ON THE PECULIARITIES OF THE TRANSPORT PROPERTIES OF MULTICOMPONENT NONIDEAL PLASMA OF UNDERWATER DISCHARGES AT HIGH PRESSURE

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It is considered the peculiarities of the transport properties of a nonideal plasma of underwater discharges at pressure range from 1 bar up to 200 bar. The transport coefficient set based on the Grad's method is compared with the data obtained by using of the Lorentzian plasma theory at the same plasma composition. Also, the calculation data are considered to be in reference with transport coefficients obtained by using the Chapman-Enskog' method. It is pointed that the nonideality effects are needed to take into consideration under calculation of properties of underwater discharge.

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INTRODUCTION

Over the last decades a substantial growth has occurred in technological applications and researching of underwater discharges (arcs and electrical pulse discharges) [1-5]. The most important influence on the plasma of underwater discharges has the processes in a zone of its contact with condensed medium.

At the initial stage of electrical pulse discharges (EPD) small-scale irregularities of heat flow distribution were detected on a surface of channels [1, 2]. Development of such perturbations was accompanied by space modulation of an irradiation intensity, strain of a surface of channels, drop of conductance of plasma. These excitations are connected with the development of Rayleigh-Taylor instability. Thus in EPD it may be realized the two different regimes of discharges the first is characterized by developed perturbation and the second is the discharges without it.

Because of that the nonideal plasma of EPD takes place in various dense states. Also, that picture is established in underwater arc discharges. In this paper it is studied the peculiarities of the transport properties of the nonideal plasma of underwater discharges in the pressure range from 1 bar up to 200 bar.

1. METHOD TO CALCULATE TRANSPORT PROPERTIES

It is considered the calculation of transport coefficients (thermal conductivity, viscosity, electrical conductivity) in dense water plasma. The most important factors determined the properties are the following: gaseous and plasma non-idealities, multicomponent contents. To include the factors into consideration the combined calculation procedure is used on the base of the Grad's method [6, 7] and Lee-More theory [8]. The non-ideality corrections to equation of state are made according to [9-11].

The obtained results are compared with the previous calculations based on the Lorentzian theory (LM) [5, 12]. Also, the calculation data are considered to be in reference with transport coefficients obtained by using the Chapman-Enskog method [13,14] and reference data [15].

The algorithm of calculation consists of three stages. At the first time it is needed to obtain the multicomponent plasma composition under certain pressure and temperature. This problem leads to the system of Saha equations with lowering of ionization energies supplemented by conservation of nuclei and electric charge. The calculations are carried out, and the following 16 species have been taken into account: e^-, H_2O, H_2O^+, H_2, H_2^+, OH, OH^+, $O2$, $O2^+$, H, H^+, O, O^+. Cu,Cu^+,Cu^{2+}.

Having been obtained plasma composition, the thermodynamic and transport properties of plasma can be calculated in the , so-called, zero-density model (ZM) i.e. without consideration of the nonideality effects. At next stage the nonideality corrections are included to obtain the set corresponding to the dense model (DM).

A number of the properties are very interested in the connection of intended use to simulate underwater discharges. Therefore it is focused attention upon such properties.

2. RESULTS AND THEIR DISCUSSIONS

The results of calculations are shown in Figs.1-6. One can see that the properties of dense water plasma have a pronounced non-monotone character with sharp pikes in certain temperature and pressure ranges. The pikes are appeared due to the dissociation, ionization and from others effects. The metal impurities are appeared in the discharge plasma due to the various circumstances. The influence of the metal admixtures causes the very important changes of the plasma properties (see Figs. 3, 6). It is obvious that the presence of impurities cause the growth of conductivity and energy density in plasma.

