EXPERIMENTS ON THE HF CW CHEMICAL LASER BEAM PROPAGATION THROUGH A LAYER OF A DISPERSE ABSORBING MEDIUM AT LOW PRESSURE

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Received December 21, 1993

This paper presents a study of the extinction process of a HF cw chemical laser beam when passing through a moving multicomponent and polydisperse medium composed of particles of carbon and magnesium oxide about 1 μm *in size at an ambient pressure of* 50 Pa . *We also describe in the paper an experimental complex developed for studying the processes of light interaction with disperse media of different densities under conditions of low–pressure atmosphere. Numerical values of the volume extinction coefficient are given as a function of particles flow density.*

Interest in the problem of laser beam propagation through the atmosphere is stimulated by great potentials of laser system applications. One of the most attractive systems is a laser complex based on cw HF (DF) chemical lasers for sounding of the atmosphere from the space . They are preferable, first of all, due to high powerful parameters and relatively small size and weight required of devices onboard the space ship.

In this connection a study of interaction of HF cw chemical laser (CWCL) beam with different constituents of the atmosphere seems to be important. The small disperse particles of anthropogenic origin are the most significant among the atmospheric constituents. The amount of these particles in upper atmosphere has increased due to their emission as the products of combustion of rocket propellant in the last few years. The characteristics of these particles differ from those of the ordinary atmospheric aerosol.[1,2] Besides, the wavelength of the HF CWCL is rather specific to studying the problems in sounding of the atmosphere, since this laser is unique to some degree.

The circumstances enumerated predetermine insufficient knowledge of the processes of interaction between the HF CWCL radiation and the above–mentioned small disperse particles. The experiments on studying of these processes are difficult, since the needed laboratory equipment including a laser source, generator of small disperse particles, and model of ambient conditions is rather complicated.

In this paper we present a description of the experimental complex designed to perform such investigations as well as the data on propagation of the HF CWCL beam through a layer of moving soot disperse particles produced by a pyrotechnic generator at the low pressure ($\lesssim$ 50 Pa) of ambient medium. The radiant flux density did not exceed 3 MW/m.^{2}

The experimental complex developed enables one to carry out the investigations on interaction between the HF CWCL beam and small disperse particles by means of wide variation in the parameters of radiation, small disperse particle medium, and ambient conditions.

The experimental complex includes HF CWCL source, experimental assembly, pyrotechnic generator producing a disperse medium, optical scheme, measuring and automatic control systems, and supplying systems.

The main specific features of the laser source are the following. The nozzle unit and CWCL optical cavity are mounted in a vacuum chamber connected with the vacuum system of 2100 m^3 volume by a pipeline of large diameter. It is pumped off to the rest pressure of 50 Pa. The reaction products are exhausted from the nozzle unit into this system. In fact, the lasing time is limited by the pressure increase time inside the vacuum chamber and comes to 15–17 s. The laser output power reaches some tens of kilowatts. The HF CWCL used is a test universal installation. All other units of the complex are developed taking into account the specific features of this installation and existing limitations (in size, reliability, lifetime, and security requirements).

One of the main parts is experimental assembly. It is intended for producing the small disperse particle flow with required parameters under low–pressure conditions. The layout of the experimental assembly is shown in Fig. 1. It includes a channel for forming a flow of disperse medium *2*, measuring channel *1* provided with windows for inputing the radiation and measuring, connecting neck *3*, prefabricated capacity *4*, and optical bench *5*. The channels *1*, *2*, the neck *3*, and the capacity *4* form the closed volume that can be pumped off. The disperse medium produced by a model generator is supplied into the formation channel *2*, then into the measuring channel, and finally through the neck *3* into the capacity *4* connected with the vacuum system of the installation. The cross section of the measuring channel in the window plane is shown in Fig. 1. In the additional pipes for windows fixing the special annular nozzles are mounted for blowing off the optics and preventing its contamination by disperse medium particles.

A device for control over particles flow density is mounted inside channels *1* and *2*. It consists of a nozzle *7* and forming assembly *8*. A round nozzle *7* has the rectangular outlet cross section. An assembly *8* has the same cross section. A nozzle *7* is connected with a forming assembly *8* by a maze packing, so the nozzle remains mobile.

