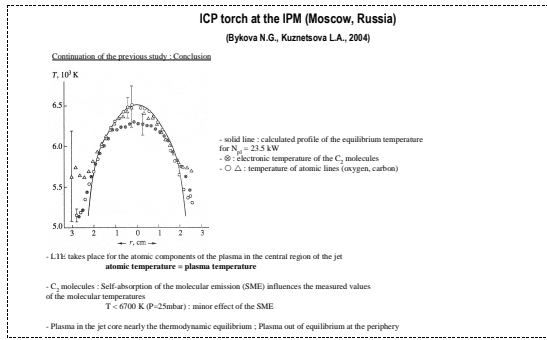


Radial profiles of the atomic temperature of a CO<sub>2</sub> plasma:  
- N<sub>0</sub> = 45 kW  
- P = 100 mbar  
solid line (1): calculated equilibrium temperature for N<sub>0</sub> = 19 kW  
solid line (2): calculated equilibrium temperature for N<sub>0</sub> = 23.5 kW

Continuation of the previous study - results of measurements of the molecular temperature



Influence of the self-absorption of molecular emission (C<sub>2</sub>, I)



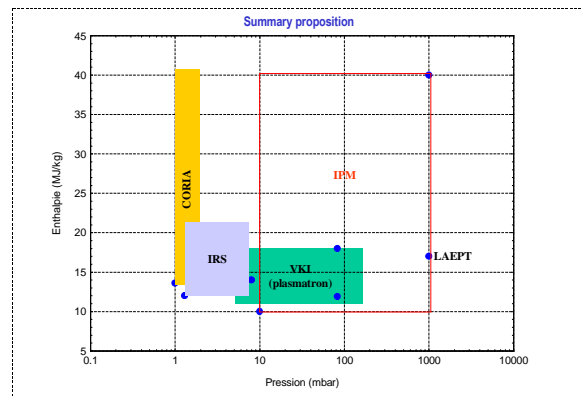
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## 7. CONCLUSION

A conclusion can not be done due to the fact that each laboratory works under different conditions in terms of flow, injected power, operating frequency and operating pressure. However, it is very interesting to gather all the data in order the domain of applications of each laboratory and also in order to create a connection between all these laboratories.

The following figure propose a regrouping of the data of each laboratory in terms of specific enthalpy and pressure. Of course, The field of investigation of each laboratories is likely to evolve.



## ACKNOWLEDGMENTS

I would like to thank all the colleagues who permitted to this presentation to exist. I express all my recognition to them and thanks once again them for all the informations that they sent to me. These colleagues are : P. Boubert, A. Bultel, G. Herdrich, A.F. Kolesnikov, M. Playez and C. Rond.

I wish that the discussion will continue in order to still work together on the atmospheric entries with inductively coupled plasma torches.