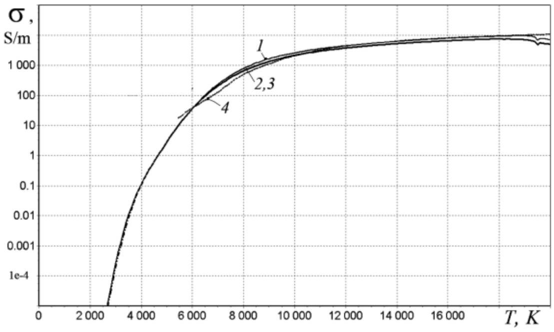

Fig. 1.Electrical conductivity of water plasma (p =1 bar). Curves 1 – Loretzian model (LM); 2 – zero-density model (ZM); 3 – dense model (DM); 4 – data from [14]

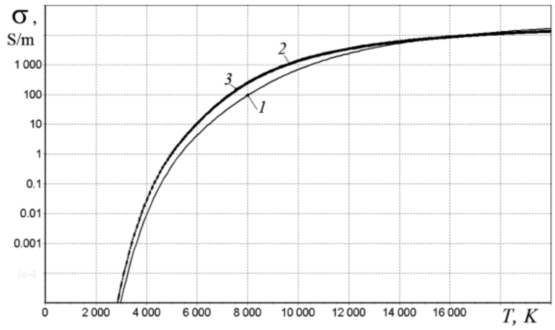

Fig. 2. Electrical conductivity of dense water plasma (p =200 bar). Curves 1 – LM; 2 – ZM; 3 – DM

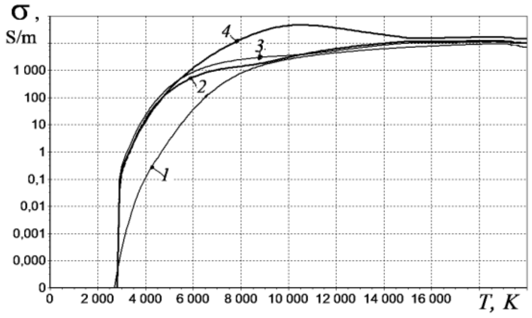

Fig. 3. Electrical conductivity of equimolar mixture of copper-water plasma (p =1 bar). Curves 1 – pure water (ZM); 2 – H_2O–Cu (99:1); 3 – H_2O–Cu (90:10); 4 – H_2O–Cu (10:90)

It should be mentioned that the plasma composition is the same as used in paper [5] that it is allowed to compare both the Grad method approach with the Lorentzian theory. The results have a similar character at normal pressure (see Figs. 1, 4). On the other hand at higher pressure the essential discrepancy takes place (see Figs. 2, 5). One can be deduced that the effects of nonideality have influence on the transport coefficients mainly in more dense conditions and the Lorentzian theory is suitable to calculate the transport properties of multicomponent plasma at relatively low temperature and normal pressure.

Also, one can see that the calculations of some properties are in a good agreement with the data from [13-15] at normal pressure. The results may be distinguished due to the various initial data for calculation.

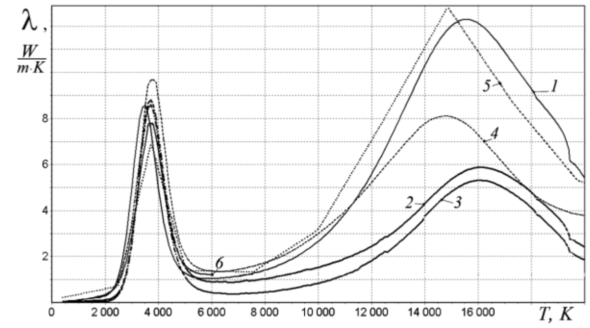

Fig. 4. Thermal conductivity of water plasma (p =1 bar). Curves 1 – LM; 2 – ZM; 3 – DM; 4 – data from [14]; 5 – [13]; 6 – [15]