0235-6880/94/05 297-04 $02.00

Its motion is provided by a special electric drive. An assembly *8* has flat side–plates which are hermetically held by flanges of channels *1* and *2*. Walls of the channel *2*, forming assembly *8*, and side–plates form a closed volume into which a portion of the gaseous disperse flow is drained. Variation of the particles flow density is provided by control over the ratio of the generator nozzle outlet cross section to the inlet cross section of the forming assembly nozzle.

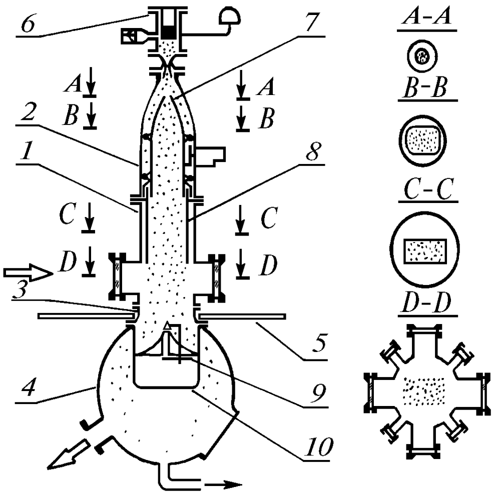


FIG. 1

A device for sampling is mounted on the connecting neck. This monokinetic device contains a calibrated channel with polished walls and a rotating disk *9* with mounted–on sample glass plates. The axes of the channel and disk are parallel and displaced so that the particles could deposit on the peripheral part of the disk. A supersonic sampling apparatus is mounted on the upper section of the channel. Before sampling it is locked by a shutter. At a certain instant it is cleared for a period of one revolution of the disk and a portion of the flow of a disperse medium is deposited on the sample glass plates.

The design of the generator of disperse medium *6* is similar to the rocket solid propellant engine. It is equipped by a blasting cartridge made of the soot forming pyrotechnic substance. The cartridge is manufactured as either end or channel charge (depending on the necessary disperse medium expenditure). The charge combustion results in the gas disperse flow formation with mass content of solid particles up to 70 %.

The optical system of the experimental complex is shown in Fig. 2, where *1* and *11* are the spherical mirrors; *2*, *3*, *10*, *12*, and *23* are the dividing plates; *4*, *8*, and *29* are the bolometric power measurers of duct type; *6* is the measuring channel; *5* and *7* are the windows; *9*, *5*, and *24* are the flat mirrors; *30* is the absorber; *13* is the blacked copper thermally thin screen; *14* is the thermovision scanner; *16*, *21*, and *25* are the lenses; *17* and *26* are the modulators; *18* and *27* are the integrating spheres; *19* and *28* are the pyroelectric MG–30A detectors; *20* is the diaphragm; and, *22* is the thermocouple calorimeter.

Optical elements of the windows in the measuring channel and lenses are made of BaF_2 (CaF_2) while dividing plates are KI quartz.

The laser beam is collimated in the disperse medium by long–focus spherical mirror *1*. Its waist length is longer than the layer thickness of a disperse medium. The dimensions of the waist cross section depend on the laser operation mode and vary from 70×30 to 40×15 mm, the largest dimension being oriented along the particle motion direction.

The measuring system of the complex includes three subsystems: measuring of radiation parameters, disperse medium parameters, and auxiliary parameters. The first subsystem contains: "Coherent Radiation" thermocouple colorimeter, model 201 (USA), two weakly inertial bolometric radiation power measurers of duct type, two MG–30A pyroelectric detectors, and T–800 "AGEMA" thermovision system (Sweden).

The subsystem elements for measuring of the parameters of a disperse medium enable one to measure the speed of particle motion in the channel, mass flow density, particles ensemble dispersity, and mass flow density distribution over the measuring channel cross section. Among these elements are the following: the above–described device for sampling, the laser Doppler anemometer, prefabricated matrix, VLR–20 microanalytic balance, and UEMV–100 V electronic microscope .

The technique for determining the parameters of a laser beam makes it possible to estimate:

– level of radiant flux density,

– extent to which radiation is attenuated by a disperse medium,

– character of radiant intensity distribution over the ray cross section.

