COMBINED NON-SELF-MAINTAINED DISCHARGE IN AIR FOR GENERATING OF CHEMICALLY ACTIVE PARTICLES

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Introduction

Development of plasma technologies for problems of external and internal gasdynamics is impossible without the detailed studies of different discharge types both self maintained and non- self maintained improvement. These questions were discussed in many scientific forums recently. In particular, the longitudinal and transversal gas discharges in air were studied in air flows [1-3] for their applications in applied problems of external and internal aerodynamics (ignition of flammable mixtures in air flows). In Ref [4] a combustion of hydrocarbon fuel under plasma assistance of formarions has been studied. In [5] the combined discharge in a supersonic air flow has been studied.

Works [3,5] have shown that main plasma parameters (electron concentra-tion N_e, and electron temperature T_e) can be independently varied in wide ranges in the non-self maintained and combined discharges. This discharge property allows to selectively excite different molecules and create different radicals in the incident gas flows. Important property of these discharges is connected with a possibility of independent variation of a strength of an external electric field and of velocities of generation of plasma components by fast particles. The present paper is devoted to an investigation of active particle generating possibility in the plasma in conditions of the experiment [5] (external electric field strength is E~640 V/cm, electron flux at the ~30 keV and current density of 0.12-0.27 A/cm^2, typical size of investigated area 20-30 mm) in a supersonic air flow (Mach number M~1,2-1,6, static pressure Pst= 16 Torr) of our investigations are compared with other possible modes of air excitation.

The combined discharge model

A consequent discharge model has to include a large number of components and plasma chemical reactions in plasma which have to be considered mutually with electric circuit. This approach requires solution of a system of stiff differential equations of particle balance, electron energy and gas temperature, see for example as it is done in [3,6]. On a basis of such a model we have undertaken plasma parameters for the combined discharge in air in external electric field at the parameter $E/N \approx 1.13 \cdot 10^{-15}$ V·cm^2 (113 Td) and $3 \cdot 10^{-15}$ V·cm^2 (300 Td) at pressures P=16, 20 and 200 Torr at the gas temperature K=300 K.

The following particles were included into the model: fast and plasma electrons $\hat{e}$, e, positive ions O_2^+, N_2^+, O^+, NO^+, N^+, negative ions O_2^-, O^-, O_3^-, neutrals O, N, [illegible], NO, vibrationally $N_2(v)$, $O_2(v)$ (v=1), and electronically excited states [illegible], $N_2(A^3\Sigma_u^+)$, $N_2(B^3\Pi_g)$ of molecules. Electron temperature T_e was calculated on a basis of rate constants (direct and reverse) of electron-molecule processes obtained by application of the package [12]. Gas temperature was calculated with using of energy defects of plasma chemical reactions. Rate constants of plasma chemical reactions were chosen from [7-11, 13]. During typical gasdynamic times we disregarded processes of thermal conductivity and diffusion of particles. Values of the electric field strength and of excitation by the fast electrons were considered to be constant during calculations.

In Fig.1-4 one can see results for standard conditions of the experiment [5]. At that we used the average velocity of excitation by the fast electrons over the electron range (the reduction factor for the excitation velocity is **W**= 1 W/cm^3 = $6.25 \cdot 10^{18}$ eV/(cm^3·s)).

In Fig. one can see the temporary evolution of the electron and gas temperatures in the combined discharge. In Fig.2 one can see the temporary evolution of the concentrations of charged particles. In Fig.3 one can see the temporary evolution of the excited particles in the plasma, and in Fig4 the concentrations of oxygen atoms, O, and molecules NO.

Parameters in figures are represented in the following units: temperatures are in 100 K, concentrations of particles are in 10^{12} cm^{-3}, time is in microseconds, μs.

Obtained results show that there takes place decreasing of O_2 molecule concentrations in the plasmachemical reactions. Simultaneously takes place generating of O atoms and later the transformation of these atoms to NO molecules in reactions with N atoms.

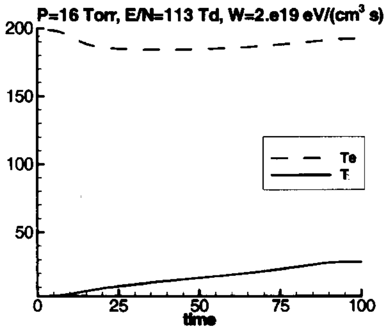

Fig.1. Temporary evolution of temperatures in the plasma of the combined discharge (temperature - in 100 K, time in μs).

