CALCULATION OF RADIATIVE HEAT TRANSFER IN ARGON ARC PLASMAS

Vladimír Aubrecht

Brno University of Technology, Dept. of Power Electrical and Electronic Engineering, Technická 8, 616 00 Brno, Czech Republic

Milada Bartlová

Brno University of Technology, Department of Physics, Technická 8, 616 00 Brno, Czech Republic

Received 5 April 2000

Radiation emission and absorption in arc plasmas are important energy transfer processes. Exact calculations, though possible in principle, are usually impossible in practice because of the need to treat a large number of spectral lines and also the continuum radiation in the whole spectrum range. Recently, we have used an approximate method of partial characteristics to evaluate the radiation intensities, radiation fluxes and the divergence of radiation fluxes for SF_6 arc plasma with cylindrical symmetry. In this paper, we have extended our calculations to *argon arc plasmas* for the plasma pressures of 0.1, 0.5 and 1.0 MPa. We have calculated the coefficients of absorption for Ar plasmas at temperatures from 300 to 35 000 K, and have used these coefficients to calculate the partial characteristics. Both the continuum and the line spectra have been included in calculations. We have taken into account the radiative photo-recombination and bremsstrahlung for the continuous spectrum, and over 500 spectral lines for the discrete spectra.

The method of partial characteristics has been applied to three-dimensional calculations of radiative heat transfer - i.e. radiation intensity, radiation flux and its divergence - in simplified temperature profiles. Conclusions have been made concerning validity and utilization of the method of partial characteristics in general gas dynamics problems.

1 Coefficients of absorption

Prediction of both radiation emission and absorption requires data of the continuum and the line spectra, respectively. The spectral coefficients of absorption (absorptivity) need to be calculated as a function of radiation frequency in the whole spectral range, from the infrared to the far ultraviolet region.

Absorptivity is proportional to the concentration of the chemical species occurring in the plasma. In the present paper, the pure Ar plasma is assumed as a mixture of Ar atoms, Ar^{+}, Ar^{++}, Ar^{+++}, Ar^{++++} ions and electrons, according to the Fig. 1. Concentrations of each species were taken from [1].

Both line and continuum radiation were considered in calculations of absorption coefficients. Photorecombination radiation and 'bremsstrahlung' radiation contribute to the continuous spectrum. Semi-empirical formulae described in more detail in [2] were used for calculation of the continuum absorption coefficients.

The absorptivity for each spectral line depends on the line shape. The fine multiplet structure and the lines overlapping should also be taken into account in the calculations. Our calculations of line broadening account for Stark and Doppler half-widths, and line shifts. Theoretical formulae are given in [2].

The calculated radiation absorption coefficients as a function of radiation frequency for plasma pressures of 10 000 and 30 000 K at pressure of 1 atm are shown in Fig. 2.

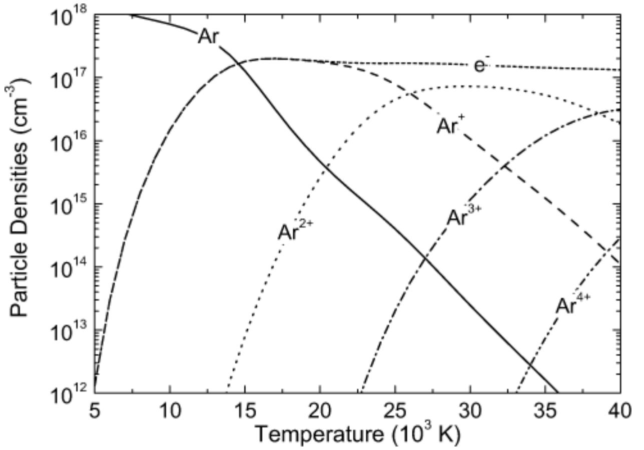

Fig. 1. Calculated composition of Ar plasmas at 1 atm.

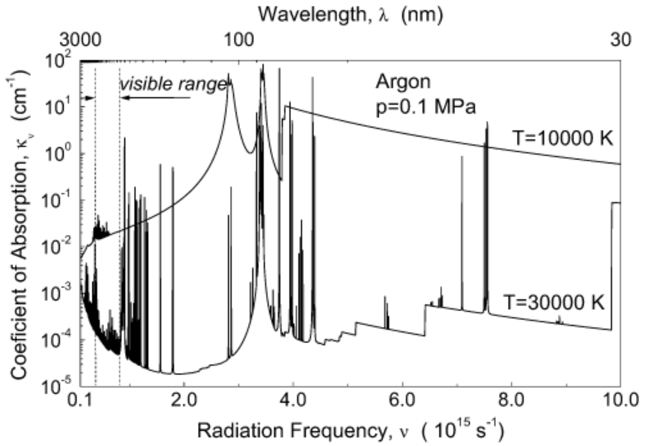

Fig. 2. Calculated absorption coefficient of Ar as a function of radiation frequency at 1 atm for temperatures of 10 000 K and 30 000 K.

2 Method of partial characteristics

Typical radiation quantities of interest: *r*adiation intensity, radiation flux and *d*ivergence of radiation flux are calculated from integrals over the radiation frequency for various line segments and solid angles of the plasma volume. Values of radiation quantities at a given point of the plasma volume depend on the temperature distribution of the entire volume of the plasma.