The laser radiant flux density at the frontal surface of the disperse medium layer is measured using a thermocouple calorimeter. A portion of radiation is directed onto calorimeter by dividing plates (see Fig. 2).

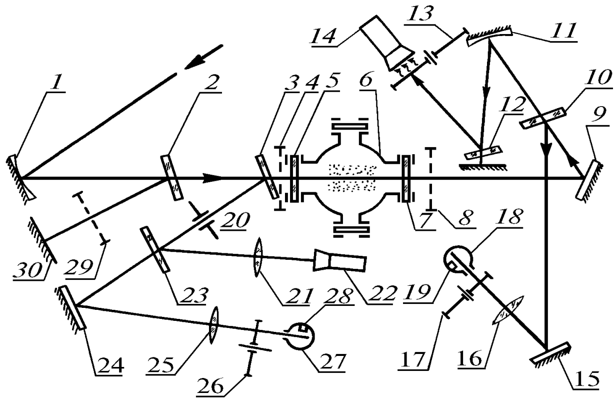


FIG. 2

The radiation extinction by the layer is estimated by using two weakly inertial net bolometers of duct type *4* and *8* positioned immediately before "input" and behind "output" windows of the measuring channel as well as based on records of two pyroelectric detectors *19* and *28*, which are illuminated by a portion of radiation directed from the "input" and "output" of the measuring channel.

The generator of a disperse medium is initiated with a time delay with respect to lasing. Such a delay allows us to record the data from all the sensors in the lack of particles in the measuring channel and to measure the scaling factors for sensor data at the input and output of the measuring channel.

This technique enabled us to carry out the measurements at a certain HF CWCL radiation instability, which was caused by some specific features of its design (exhausting into the vacuum system of a finite volume).

To estimate the laser radiant flux density distribution over the plane normal to the ray direction, a portion of radiation was directed from the output of the disperse medium onto a thin copper screen with a blacked surface, where the ray cross section was imaged. The temperature field in the zone of heating was fixed by a thermovision scanner whose information was sent to the monitor and recorded on the magnetic computer disk. The exposure frequency was equal to 25 frames per second.

The particle velocity in disperse medium flow was measured by a laser Doppler anemometer, and mass density of the particles flow was obtained by sampling. The particle ensemble dispersity was characterized by statistic histogram of particle size distribution plotted using the conventional procedure.

During our experiments the parameters of the disperse medium produced by a pyrotechnic generator were more precisely determined. The X–ray structure analysis of the solid phase demonstrated that the particles, on the average, contain equal amount of carbon and magnesium oxide as well as about 7% of amorphous component which is probably composed of the decomposition products of the internal thermostable coverage of the generator.

The shape, structure, and dispersity of the particles were examined using an UEMV–100 V electron microscope. Two levels were observed in the solid phase structure: microparticles 0.02–0.1 μm in size close to spheric in their shape (about 10%) and primary aggregates consisting of chaotically oriented microparticle ensembles. The shape of primary aggregates differs significantly from spherical. The particle size distribution was described by lognormal function with mathematical expectation of 1 μm and variance of 0.096 μm.

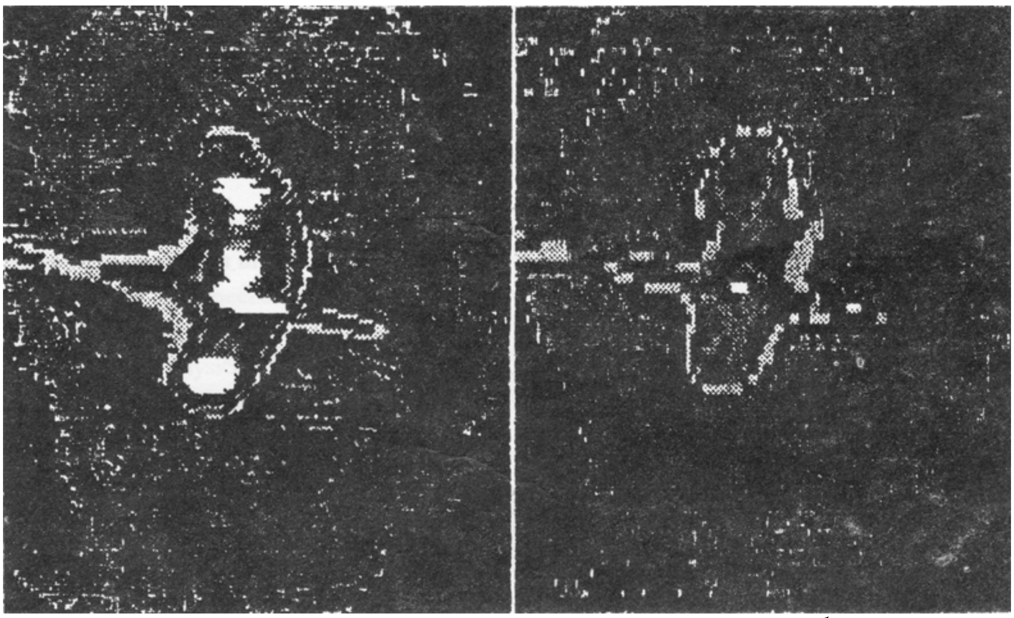
Thus, the particles produced by a pyrotechnic generator are similar to a considerable extent to the small disperse constituent of the anthropogenic pollution in the upper atmosphere.[3]

