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KINETIC COOLING OF AN ATMOSPHERE IN LASER RADIATION EFFECT ON MIXTURE OF THE ATMOSPHERIC GASES

Within the refined 3-model model of kinetic processes there is quantitatively examined an effect of atmosphere kinetic cooling while passing powerful laser radiation through a mixture of CO_2*-*N_2*-*H_20 *atmospheric gases.*

Key words: *atmosphere cooling, powerful laser radiation, mixture of atmospheric gases*

At present time it is of a great importance investigation of the powerful laser radiation interaction with an atmosphere (atmospheric gases) and search of new non-linear optical atmospheric effects (c.f.[1-15]).. The latter is directly related with problems of modern laser (lidar) meteorology. From the pointview of an atmospheric physics non-linear optical effects in an atmosphere could find quite simple qualitative explanation within microscopic level. Really, one should say about a redistribution of molecules on the energy levels of internal degree of freedom in the resonant absorption of IR laser radiation by the atmospheric molecular gases. As a result of quite complicated processes one could define an essential changing of the gases absorption coefficient due to the saturation of absorption [1]. One of the most interesting effects to be mentioned is an effect of the kinetic cooling of environment (mixture of gases), as it was at first predicted in ref. [2,5]. Usually the effect of kinetical cooling (CO_2) in a process of absorption of the laser pulse energy by molecular gas is considered for the middle latitude atmosphere and for special form of a laser pulse.

In series of papers (see, for example, [8-11]) computational modelling energy and heat exchange kinetics in the mixture of the CO_2-N_2-H_20 atmospheric gases interacting with IR laser radiation has been carried out within master three-mode kinetical model. It is obvious that using more precise values for all model constants and generally speaking the more advanced atmospheric model parameters may lead to quantitative changing in the temporary dependence of the resonant absorption coefficient by CO_2. So, in the last there are developed more refined, advanced models [12-15] regarding determination of the atomic and molecular constants and correspondingly interaction of the atoms and molecules of the atmosphere gases with a powerful laser radiation. Let us remind that the creation and accumulation of the excited molecules of nitrogen owing to the resonant transfer of excitation from the molecules CO_2 results in the change of environment polarizability. Perturbing the complex conductivity of environment, all these effects are able to transform significantly the impulse energetics of IR lasers in an atmosphere and significantly change realization of different non-linear laser-aerosol effects. This paper, which goes on our work on atmospheric optics and photochemistry [8-15], is devoted to quantitative examination of an atmosphere kinetic cooling effect while passing powerful laser radiation through a mixture of CO_2-N_2-H_20 atmospheric gases..

As usually, we start from the modified three-mode model of kinetic processes (see, for example, [11]) in order to take into consideration the energy exchange and relaxation processes in the CO_2.– N_2 – H_2O mixture interacting with a laser radiation. As in ref. [11-13] we consider a kinetics of three levels: 10°0, 00°1 (CO_2) and v = 1 (N_2). Availability of atmospheric constituents O_2 and H_2O is allowed for the definition of the rate of vibrating-transitional relaxation of N_2. The system of balance equations for relative populations is written in a standard form as follows:

$$\frac{dx_1}{dt} = -\beta(\omega + 2gP_{10})x_1 + \beta\omega x_2 + 2\beta gP_{10})x_1^0,$$
$$\frac{dx_2}{dt} = \omega x_1 - (\omega + Q + P_{20})x_2 + Qx_3 + P_{20}x_2^0, \qquad (1)$$
$$\frac{dx_3}{dt} = \delta Qx_2 - (\delta Q + P_{30})x_3 + P_{30}x_3^0.$$

Here the following notations are used:

$$x_1 = N_{100}/\,N_{\mathrm{CO_2}}\,, x_2 = N_{001}/\,N_{\mathrm{CO_2}}\,,\ x_3 = \delta N_{\mathrm{N_2}}\,/\,N_{\mathrm{CO_2}}\,, \qquad (2)$$

where N_{100}, N_{001} are the level populations 10°0, 00°1 (CO_2); $N_{\mathrm{N_2}}$ is the level population v = 1 (N_2); $N_{\mathrm{CO_2}}$ is the concentration of CO_2 molecules; δ is the ratio of the common concentrations of CO_2 and N_2 in the atmosphere ($\delta = 3.85\cdot10^{-4}$); x_1^0, x_2^0 and x_3^0 are the equilibrium relative values of populations under gas temperature T:

$$x_1^0 = \exp\left(-E_1/T\right),\ \ x_2^0 = x_3^0 = \exp\left(E_2/T\right). \qquad (3)$$

The values E_1 and E_2 in (1) are the energies (K) of levels 10°0, 00°1 (consider the energy of quantum N_2 equal to E_2); P_{10}, P_{20} and P_{30} are the probabilities (s^{-1}) of the collisional deactivation of levels 10°0, 00°1 (CO_2) and v = 1 (N_2), Q is the probability (s^{-1}) of resonant transfer in the reaction $CO_2 \rightarrow N_2$,ω is the probability (s^{-1}) of CO_2 light excitation, $g = 3$ is the statistical weight of level 02°0, $\beta = (1+g)^{-1} = 1/4$.

