It is seen from the results obtained in this paper that the mentioned difference in the action of admixtures of distinct structure on turbulence appears even in the stream acoustic characteristics measurements.

NOTATION

α is the diffusor aperture angle, degrees; ν is the kinematic viscosity, cm^2/sec; λ is the friction drag coefficient; Re is the Reynolds number over the pipeline diameter; P is the acoustic noise signal level, dB, f is frequency, 1/sec; ΔL is the spectral increase determined as the ratio between the sighnal level in a three-octave frequency band in pure water flow and the acoustic signal level in a flow of solutions with surfactant admixtures, dB.

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LASER DIAGNOSTICS OF THE WORKING MEDIUM IN AN ELECTRICAL DISCHARGE CO_2-LASER WITH A CLOSED PUMPING LOOP

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Results are presented of an experimental investigation of the amplifier characteristics and temperature measurements of the upper laser level and the progressive tempeature of the working medium of a pumping electrical discharge CO_2 laser in the range of pumping power variation 18-65 kW. It is shown that growth of the progressive temperature of the active medium is the main reason for degradiation of laser operation efficiency at large (above 50 kW) values of the pumping power.

To a great extent the significant interest in flow-through laser systems with electrical excitation is due to the possibilities of their extensive utilization in various branches of science and engineering. Further perfection of electrical discharge laser apparatus to improve the energetic characteristics depends at this time on the solution of a number of particular problems, such as, say, the creation of a highly efficient system of working medium

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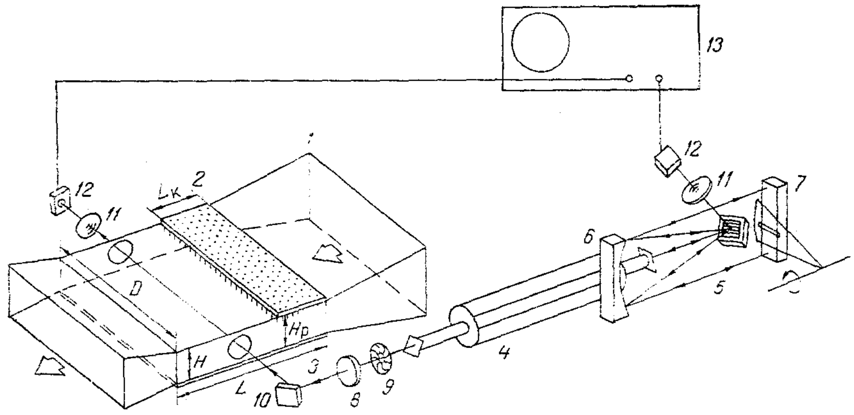

Fig. 1. Working chamber unit and optical diagram for investigation of the gain characteristics of a laser-active medium: 1) working channel; 2) stub cathodes; 3) anode plate; 4) active element of the probing laser; 5) diffraction grating; 6, 7) spherical and flat "opaque" mirrors of the resonator; 8) resonator output semi-opaque mirror; 9) iris diaphragm; 10) rotating mirror; 11) focusing lenses; 12) laser radiation detector; 13) oscilloscope; L = 0.35 m; L_k = 0.082 m; D = 1.27 m; H = 0.075 m; H_p = 0.063.

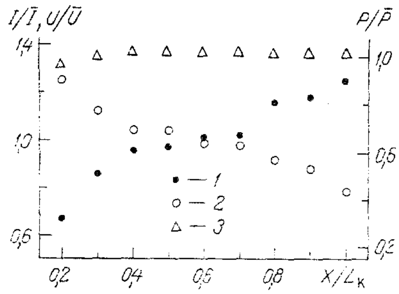

Fig. 2. Change in local current, voltage, and power of the discharge downstream:

1) I/Ī; 2) U/Ū; 3) P/P̄. Pumping rate 100 m/sec, pressure 60 gPa.

stimulation by an electrical discharge, prevention of thermal heating of the lasing-active medium, optimization of stream gasdynamics, organization of effective derivation of lasing energy stored in the gas, etc. Considerable attention is paid in the development of promising technological laser schemes to pumping systems whose correct structure selection mostly governs the laser efficiency as a whole. For a whole manifold of electrical system structures for medium stimulation [1-4] it is sufficiently difficult to make a well-founded deduction about the efficiency of any modification and to point out the path of its future perfection. Indeed, such active medium characteristics, usually determined experimentally, as the gain does not permit a unique determination of the efficiency of the electrical stimulation. The generation power also does not yield a complete representation of the pumping efficiency since it depends substantially on the resonator efficiency. Therefore, it is expedient to use the diagnostics methods that would permit obtaining information about the populations of the lasing levels when estimating the efficiency of active medium stimulation. Among such methods might be the method of determining the vibrational temperatures by recording the spectrum distributions of the active medium gain which was used successfully to diagnose processes in the working media of gasdynamic CO_2-lasers [5]. This method was used in this paper to estimate the efficiency of a stimulation system in a fast flow-though electrical discharge CO_2-laser.

