PLANCK AND ROSSELAND MEANS OF ABSORPTION COEFFICIENTS IN SF_6

Nadezda Bogatyreva

Doctoral Degree Programme (4), FEEC BUT

E-mail: xbogat00@stud.feec.vutbr.cz

Supervised by: Milada Bartlová

E-mail: bartlova@feec.vutbr.cz

Abstract: Planck and Rosseland mean absorption coefficients were calculated for thermal SF_6 plasma as a function of plasma temperature 1 000 - 35 000 K at plasma pressure 0.5 MPa of the frequency range (0.01-10)x10^{15} s^{-1}.

Keywords: absorption coefficient, Planck mean, Rosseland mean, SF_6

1. INTRODUCTION

Radiation transport of energy plays an important role in many plasma processing devices. To gain information about physical processes occurring in electric arcs by means of measurements is very difficult due to extreme experimental conditions such as high temperature, pressure and velocity of the gas. In such cases, the mathematical modeling is of great importance. However, the non-linearity of equations describing the radiation field and strong dependence of input parameters on the radiation frequency and properties of the medium make mathematical plasma models very complicated.

2. EQUATION OF RADIATION TRANSFER

The equation of transfer radiation energy is considered to be complicated. The full stationary equation for absorbing and emitting medium has the form

$$\vec{\Omega}\cdot \text{grad}\, I_\nu = k_\nu (I_{b\nu} - I_\nu)\,, \tag{1}$$

where $\vec{\Omega}$ is the unit vector defining the radiation direction, k_ν is the absorption coefficient per unit length at frequency ν, I_ν is the monochromatic intensity of radiation, and $I_{b\nu}$ is the specific blackbody radiation intensity which is given by Planck formula

$$I_{b\nu} = B(\nu,T) = \frac{2h\nu^3}{c^2}\cdot\frac{1}{e^{\frac{h\nu}{kT}}-1}\,. \tag{2}$$

Here, h is the Planck constant, ν is the frequency of radiation, c denotes the velocity of light, k is the Boltzmann constant, and T is the temperature.

In general, the spectral intensity, which is dependent variable of this equation, depends on the independent variables ($\vec{r}$, ν, $\vec{\Omega}$). The method of spherical harmonics (P_N-approximation) which is based on the transformation the equation of transfer into a set of simultaneous partial differential equations enables us to obtain an approximate solution of required accuracy.

Radiation in arc plasma depends, besides others physical quantities, on composition and on concentrations of all chemical species occurring in the plasma, due to different absorption properties of various species. Absorption coefficients of SF_6 plasma at the pressure of 0.5 MPa and for temperatures of 5 000 K and 25 000 K is shown in Fig. 1. Equilibrium compositions of thermal plasma SF_6 can be computed using Tmdgas computer code ([2], [3]). Both line and continuum radiations were considered in calculations of absorption coefficients. [5]

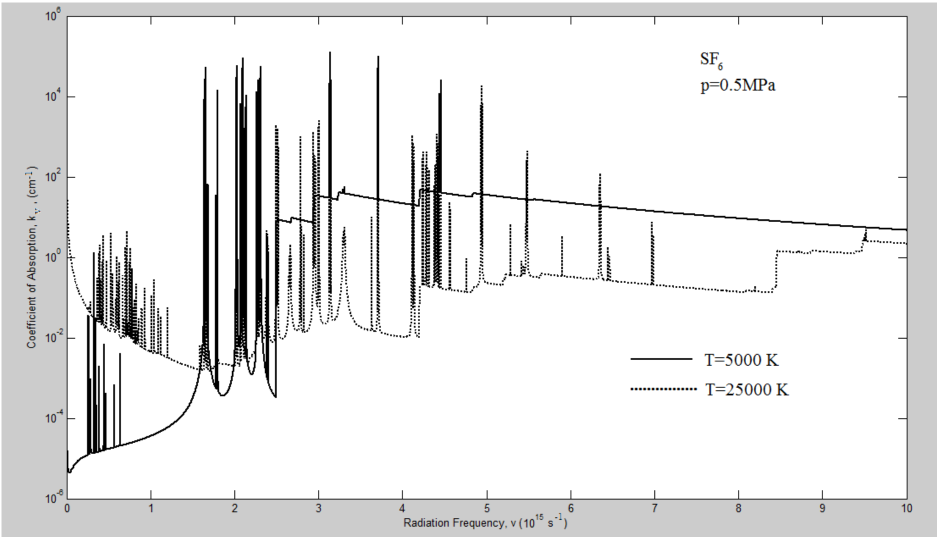


Fig. 1. Absorption coefficient of SF_6 thermal plasma as a function of frequency for temperatures 5 000 K and 25 000 K.