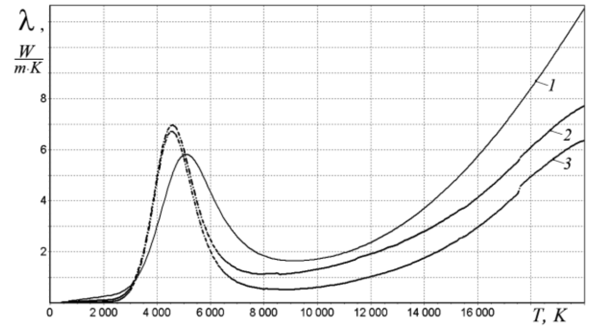

Fig. 5. Thermal conductivity of dense water plasma (p =200 bar). Curves 1 – LM; 2 – ZM; 3 – DM

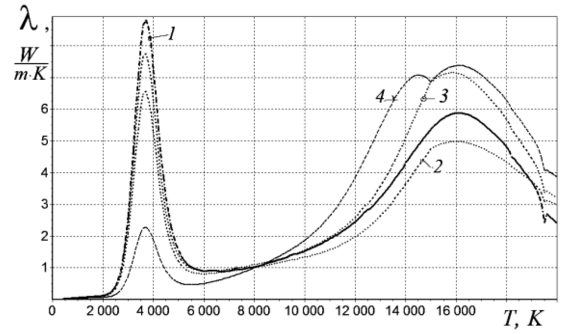

Fig. 6. Thermal conductivity of equimolar mixture of copper-water plasma (p =1 bar). Curves 1 – pure water (ZM); 2 – H_2O–Cu (99:1); 3 – H_2O–Cu (90:10); 4 – H_2O–Cu (10:90)

CONCLUSIONS

The properties of dense water plasma of underwater discharges are essentially depended on both the temperature and pressure conditions. The properties have a pronounced non-monotone character with sharp pikes in certain temperature ranges.

The calculations are carried out on the base of the Grad's method including the nonideality effects. At atmospheric pressure the results are in a good agreement with the previous calculations and data calculated on the base of Chapman-Enskog' method. On the other hand it should be pointed that the nonideality effects are needed to take into consideration under calculation of properties of underwater discharge at high pressure.

The obtained results confirm the conclusion of paper [12] that the Lorentzian theory is suitable to calculate the transport properties of multicomponent plasma at relatively low temperature and normal pressure.

Also, it is considered the influence of copper admixtures on the transport properties of water plasma.

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ОБ ОСОБЕННОСТЯХ ТРАНСПОРТНЫХ СВОЙСТВ МНОГОКОМПОНЕНТНОЙ НЕИДЕАЛЬНОЙ ПЛАЗМЫ ПОДВОДНЫХ РАЗРЯДОВ ПРИ ВЫСОКОМ ДАВЛЕНИИ

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Рассмотрены особенности транспортных свойств неидеальной плазмы подводных разрядов в диапазоне давлений 1…200 бар. Транспортные коэффициенты, которые рассчитывались на основе метода Грэда, сравниваются с результатами, полученными исходя из лоренцевой теории при одинаковом составе плазмы. Также результаты вычислений сравниваются с данными, полученными методом Чепмена-Энскога. Подчеркивается необходимость принятия во внимание эффектов неидеальности при расчете свойств подводных разрядов.

ПРО ОСОБЛИВОСТІ ТРАНСПОРТНИХ ВЛАСТИВОСТЕЙ БАГАТОКОМПОНЕНТНОЇ НЕІДЕАЛЬНОЇ ПЛАЗМИ ПІДВОДНИХ РОЗРЯДІВ ЗА ВИСОКОГО ТИСКУ

П.Д. Старчик, П.В. Порицький

Розглянуто особливості транспортних властивостей неідеальної плазми підводних розрядів у воді в діапазоні тисків 1…200 бар. Транспортні коефіцієнти, що були розраховані на основі методу Ґреда, порівняно із результатами, які ґрунтувалися на лоренцевій теорії за однакового складу плазми. Також результати обчислень порівнювалися із даними, отриманими за допомогою метода Чепмена-Енскоґа. Наголошено на необхідність взяття до уваги ефектів неідеальності плазми для розрахунку властивостей плазми підводних розрядів.