The experiments were performed on the installation of the Institute of Flow-Through Machines of the Polish Academy of Sciences (Gdansk, PPR) [4]. The laser consisted of a work-

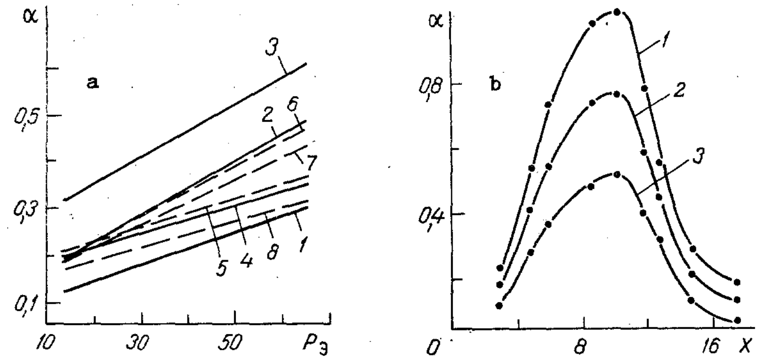

Fig. 3. Dependence of the gain on the magnitude of the power in the discharge gap (a) and on the distance to the first row of stub cathodes (b). Pumping rate 100 m/sec, pressure 60 gPa: a: 1) line P8 of the 00°1-10°0 CO_2 band; 2) P14; 3) P20; 4) P28; 5) R12; 6) R18; 7) R22; ;8) R28; straight lines are the result of processing the experimental data by least squares; b: the line P20 and of the 00°1-10°0 band; 1) P_e = 55 kW; 2) 40; 3) 25. α, m^{-1}; P_e, kW;, x, cm.

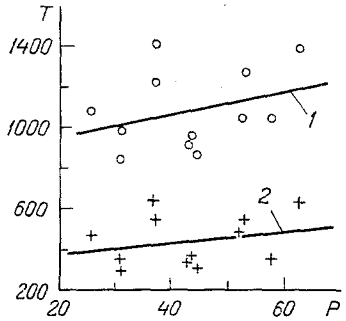

Fig. 4. Dependences of the temperature of the upper lasing level and the translational temperature of the medium on the magnitude of the power in the discharge gap: 1) T_3; 2) T. T, K.

ing chamber, heat exchanger, and compressor. All the laser elements wre connected to a pipeline forming a closed channel that permitted realization of an autonomous laser operation mode without ejection of exhaust gases into the atmosphere. A CO_2:N_2:He mixture in the relationship 1:2:7 at a 80-133 gPa pressure was used as working medium. The working mixture could be pumped through the working chamber at a 100 m/sec velocity to assure effective laser operation. The working mixture was prepared by a manometric method directly in the gasdynamic channel of the installation with subsequent forced mixing.

The inevitable heating of the medium during realization of a closed pumping cycle was compensated by cooling the gas in the heat exchanger. The total volume of the laser channel was about 6 m^3. The working chamber with 0.07 × 0.35 × 1.27 m dimensions in which pumping the working medium by an electrical discharge was realized, was insulated from the rest of the channel by dielectrical junctions. The working chamber (Fig. 1) was a constant-section channel in the zone of electrode disposition with a subsequent slight expansion. The height of the constant-section channel was 75 mm for a 1250 mm gasdynamic channel width. Anodes, cast copper slabs 360 mm long arranged flush with the channel wall, were installed in the upper and lower channel walls, as was a sectioned cathode. This latter was a set of needle electrodes fabricated from 1.5 mm diameter tungsten wire at the end of flatly cut and mounted on 15 modular ceramic 80 × 350 × 20 mm slabs. Each modular slab contained 68 cathodes, therefore, the total number of cathodes was 1020.