The absorption coefficients were calculated for the frequency range (0.01-10)x10^{15} s^{-1}.

According to the absorption coefficients variation, the frequency range was divided into 10 parts. There is division in Tab. 1.

interval	1	2	3	4	5	6	7	8	9	10
$\nu(10^{15}s^{-1})$	0.03 - 0.057	0.057-0.296	0.296-0.386	0.386-0.746	0.746-0.986	0.986-1.71	1.71-2.098	2.098-2.64	2.64-2.997	2.997-4.49

Tab. 1. Limits of specific frequency intervals.

Two types of average absorption coefficients have been calculated for temperatures T= (1 000; 35 000) K at the SF_6 plasma pressure p = 0.5 MPa in frequency intervals given in Tab 1.

1) The Planck mean absorption coefficient is determined by

$$\bar{k}_P = \frac{\int_0^\infty k(\nu)B(\nu)\mathrm{d}\nu}{\int_0^\infty B(\nu)\mathrm{d}\nu}, \qquad (3)$$

where $k(\nu)$ is the spectral absorption coefficient, and $B(\nu)$ is the Planck equilibrium radiation intensity (2).

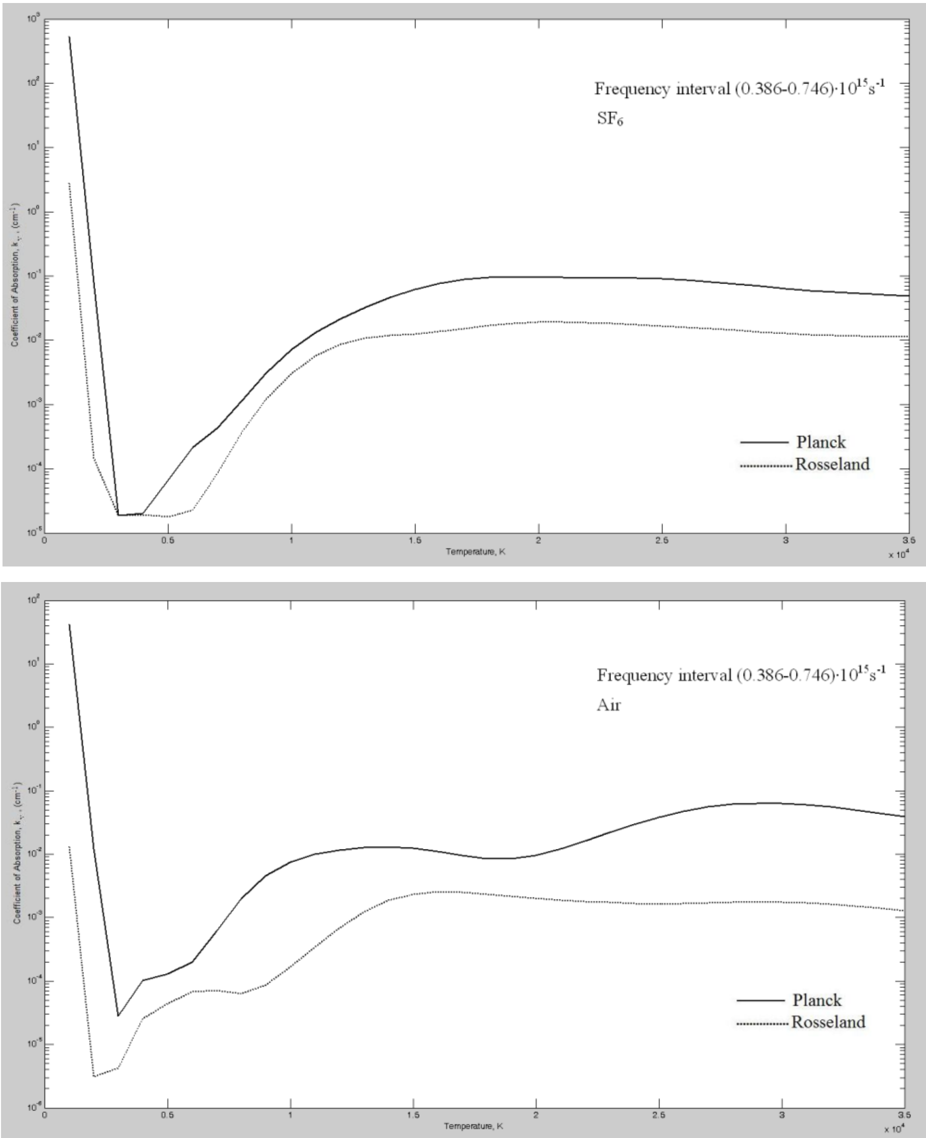
2) The Rosseland mean absorption coefficient is given by

