Computation of the NEC with the overlapping lines consideration on the $CH_4 - Ar$ plasma discharge

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Keywords

- **Thermal plasma radiation.**
- **Net emission coefficient.**
- **Absorption coefficient.**

Introduction

- Modeling of such plasmas and calculation of the energy balance require a deep knowledge of the radiative transfer.
- The overall modeling of arcs or thermal plasmas of a sort found in physical-chemical processes requires a good understanding of the thermodynamic properties and transport coefficients.
- The net emission coefficient (**NEC**) which corresponds to the locally radiated power and takes auto-absorption of the radiation into account.
- Net emission coefficients of radiation were calculated for isothermal plasma of $\mathbf{CH_4 - Ar}$ as a function of the plasma temperature 5000-30000 K and the arc radius (**0** - **1** cm) at various plasma pressures. Calculations take into account continuum and line radiations.
- In this work, the values of NEC have been calculated by overlapping lines consideration over the temperature and pressure ranges of thermal plasma.
- Values of net emission coefficients calculated for various spectral regions were compared with others author ś works.

Method of calculation

The general study of radiation emitted by plasma is composed of two parts.

- The first part describes the different mechanisms responsible for the radiation emission. The total radiation results from the superposition of the continuum and the line spectra.
  - The continuum spectrum is due to radiative attachment, radiative recombination and Bremsstrahlung effect.
  - The line spectrum is produced when an electron in a given atom can jump from one energy level $\mathbf{E_m}$ to another energy level $\mathbf{E_n}$.
- The second part solves the equation of radiative transfer and determines the net emission escaping from the plasma. To calculate the radiation which escapes from the plasma, we must solve the equation of radiative transfer written in the form of :

$$\varepsilon_{N\nu} = k'_\nu (B_\nu - J_\nu)$$

with $J_\nu = B_\nu \left[1 - G_1 k'_\nu R\right]$

k'_ν is the absorption coefficient corrected for the induced emission.

$$k'_\nu = k_\nu \left[1 - \exp\left(-\frac{h\nu}{KT}\right)\right]$$

$\mathbf{B_\nu}$ is the blackbody radiation density, $\mathbf{J_\nu}$ is the average radiation intensity. In the case of an isothermal plasma with a simplified cylindrical geometry, it is possible to write, in anisotropic medium, **NEC** in the form of :

$$\varepsilon_N(T) = \int B_\nu(T)\left[k_c + k_0 P(\nu)\right]\left[1 - \exp\left(-\frac{h\nu}{KT}\right)\right]$$
$$\exp\left\{-(k_c + k_0 P(\nu))\left[1 - \exp\left(-\frac{h\nu}{KT}\right) R\right]\right\}$$

where $\mathbf{k_c}$ is the absorption coefficient of the continuum, $\mathbf{k_0}$ is the absorption coefficient on the medium line and $\mathbf{P(\nu)}$ is the line profile.

To calculate **NEC** one must know its profile, which is related to the broadening phenomena (Doppler effect, stark effect ...). When the Stark profile is Lorentzian, the resultant profile, taking the Doppler effects into account, is a Voigt one, but the line profile of hydrogen does not have the same form (Voigt profile). The profile is close to a Holtzmark one with a very complicated expression, we used the values tabulated by Vidal.

All the theoretical calculations involving transport and emission coefficients etc require knowledge of the plasma chemical composition. When the plasma is in **LTE**, quantitative relationships are established between substances taking part in the plasma composition. Under these conditions, a calculation of the densities for different species is possible with an application of the following equilibrium laws: Saha law; Guldberg Waage law; Dalton law; Electrical neutrality; Conservation law of matter.

Results

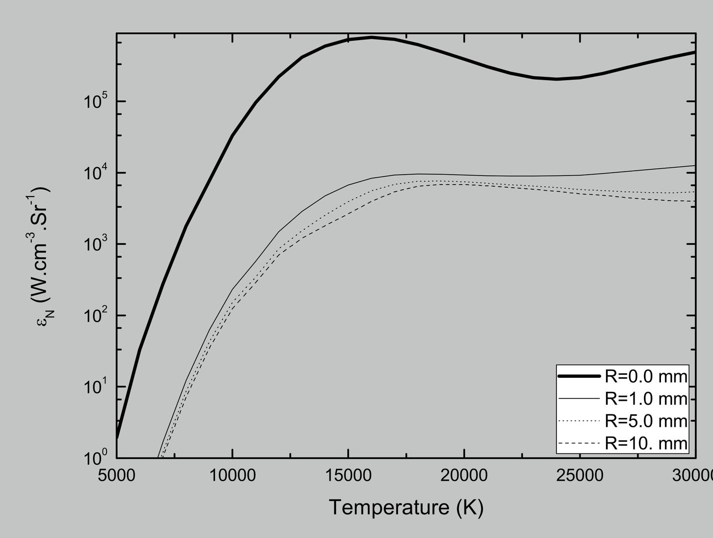

Fig.1.

