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STUDYING PHOTOKINETICS OF THE IR LASER RADIATION EFFECT ON MIXTURE OF THE CO2-N2-H20 GASES FOR DIFFERENT ATMOSPHERIC MODELS

A kinetics of energy exchange in the mixture of the atmosphere CO_2-N_2-H_20 gases under passing the powerful CO_2 laser radiation pulses within the three-mode model of kinetical processes is studied. More accurate data for the absorption coefficient are presented.

At present time the environmental physics has a great progress, provided by implementation of the modern quantum electronics and laser physics methods and technologies in order to study unusual features of the "laser radiation- substance (gases, solids etc.) interaction. A special interest attracts a problem of interaction of the powerful laser radiation with an aerosol ensemble and search of new non-linear optical effects. The latter is directly related with problems of modern aerosol laser physics (c.f.[1-13]). One could remind that there is 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 interesting effect else 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. Besides, the approximate values for constants of collisional deactivation and resonant transfer in reaction CO_2-N_2 are usually used. In series of papers (see, for example, [11-13], computational modelling of the 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 the general 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.

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.

The aim of this paper is to present more accurate data for kinetics of energy and heat exchange in the mixture CO_2-N_2-H_20 gases in atmosphere under passing the powerful CO_2 laser radiation pulses on the basis of using the more advanced atmospheric model and more precise values for all kinetical model constants.

As usually, we start from the modified three-mode model of kinetic processes (see, for example, [1,11-13] 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:

$$\frac{dx_1}{dt} = -\beta(\omega + 2gP_{10})x_1 + \beta\omega x_2 + 2\beta gP_{10} x_1^0,$$

$$\frac{dx_2}{dt} = \omega x_1 - (\omega + Q + P_{20})x_2 + Qx_3 + P_{20} x_2^0,$$

$$\frac{dx_3}{dt} = \delta Qx_2 - (\delta Q + P_{30})x_3 + P_{30} x_3^0. \tag{1}$$

Here the following notations are used:

$$x_1 = N_{100}/N_{CO_2},$$
$$x_2 = N_{001}/N_{CO_2}, \tag{2}$$
$$x_3 = \delta N_{N_2}/N_{CO_2},$$

where $N_{100,}$ N_{001} are the level populations 10°0, 00°1 (CO_2); N_{N_2} is the level population v = 1 (N_2); N_{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 ($\delta = 3.85\times10^{-4}$); x_1^0 , x_2^0 and x_3^0 are the equilibrium relative values of populations under gas temperature T:

$$x_1^0 = \exp(-E_1/T),$$
$$x_2^0 = x_3^0 = \exp(E_2/T); \tag{3}$$

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:

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

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

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

Here T and p are the air temperature and pressure, σ_0 is the cross-section of resonant absorption under $T = T_0$, $p = p_0$. One could remind that 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 $\alpha_g = \alpha_{CO_2} + \alpha_{H_2O}$ 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.

The changing population of the low level 10°0 (CO_2), population of the level 00°1, the vibrating-transitional relaxation (VT-relaxation) and the inter modal vibrating-vibrating relaxation (VV'-relaxation) processes define the physics of resonant absorption processes. Moreover, the above indicated processes result in a redistribution of the energy between the vibrating and transitional freedom of the molecules. According to ref.[1], the threshold value, which corresponds to the decrease of absorption coefficient in two times, for the strength of saturation of absorption in vibrating-rotary conversion give $I_{sat} = (2 \div 5)$ 10^5 W cm^{-2} for atmospheric CO_2. In this case the pulse duration t_i must satisfy the condition $t_R \ll t_i < t_{VT}$, where t_R and t_{VT} are the times of rotary and vibrating-transitional relaxation's. by The fast exchange of level 10°0 with basic state, and by the relatively slow relaxation of high level 00°1define a renewal process of thermodynamic equilibrium is characterized. The latter provides an energy outflow from the transitional degree of freedom onto vibrating ones and in the cooling of environment. It is easily understand that using more powerful laser radiation sources can lead to a strong non-linear interaction phenomena and, as result, significantly change a photo-kinetics of the corresponding processes.

In table 1 we present mode accurate our data (column C) for the relative coefficient of absorption $\overline{\alpha}_{O\ 2}$, which is normalized on the linear coefficient of absorption, calculated using (1) on corresponding height *H*. All data for $\overline{\alpha}_{O\ 2}$ 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. [14-20]). In table 1 there are presented also the analogous data from ref. [2] (column A) , from ref. [13] (column B).