To account for emission and absorption of radiation energy, integrations need to be made to account for radiation for all elements along any particular direction simultaneously with integrations over all solid angles. Usually direct frequency integration of the spectral characteristics of the radiation field in solving gas dynamics problems is impossible in practice, even with modern computers, due to the large computation times that are required, so that some approximation have to be used.

In our recent papers [3, 4], we have used the approximate *m*ethod of partial characteristics as formulated by Sevast'yanenko [5] for prediction of radiation intensities, radiation fluxes and the divergence of radiation fluxes for various temperature profiles of SF_6 arc plasmas. In this paper we applied the same method to the electric arc plasma in argon. The argon arc plasma is widely used in plasma jets both in industry and laboratory applications.

The principle the method of partial characteristics is that an integrals over radiation frequencies in equations for radiation quantities can be performed in advance to form a functions, called partial characteristics. These functions are stored in data tables according to several parameters, such as plasma pressure, temperature and geometrical dimensions. Computation of the tables of partial characteristics is very time demanding, but they are computed only once and then it is possible to use them repeatedly in different kinds of gas dynamics problems.

3 Results

Up to know we have been preparing tables of partial characteristics for SF_6 arc plasmas at pressures from 0.1 to 6 MPa and for argon arc plasmas at pressures from 0.1 to 1 MPa. In both cases the plasma temperatures cover the range from 300 K to 40 000 K with geometrical distance from 0.0001 to 1 m.

Calculated radiation intensities, fluxes and divergence of fluxes for SF_6 arc plasmas with various temperature distributions were presented in our previous papers [3, 4]. Similar results for argon arc plasma at pressures of 1, 5 and 10 atm are given in Figs. 3 and 4. Parabolic temperature distribution was assumed in both cases (dotted line). Thick curves in the figures represent radial distribution of radiation flux density (Fig. 3) and its divergence (Fig. 4) in the middle of the plasma cylinder with the height of 2 cm and radius of 0.25 cm. It can be seen that a role of the radiation in the arc plasma energy balance increases rapidly with the plasma pressure. Note the negative portion of the divergence of radiation flux at the arc edge which demonstrates absorption of radiation energy and consecutive heating of the outer parts of the plasma column.

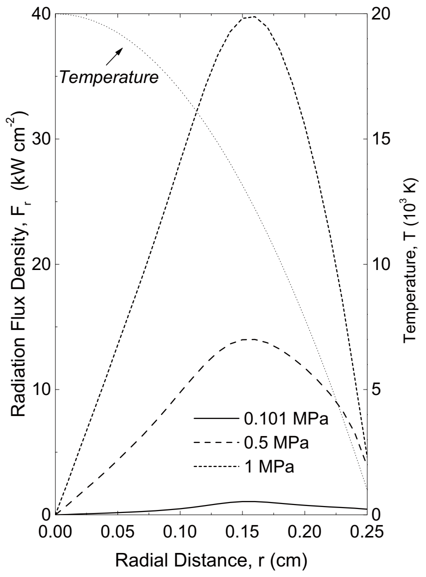

Fig. 3. Calculated radiation flux in an arc plasma column for various plasma pressures.

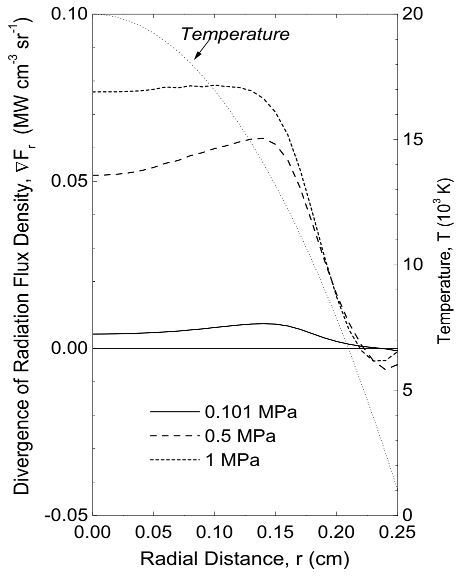

Fig. 4. Calculated divergence of radiation flux in an arc plasma column for various plasma pressures.

It has been found that the method of partial characteristics is a very good mathematical tool for prediction of radiative heat transfer in the arc plasmas. If the tables of partial characteristics are used, the calculations of radiation quantities are not so time demanding and yield a good agreement with exact calculations. Using simple programme routines, it is possible to include radiative heat transfer into more complex codes for gas dynamics problems solution.

Authors gratefully acknowledge support under research projects Nos. 20/10U (52010) and CEZ: J22/98: 262200010.

References

[1] O. Coufal, private communication.

[2] R. W. Liebermann and J.J. Lowke: J. Quant. Spectrosc. Radiat. Transfer **16** (1976) 253.

[3] V. Aubrecht and J.J. Lowke: J. Phys. D: Appl. Phys. **27** (1994) 2066.

[4] V. Aubrecht and M. Bartlová: IEEE Trans. on Plasma Science **25** (5) (1997) 815.

[5] V.G. Sevast'yanenko: J. Eng. Phys. **36** (2) (1979) 138.