$$\overline{k^{-1}} = \frac{\int_0^\infty k^{-1}(\nu)\frac{dB(\nu)}{dT}\mathrm{d}\nu}{\int_0^\infty \frac{dB(\nu)}{dT}\mathrm{d}\nu}, \quad (4)$$

where the temperature derivative of Planck function is

$$\frac{\mathrm{d}B}{\mathrm{d}T} = \frac{2h^2\nu^4}{kT^2c^2}\cdot\frac{e^{\frac{h\nu}{kT}}}{\left(e^{\frac{h\nu}{kT}}-1\right)^2}. \quad (5)$$

Comparison of two different mean values for two selected frequency intervals $(0.386\text{-}0.746)\mathrm{x}10^{15}\ \mathrm{s}^{-1}$ and $(1.71\text{-}2.098)\mathrm{x}10^{15}\ \mathrm{s}^{-1}$ for two types of plasma (air and SF_6) is given in Fig. 2.



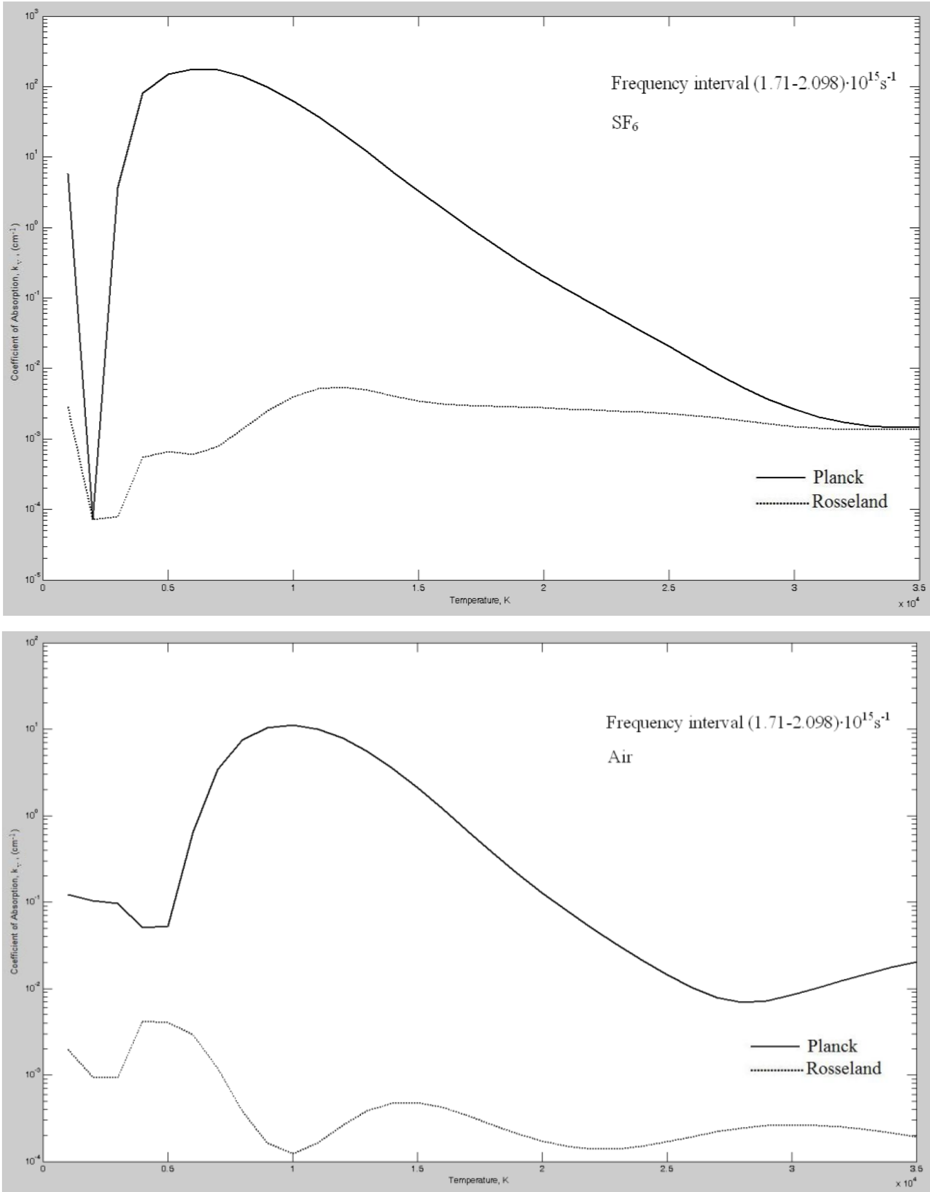


Fig.2. Planck and Rosseland mean absorption coefficients of air plasma and SF_6 plasma in the corresponding frequency intervals 4 and 7 from Tab.1.

3. CONCLUSION

Planck and Rosseland mean absorption coefficients of SF_6 plasma have been calculated for 10 specific frequency intervals at the pressure p=0.5 MPa. Dependences of these mean absorption coefficients on the temperature were graphed. Comparison of two different mean values of air plasma and SF_6 plasma for two selected frequency intervals is given in Fig. 2.

Choice of the mean absorption coefficients for different intervals depends on the view of spectrum. Rosseland mean is a good approximation for optical thick plasma, Planck mean is valid for optical thin plasma. Due to the complicated spectrum neither Rosseland nor Planck mean can be a good approximation for the whole frequency interval. Rosseland mean ignores the influence of discrete spectrum which results to the underestimation of absorption. Planck mean overestimates the influence of spectral lines, and therefore overvalues the absorption.