As usually, the solution of the differential equations system (1) allows defining a coefficient of absorption of the radiation by the CO_2 molecules according to the formula:

$$\alpha_{\mathrm{CO_2}} = \sigma(x_1 - x_2)N_{\mathrm{CO_2}}\,. \qquad (4)$$

The σ in (4) is dependent upon the thermodynamical medium parameters as follows [2]:

$$\sigma = \sigma_0\,\frac{P}{P_0}\left(\frac{T}{T_0}\right)^{1/2}, \qquad (5)$$

Here T and p are the air temperature and pressure, σ_0 is the cross-section of resonant absorption under $T = T_0$, $p = p_0$. The absorption coefficient for carbon dioxide and water vapour is dependent upon the thermodynamical parameters of aerosol atmosphere. In particular, for radiation of CO_2-laser the coefficient of absorption by atmosphere defined as

$$\alpha_g = \alpha_{\mathrm{CO_2}} + \alpha_{\mathrm{H_2O}}$$

is equal in conditions, which are typical for summer mid-latitudes, $\alpha_g(H{=}0) = 2.4\cdot10^6$ cm^{-1}, from which $0.8\cdot10^6$ cm^{-1} accounts for CO_2 and the rest – for water vapour (data are from ref. [2]) . On the large heights the sharp decrease of air moisture occurs and absorption coefficient is mainly defined by the carbon dioxide.

In Refs. [11] we have presented accurate our data for the relative coefficient of absorption $\overline{\alpha}_{\mathrm{CO_2}}$, which is normalized on the linear coefficient of absorption, calculated using (1) on corresponding height H. All data for $\overline{\alpha}_{\mathrm{CO_2}}$ are obtained for the height distribution of the pressure and temperature according to the advanced mid-latitude atmospheric model (all data are presented in series of refs. [1,16-19]).

When the resonant interaction of intense radiation of a CO2 - laser gas then the real part of the complex permittivity is changed

$$\varepsilon_N = \frac{\partial \varepsilon}{\partial \rho}\Delta\rho + \frac{\partial \varepsilon}{\partial \chi}\Delta\chi \tag{6}$$

where $\Delta\rho$ and $\Delta\chi$ - perturbation of the density and polarizability of the medium.

Change in density is caused by heating or cooling of the gas in the absorption of laser energy by molecular gas. The bulk density of the heat sources is expressed as follows:

$$q_T = \alpha_{H_2O} I + q_{T\,CO_2}; \tag{7}$$

$$q_{T_{CO_2}} = E_1 P_{10}\left(N_{100} - N_{100}^0\right) + E_2 P_{20}\left(N_{001} - N_{001}^0\right) + E_2 P_{30}\left(N_{N_2} - N_{N_2}^0\right). \tag{8}$$

As can be seen from Eq. (7), the first term in this expression describes the evolution of heat due to the absorption of light energy by water vapor, the second term describes the energy flow in to translational degrees of freedom due to the vibrational relaxation of CO_2 and N_2. Heating of the gas steam does not compensate for its carbon dioxide cooling. The effect of kinetic cooling disappears at a certain critical intensity [1,2]. This is due to the fact that at high intensities the flow of energy from the translational degrees of freedom in the vibrational responsible reaches its maximum value and becomes independent of the incident radiation power. But the flow of energy to the translational degrees of freedom due to the absorption of radiation by water vapor, leading to the heating of the gas, is proportional to the radiation power. Therefore, starting from a certain critical power, heating the gas will dominate the cooling it for any time. For estimates, the altitude distributions of pressure and temperature are selected in accordance with the mid-latitude atmosphere model [9]. The final qunatitative estimate is as follows

$$\alpha_{\mathrm{H_2O}}^0 < (E_1/(E_2 - E_1))\alpha_{\mathrm{CO_2}}^0 = 1.48\alpha_{\mathrm{CO_2}}^0 \tag{9}$$

and it corresponds to the evolution of an effect of kinetic cooling.

References

1. *Zuev V.E., Zemlyanov A.A., Kopytin Y.D., Kuzikovsky A.V.* Powerful laser radiation in an atmospheric aerosol.-Novosybirsk, 1984.-224p.
2. *Zuev V.E., Zemlyanov A.A., Kopytin Y.D.* Nonlinear Optics of Atmosphere.- L.:Hidrometeoizd., 1991.-256p.
3. Bagratashvili V.N., Letokhov V.S., Makarov A.A., Ryabov E.A. Multi-Photon Processes in Molecules in Infrared laser field.-M.: Nauka,1991-180p.
4. *Bates N.R., Merlivat L.* The influence of short-term wind variability on air-sea CO2 exchange // Geophysical Research Letters. – 2001. – Vol. 28. – No. 17. – P. 3281-3284.
5. Gordiets B.F., Osipov A.I., Khokhlov R.V. About cooling the gas under powerful CO_2 laser radiation passing in atmosphere// J.Techn.Phys.-1974.-Vol.14.-P.1063-1069.
6. *Glushkov A.V., Khokhlov V.N., Prepelitsa G.P., Tsenenko I.A.* Temporal variability of the atmosphere ozone content: Effect of North-Atlantic oscillation// Optics of atmosphere and ocean.-2004.-Vol.14,N7.-p.219-223.