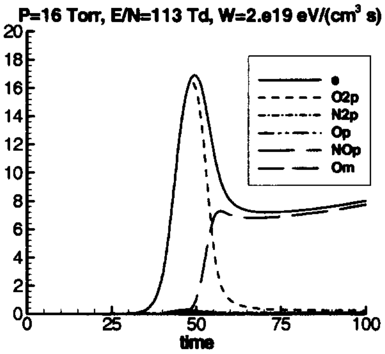

Fig.2. Evolutions of charged particle concentrations in the combined discharge plasma: e-electrons, O2p≡O_2^+, N2p≡N_2^+, NOp≡NO^+, Op≡O^+, Om≡O^-

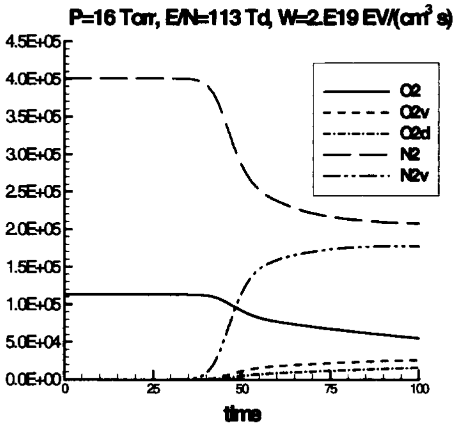

Fig.3. Evolutions of the excited particle concentrations in the combined discharge plasma: O2v≡$O_2(v=1)$, N2v≡$N_2(v=1)$, O2d≡$O_2(a^1\Delta_g)$

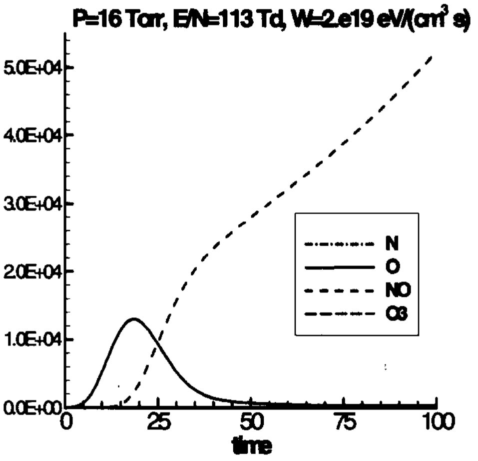

Fig.4. Evolutions of concentrations of atoms O and molecules NO in the combined discharge plasma (concentrations are in 10^{12} cm^{-3}, time is in μs).

The concentrations of O_2, O and NO are considerably higher than those of charged particles and of electronically and vibrationally excited O_2 molecules. Hence Namely O_2, O and NO particles can play the key role in combustion processes at addition of a hydrocarbon fuel to the plasma to a mixture. The combustion processes can be essentially retarded at accumulation with the decrease of O_2 and O concentrations.

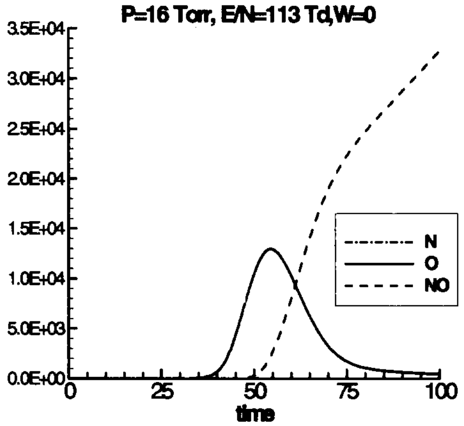

Fig.5 Evolution of concentrations of atoms O and molecules NO in the combined discharge in the absence of the excitation by fast electrons (concentrations are in 10^{12} cm^{-3}, time is in μs).

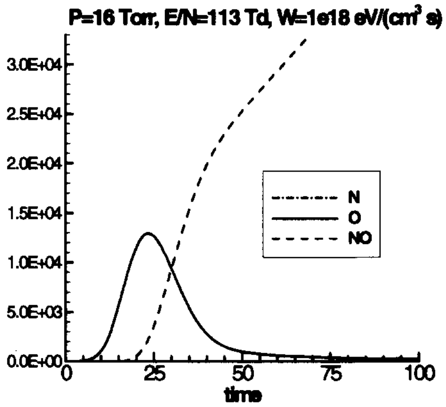

Fig.6. Evolutions of concentrations of atoms O and molecules NO in the combined discharge at low excitation by fast electrons.

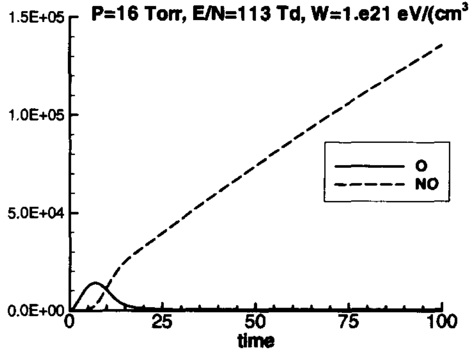

Fig.7 Evolutions of concentrations of atoms O and molecules NO in the combined discharge at strong excitation by fast electrons

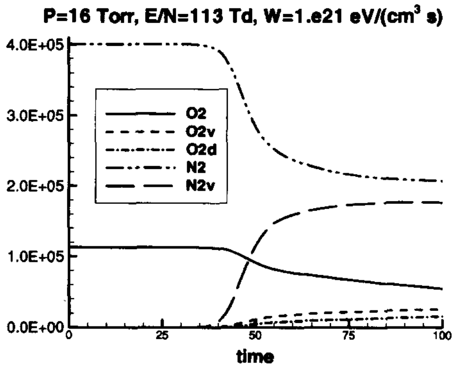

Fig.8 Evolutions of excited particle concentrations in the combined discharge at strong excitation by fast electrons

In Fig. 5-7 one can see the temporary evolution of atoms O, molecules NO, excited and neutral particles at weak and strong (with respect to the standard one presented in Fig.1-4) levels of the gas excitation by the fast electrons in the combined discharge.