One of the ways to calculate the average is selected according to the value of the absorption coefficient. Planck mean is appropriate for the frequency intervals with low values of absorption coefficients. Rosseland mean fits the intervals with high values of absorption coefficients.

Calculations of the mean absorption coefficients for the SF_6 plasma have been made and compared with calculations for the air plasma. This comparison shows that the values of mean absorption coefficients for SF_6 are greater than the values for air. It depends on the composition of the plasma; various species have different absorption properties.

ACKNOWLEDGEMENT

This work has been supported by the Czech Science Foundation under project No. GD102/09/H074 and from Ministry of Education, Youth and Sports under project No. MSM0021630503.

REFERENCES

[1] Chetverushkin, B.N.: Matemeticheskoe modelirovanie zadach dinamiki izluchajushchego gaza. Moskva, ”Nauka”, 1985, p. 304.

[2] Coufal, O. Database system of thermodynamic properties of individual substances at high temperatures. J.Phys.D: Appl.Phys. 38, 2005, p. 1265-1274.

[3] Coufal, O. http://www.feec.vutbr.cz/~coufal

[4] Aubrecht, V., Bartlova, M. Radiation Transfer in Air Thermal Plasmas. In: Proc. of XVIth Symposium on Physics of Switching Arc, Brno, 2005, p. 9-12.

[5] Aubrecht, V., Bartlova, M. Net emission coefficients of radiation in air and SF6 thermal plasmas. Plasma Chem. Plasma Process. 29, 2009, p. 131-147.