As carried out investigations show, the complicated chemical composition, polydispersity, and irregular shape of the particles make it difficult to calculate theoretically the optical characteristics of such a medium, that provides support once more for necessity of their experimental measuring.

The mass density $\overline{m}$ was chosen as the main kinetic parameter of the particles flow. It equals the mass of the particles passing through the unit cross section during the unit time. The variation in the mass density m within the range $0.08 < \overline{m} < 0.30$ kg/m^2/s was observed by varying the forming nozzle position. The distribution of the flow density over the cross section of measuring channel was also obtained. It was found to be close to uniform.

The investigation of propagation of HF CWCL beam through the described disperse medium showed that this medium is mainly absorbing at the given wavelength.

This conclusion is based on the distribution of radiant intensity in the output window plane in the lack of the disperse medium in measuring channel (initial distribution) (Fig. 3*a*) and in the presence of a layer of the disperse medium (Fig. 3*b*). One can see from these thermograms that the extinction of radiation is close to uniform over all the square of a spot. There is no spot size increase in this case.



a *b*

FIG. 3

Such a conclusion is confirmed also by input bolometer data (Fig. 2, position *4*). When the generator of a disperse medium is started, there is no increase in the detected radiant intensity. Therefore, that testifies that the intensity of the backscattered radiation is low.

The mainly absorbing origin of extinction for the laser radiation at $\lambda = 2.71$ μm by the disperse medium under investigation is caused, first of all, by its small dispersity. As is shown above, the size of particles are considerably less than the radiation wavelength and therefore the contribution of scattering into extinction is negligible. That is in agreement with theoretical conclusions[2] and available experimental data.[4]

The mass density of particles flow was varied in an additional run of experiments. It was found that the extinction of radiation can be described by the Bouguer equation with sufficient accuracy and the volume extinction factor is directly proportional to the mass density of the particles flow (Fig. 4). It varies from 5–8 m^{-1} at $\overline{m} = 0.1$ kg/m^2/s to 19–21 m^{-1} at $\overline{m} = 0.25$ kg/m^2/s.

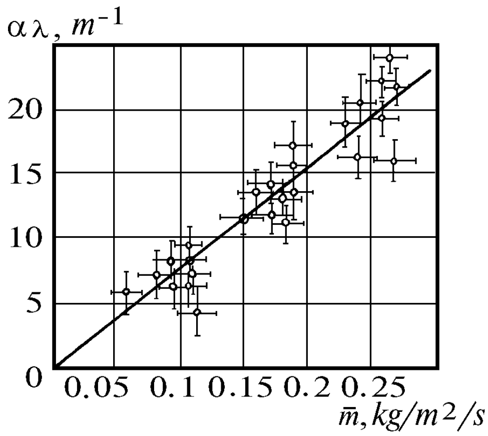


FIG. 4

Thus, the investigation performed demonstrates that the small disperse media of such a composition and origin are strong obstracles for HF CWCL beam propagation through the upper atmosphere due to their shielding effect. This fact is to be taken into account when sounding of different objects from the space using HF CWCL — based systems.

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