7. *Stephens B.B., Keeling R.F., Heimann M., Six K.D., Murnane R., Caldeira K.* Testing global ocean carbon cycle models using measurements of atmospheric O_2 and CO_2 concentration // Global Biogeochemical Cycles. – 1998. – Vol. 12. – No. 2. – P. 213-230.
8. Glushkov A.V., Ambrosov S.V., Malinovskaya S.V. etal, Spectroscopy of carbon dioxide: Oscillator strengths and energies of transitions in spectra of CO_2 // Optics and Spectroscopy.- 1996.- T.80,N1.-C.60-65.
9. *Turin A.V., Prepelitsa G.P., Kozlovskaya V.P.*, Kinetics of energy and heat exchange in mixture CO_2-N_2-H_20 of atmospheric gases interacting with IR laser radiation: Precise 3-mode kinetical model// Phys. Aerodisp. Syst.-2003.-N40.-P.123-128.
10. *Glushkov A.V., Malinovskaya S.V.,Shpinareva I.M., Kozlovskaya V.P., Gura V.I.* Quantum stochastic modelling energy transfer and effect of rotational and V-T relaxation on multiphoton excitation and dissociation for CF_3Br molecules// Int. Journ.Quant.Chem.-2005.-Vol.104,N(5).-P.512-520.
11. *Prepelitsa G.P., Bunyakova Yu., Korban V.Kh., Seredenko S.S., Karpenko A.* Photokinetics of the IR laser radiation effect on mixture of the CO_2-N_2-H_20 gases: advanced atmospheric model//Photoelectronics.-2009.-N18.-P.36-39.
12. *Glushkov A.V., Khetselius O.Yu., Svinarenko A.A., Mischenko E.V., Florko T.A.* Optimized perturbation theory scheme for calculating the interatomic potentials and hyperfine lines shift for heavy atoms in the buffer inert gas//Int. Journ. of Quantum Chemistry.-2009.-Vol.109,N14.-P.3325-3329.
13. *Glushkov A.V., Khetselius O.Yu., Svinarenko A.A., Prepelitsa G.P. , Shakhman A.N.* Spectroscopy of cooperative laser-electron nuclear processes in diatomic and multiatomic molecules//Spectral Lines Shape (AIP, USA).-2010.-Vol.16.-P.269-273.
14. Fedchuk A.P., Glushkov A.V., Lepikh Ya.I., Svinarenko A.A., Loboda A.V., Lopatkin Yu.M. The Green's functions and density functional approach to vibrational structure in the photoelectron spectra of carbon oxide molecule//Photoelectr.-2010.-N19.-P.115-120.
15. *Khetselius O.Yu., Florko T.A., Svinarenko A.A., Tkach T.B.* Radiative and collisional spectroscopy of hyperfine lines of the Li-like heavy ions and Tl atom in an atmosphere of inert gas//Physica Scripta (IOP, London).-2013.- Vol.T153-P.01437 (5p.).
16. *Wang, C.* ENSO, climate variability, and the Walker and Hadley circulations. The Hadley Circulation: Present, Past, and Future (Eds H. F. Diaz and R. S. Bradley). Springer (2004).
17. *Boer G.J., Sargent N.E.* Vertically integrated budgets of mass and energy for the globe // J. Atmos. Sci. – 1985. – Vol. 42. – P. 1592-1613.
18. *Trenberth K.E., Stepaniak D.P., Caron J.M.* Interannual variations in the atmospheric heat budget // J. Geophys. Res. – 2002. – Vol. 107. – P. 4-1 – 4-15.
19. *Fyfe J.C., Boer G.J., Flato G.M.* Predictable winter climate in the North Atlantic sector during the 1997–1999 ENSO cycle // Geophysical Research Letters. – 1999. – Vol. 26. – No. 21. – P. 1601-1604.

Кінетична охолодження атмосфери при взаємодії потужного лазерного випромінювання з сумішшю атмосферних газів

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В рамках уточненої 3-модової моделі кінетичних процесів кількісно досліджений ефект кінетичного охолодження атмосфери при проходженні потужного лазерного випромінювання через суміш CO_2-N_2-H_20 *атмосферних газів.*

Ключові слова: *охолодження атмосфери, потужне лазерне випромінювання, суміш атмосферних газів*

Кинетическая охлаждение атмосферы при взаимодействии мощного лазерного излучения со смесью атмосферных газов

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В рамках уточненной 3-модовой модели кинетических процессов количественно исследован эффект кинетического охлаждения атмосферы при прохождении мощного лазерного излучения через смесь CO_2-N_2-H_20 *атмосферных газов.*

Ключевые слова: *охлаждение атмосферы, мощное лазерное излучение, смесь атмосферных газов*