Our calculations show that the existence of fast electron excitation in the combined discharge can essentially change times of active radicals O accumulation and decreasing of the O_2 molecule concentrations, i.e. to realize the selective impact to the accumulation of the chemically active particles in the plasma.

Discussion

Obtained results show that in conditions of the experiment [5] in the combine discharge the generation of active particles takes place. At that the strong excitation of the media can lead to quick transformations of active radicals (O) to other particles (NO), which are not of great interest from the point of view of plasma assisted combustion. So there is a question if the process of O atoms transformation to molecules NO is important in case of gas discharges with strong excitation of molecules, say in discharges with high parameter E/N ~ 3 $\cdot 10^{-15}$ V$\cdot$cm^2 (300 Td).

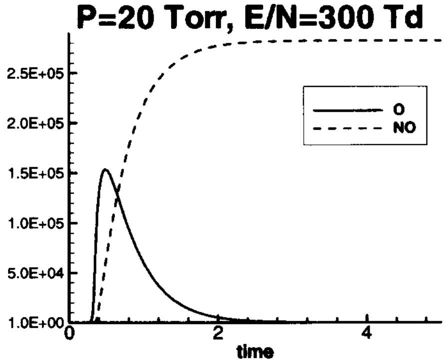
P=20 Torr, E/N=300 Td

Fig.9 Temporary evolution of O and NO concentrations at strong excitation in the glow discharge at 20 Torr

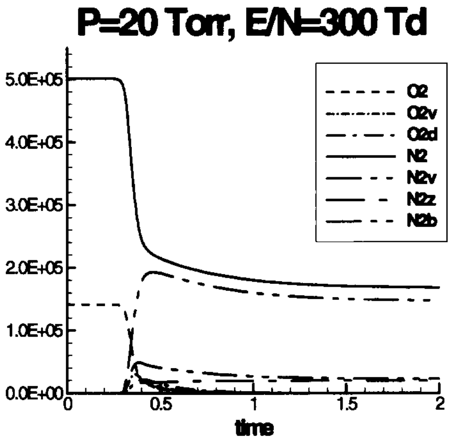
P=20 Torr, E/N=300 Td

Fig.10. Temporary excitation of excited molecules at strong excitation in the glow discharge at 20 Torr

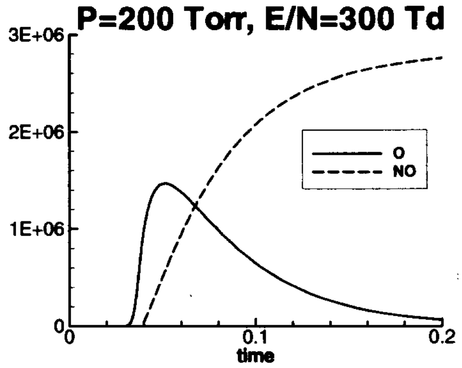
P=200 Torr, E/N=300 Td

Fig.11 Temporary evolution of O and NO concentrations at strong excitation in the glow discharge at 200 Torr

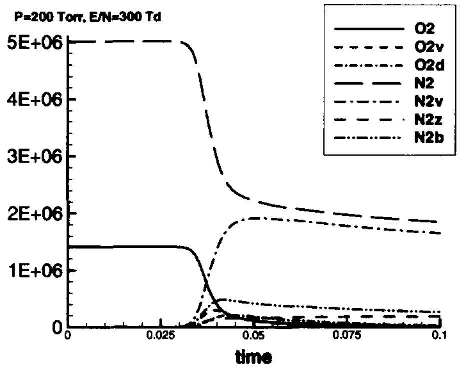

Fig.12. Temporary evolution of excited molecules at strong excitation in the glow discharge at 200 Torr (concentrations are in 10^{12} cm^{-1}, time is in μs).

We have calculated temporary evolutions of excited and chemically active particles in these conditions. One can see from Fig.9-12 that in the case of the glow discharge at high E/N values the quick transformation of atoms O into NO also takes place, and even more sharp decreasing of O2 molecule concentrations is observed. So it can be supposed that namely the processes with these particles, but not with excited ones, put limits to the temporary ranges of applicability of glow discharges with the strong molecule excitation to the combustion problems.

Conclusions

On a basis of the combined discharge model it was revealed that this discharge can realize the selective generation of atoms O, molecules NO and decreasing of O_2 molecule concentration in the plasma.

Note that independent variation of the E/N value and the rate of fast electron-gas excitation W in the combined discharge allows to optimize the stimulating combustion processes in a flow.

It was shown in the presented work that the transformation of the oxygen atoms O into molecules NO and sharp decreasing of the O_2 molecule concentrations at strong discharge –gas excitation (high values of E/N parameter) puts limits to typical times of their application for the combustion problems.

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