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 CO2-N2-H20 gases under passing the powerful CO2 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 (CO2) 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 CO2-N2 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 CO2-N2-H20 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 CO2.

Let us remind that the creation and accumulation of the excited molecules of nitrogen owing to the resonant transfer of excitation from the molecules CO2 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 CO2-N2-H20 gases in atmosphere under passing the powerful CO2 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 CO2-N2-H20 mixture interacting with a laser radiation. As in ref. [11-13] we consider a kinetics of three levels: 10°0, 00°1 (CO2) and v = 1 (N2). Availability of atmospheric constituents O2
and H₂O is allowed for the definition of the rate of vibrating-transitional relaxation of N₂. The system of balance equations for relative populations is written in a standard form as follows:

\[
\frac{dx_1}{dt} = \omega x_1 - (\omega + Q + P_{20}) x_2 + Q x_3 + P_{20} x_0^0,
\]

\[
\frac{dx_2}{dt} = \delta Q x_2 - (\delta Q + P_{30}) x_3 + P_{30} x_0^0.
\]

Here the following notations are used:

\[
x_i = N_{100}/N_0 ,
\]

\[
x_2 = N_{001}/N_0 ,
\]

\[
x_3 = \delta N_{10}/N_0 ,
\]

where \( N_{100}, N_{001} \) are the level populations \( v=1 \) (\( N_2 \)); \( N_0 \) is the concentration of CO₂ molecules; \( \delta \) is the ratio of the common concentrations of CO₂ and \( N_2 \) in the atmosphere (\( \delta = 3.85 \times 10^{-4} \)); \( x_1^0, x_2^0 \) and \( x_3^0 \) are the equilibrium relative values of populations under gas temperature \( T \):

\[
x_1^0 = \exp(-E_1/T),
\]

\[
x_2^0 = \exp(E_2/T); \quad (3)
\]

The values \( E_1 \) and \( E_2 \) in (1) are the energies (K) of levels \( 10^0, 00^1 \) (CO₂) ; \( P_{10}, P_{20} \) and \( P_{30} \) are the probabilities (s⁻¹) of the collisional deactivation of levels \( 10^0, 00^1 \) (CO₂) and \( v = 1 \) (\( N_2 \)); \( Q \) is the probability (s⁻¹) of resonant transfer in the reaction \( \text{CO}_2 \rightarrow N_2 \omega \) is the probability (s⁻¹) of CO₂ 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 CO₂ molecules according to the formula:

\[
\alpha_{0} = \sigma_0 \frac{P}{R_0} \left( \frac{T}{T_0} \right)^{1/2}, \quad (5)
\]

Here \( T \) and \( P \) are the air temperature and pressure, \( \sigma_0 \) 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 CO₂-laser the coefficient of absorption by atmosphere defined as

\[
\alpha_{g} = \alpha_{\text{O}2} + \alpha_{\text{H}_{2}O} \text{ is equal in conditions, which are typical for summer mid-latitudes, } \alpha_{g} (H=0) = 2.4 \times 10^6 \text{ cm}^{-1}, \text{ from which } 0.8 \times 10^6 \text{ cm}^{-1} \text{ accounts for CO₂ and the rest – for water vapour (data are from ref. [2]). On the large heights the sharp decrease of air moisture occurs and absorption coefficient is mainly defined by the carbon dioxide.}
\]

The changing population of the low level \( 10^0 \) (CO₂), 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 \( I_{sat} = (2 \div 5) \times 10^6 \) W cm⁻² for atmospheric CO₂. In this case the pulse duration \( t \) must satisfy the condition \( t \ll t_i < t_{i+1} \), where \( t_i \) and \( t_{i+1} \) 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 \( 00^1 \) define 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 $\tau_{O_2}$, which is normalized on the linear coefficient of absorption, calculated using (1) on corresponding height $H$. All data for $\tau_{O_2}$ 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.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>1</td>
<td>0,60</td>
<td>0,12</td>
<td>0,57</td>
<td>0,13</td>
</tr>
<tr>
<td>2</td>
<td>0,52</td>
<td>0,08</td>
<td>0,46</td>
<td>0,05</td>
</tr>
<tr>
<td>3</td>
<td>0,63</td>
<td>0,27</td>
<td>0,59</td>
<td>0,19</td>
</tr>
<tr>
<td>4</td>
<td>0,67</td>
<td>0,35</td>
<td>0,64</td>
<td>0,28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T μs</th>
<th>C [14] 10×I; G H=0</th>
<th>C [14] 10×I; G H=10</th>
<th>D, this 10×I; G H=0</th>
<th>D, this 10×I; G H=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>1</td>
<td>0,54</td>
<td>0,11</td>
<td>0,54</td>
<td>0,11</td>
</tr>
<tr>
<td>2</td>
<td>0,42</td>
<td>0,04</td>
<td>0,42</td>
<td>0,04</td>
</tr>
<tr>
<td>3</td>
<td>0,57</td>
<td>0,16</td>
<td>0,57</td>
<td>0,16</td>
</tr>
<tr>
<td>4</td>
<td>0,60</td>
<td>0,25</td>
<td>0,60</td>
<td>0,25</td>
</tr>
</tbody>
</table>

In Refs.[2,13,14] the analogous data for the relative coefficient of absorption $\tau_{O_2}$ 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 $\omega$ 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.

**References**

6. Glushkov A., Malinovskaya S., Shpinareva I., Kozlovskaya V., Gura V., Quantum stochastic modelling energy transfer and effect of rotational and V-T relaxation on multiphoton excitation and dissociation for $CF_3Br$ molecules//


This article has been received in May 2016
STUDYING PHOTOKINETICS OF THE IR LASER RADIATION EFFECT ON MIXTURE OF THE CO\textsubscript{2}-N\textsubscript{2}-H\textsubscript{2}O GASES FOR DIFFERENT ATMOSPHERIC MODELS

Abstract. A kinetics of energy exchange in the mixture of the atmosphere CO\textsubscript{2}-N\textsubscript{2}-H\textsubscript{2}O gases under passing the powerful CO\textsubscript{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.