Table 1.

Temporary dependence of resonant absorption relative coefficient $\overline{\alpha}_{O\ 2}$ (sm^{-1}) of laser radiation (λ=10,6μm) by CO_2 for rectangular (R) laser pulses (intensity I=10^5 W/sm^2) on the height (H, km) for the mid-latitude atmospheric model [1]: A- data of modelling [2]; B- data of modelling [13], C- data of modelling [14], D- this work

T μs	A [2] 10×I; R H=0	A[2] 10×I;R H=10	B [13] 10×I; G H=0	B [13] 10×I; G H=10
0	1,0	1,0	1,0	1,0
1	0,60	0,12	0,57	0,13
2	0,52	0,08	0,46	0,05
3	0,63	0,27	0.59	0,19
4	0,67	0,35	0,64	0,28
T μs	C [14] 10×I; G H=0	C [14] 10×I; G H=10	D, this 10×I; G H=0	D, this 10×I; G H=10
0	1,0	1,0	1,0	1,0
1	0,54	0,11	0,54	0,11
2	0,42	0,04	0,42	0,04
3	0.57	0,16	0.57	0,16
4	0,60	0,25	0,60	0,25

In Refs.[2 13,14] the analogous data for the relative coefficient of absorption $\overline{\alpha}_{O\ 2}$ and the height distribution of pressure and temperature are presented and obtained in a case of using the Odessa-latitude atmospheric conditions according to atmospheric model [7,8]. Here we use the world standard atmospheric model conditions [14-20]. Important moment is also connected with the more correct choice of probabilities P_{10}, P_{20} and P_{30} of the collisional deactivation of levels 10°0, 00°1 (CO_2) and v = 1 (N_2), probability *Q* of resonant transfer in the reaction $CO_2 \rightarrow N_2$, probability ω of CO_2 light excitation and other constants in comparison with refs. [2,13]. Let us in conclusion to note that obviously a quality of choice of the corresponding molecular constants and the corresponding atmospheric model parameters is of a great importance in modelling the effect of kinetic cooling of the CO_2 under propagation of the laser radiation in atmosphere. Naturally, principally another situation will occur in a case of the super intense laser pulses using for the atmosphere monitoring. Obviously, the modified model of photokinetical processes is to be developed in this case.

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Abstract. A kinetics of energy exchange in the mixture of the atmosphere CO_2-N_2-H_20 gases under passing the powerful CO_2 laser radiation pulses within the three-mode model of kinetical processes is studied. More accurate data for the absorption coefficient are presented.

Key words: photokinetics, laser field, mixture of gases, atmospheric model

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ИЗУЧЕНИЕ ФОТОКИНЕТИКИ ВЗАИМОДЕЙСТВИЯ ИК ЛАЗЕРНОГО ИЗЛУЧЕНИЯ СО СМЕСЬЮ CO_2-N_2-H_20 ГАЗОВ ДЛЯ РАЗНЫХ АТМОСФЕРНЫХ МОДЕЛЕЙ

Резюме. Рассмотрена фотокинетика энергообмена в смеси CO_2-N_2-H_20 атмосферных газов при прохождении через атмосферу мощного излучения CO_2 лазера в рамках уточненной 3-модовой модели кинетических процессов. Получены более точные значения коэффициента поглощения.

Ключевые слова: фотокинетика, лазерное поле, смесь газов, атмосферная модель

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ДОСЛІДЖЕННЯ ФОТОКІНЕТИКИ ВЗАЄМОДІЇ ІЧ ЛАЗЕРНОГО ВИПРОМІНЮВАННЯ ІЗ СУМІШЕЙ CO_2-N_2-H_20 ГАЗІВ ДЛЯ РІЗНИХ АТМОСФЕРНИХ МОДЕЛЕЙ

Резюме. Розглянуто фотокінетику енергообміну у сумішу CO_2-N_2-H_20 атмосферних газів при проходженні скрізь атмосферу міцного випромінювання CO_2 лазера у межах уточненої 3-модової моделі кінетичних процесів. Отримані більш точні оцінки для коефіцієнта поглинання.

Ключові слова: фотокінетика, лазерне поле, суміш газів, атмосферна модель