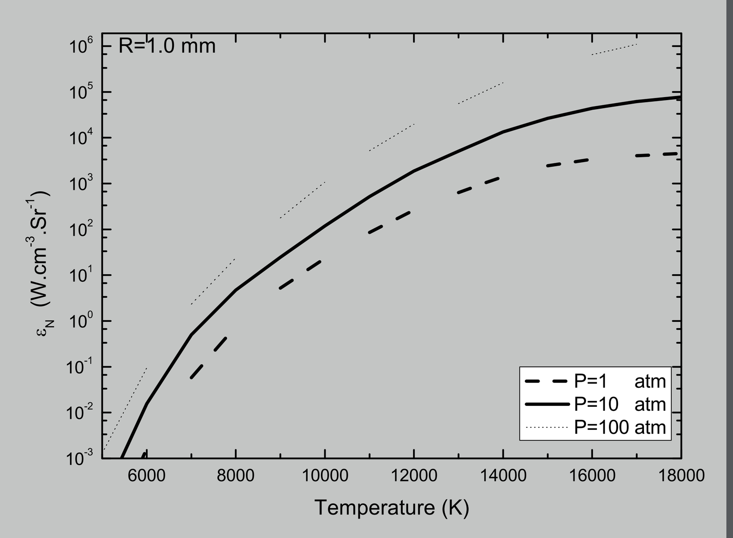

Fig.2.

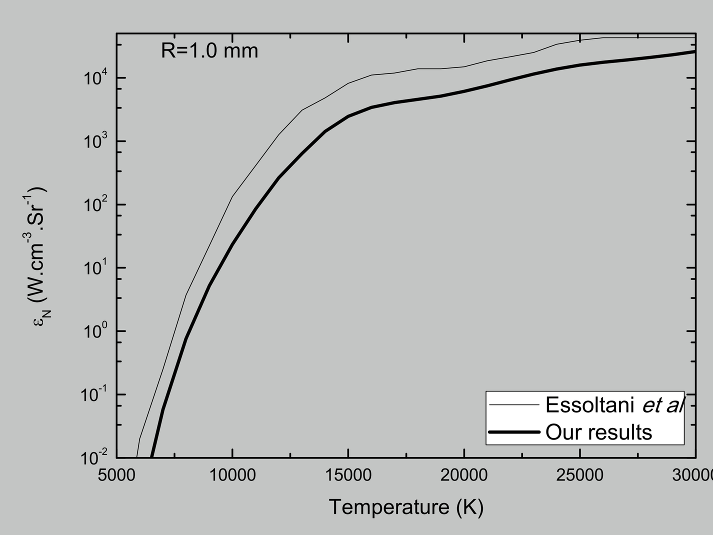

Fig.3.

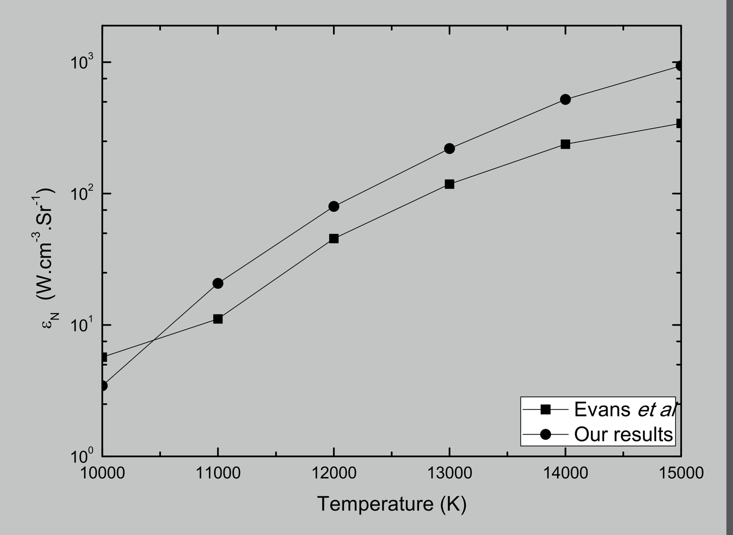

Fig.4.

Discussions

We could obtain a real absorption spectrum from **32** to **4500 nm** range with a **10 − 3 nm** wave-length step, which enabled us to calculate, using language **FORTRAN**, the net emission coefficient used to represent the radiative losses energy in the arcs modeling. **Fig.1** represents the total radiation emitted by the plasma. This radiation is partially re-absorbed with its crossing; the plasma absorption increases with optical thickness and therefore with radius. When the plasma is optically thin ($\mathbf{R = 0}$ **mm**), **NEC** is roughly proportional to the pressure because of its dependence on the plasma composition which itself depends on the pressure through the ideal gas law (Dalton's law). **Fig.2** illustrates this relation which exists between the total radiation and pressure. Two comparisons are made which take absorption into account. The first is between the results of the total radiation using a **line by line** method from Essoltani and ours results and is illustrated in **Fig.3**. In order to show the validity of our results, **Fig.4** shows the second comparison between our calculated values carried out for **NEC** related to lines where the wavelength is beyond **200 nm** and those from measurements by Evans. This result is quite consistent.

Conclusions

- The contribution of resonance lines plays a significant part in the emitted radiation. These lines are strongly absorbed in the first crossed millimeter.
- The NEC is roughly proportional to the pressure.
- The first comparison between Essoltani and ours results shows that when the overlapping of the lines is neglected, it overestimates the **NEC**. This is expected since the absorption coefficient is smaller.
- The **NEC** calculation at atmospheric pressure for pure argon agrees fairly well with the measurement by Evans.

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