The cathodes were disposed in rows in a checkerboard order relative to each other on the modular plate, their stacking density hence equalled 0.9 pins/cm^2. The cathodes projected 12 mm outside the limits of the dielectric plate. Cooling the cathodes was convective by the free stream of working gas. The spacing between the cathodes and anode was 63 mm. The total discharge zone equalled 6000 cm^3.

Discharge stabilzation was realized because of utilization of 204 kΩ resistors of 150 W power in the supply loop of each stub cathode. The electrode system being used assured highly efficient pumping of the working medium: the mean current density was around 20 mA/cm^2 and the maximal achievable specific electrical power per unit mass of gas in the stream was above 200 J/g. As regards the stremwise distribution of the electrical characteristics in the dischage zone, as the data presented in Fig. 2 indicate, then a discharge current growth occurs on every succeeding row of cathodes for an appropriate voltage drop in the discharge gap, which is due to growth of the degree of ionization of the medium downstream in the discharge zone. The power in the gas on the whole length of the discharge gap turned out to be constant here within 3-4% limits, which permits making a deduction about the ignition of an electrical discharge sufficiently homogeneous in the stream and the realization of a working medium stimulation mode with minimal heating. However, it should be noted that inhomogeity of the discharge across the stream can reach ~6% in such electrical discharge systems [6], which is associated primarily with the inhomogeneous gas velocity distribution in this direction. In principle, this inhomogeneity can be eliminated by a more exact choice of the values of the individual resistors in the stub cathode loop.

Gain measurements are of great value for optimization of the working medium stimulation modes.

Windows of KCl were installed in the side walls of the working chamber to realize the laser diagnostics. A laser spectrograph [7] whose basis was the pumping active element of a ZLM-100 industrial laser (see Fig. 1) was used as laser radiation source. The gas parameters in the active element were maintained by the following: composition $CO_2:H_2:He = 1:1.5:8$, pressure 13-16 gPa, current 15 mA, pumping rate ~0.1 m/sec. The parameters mentioned assured a sufficiently broad spectrum composition of the probing radiation and stable generation in individual lines in the mode of fast laser tuning over the generation spectrum. A 100 lines/mm diffraction grating with flash angle 32° was used as the dispersion element in the probing laser. Derivation of radiation from the resonator was realized by both the semiopaque resonator mirror and the xero-th order of the diffraction grating. The laser optical diagram permitted extraction of any line out of the generation spectrum by using a special mask with slits arranged at the completely reflecting mirror of the resonator. Fast tuning from one extracted generation line to another was realized because of placement of a rotating disc with 1.5 mm wide radial slits along with a fixed mask. The rate of tuning over the spectrum here depended on the rate of disc rotation and varied within broad limits in conformity with the conditions of the experiment. Measurement of the gain in the working chamber of a fast-flow-through CO_2-laser was performed at the vibrational-rotational lines R12, R18, R22, R28, P8, P14, P20, P28 of the 00°1-10°0 CO_2 band on the axis of the gasdynamic channel and at different distances from the cathode. The probing laser generation lines were first identified by a CO_2 spectrum analyzer.

Measurement of the active medium gain was realized by a two-armed scheme (see Fig. 1) from a comparison of the intensities in the working and reference beams. After passing the working chamber the laser spectrograph radiation in the working arm went through the iris and was focused on the receiving area of an uncooled Cd, Hg/Te detector of IR radiation of the RADEC R-005-2 type. Radiation issuing from the resonator of a diagnostic laser in the zero-th order of the diffraction grating was used as the reference beam.

Investigation of the gain characteristics of a gas-flow-through electrical discharge laser was carried out for a 80 gPa working medium pressure in the gasdynamic channel and a 100 m/sec pumping rate. The magnitude of the electrical power P_e in the discharge gap varied from 16 to 67 kW. The results of the investigation are represented in Fig. 3.

To determine the spectral composition of technological laser radiation in the generation mode we experimentally investigated the dependence of the gain of its working medium at different vibrational-rotational transitions in the P- and R-branches of the 00°1-10°0 band for different pumping levels of the medium (Fig. 3a). It was here established that in practically the whole range of P_e variation, generation at the strongest P20 line was most probable. Meanwhile the gain at the other lines of this band are also adequate to obtain generation. Therefore, during laser operation tuning over the generation spectrum is possible when using appropriate kinds of selective resonators.

From the viewpoint of the optimal resonator disposition, the gain distribution over the stream is quite important. As is seen from Fig. 3b, the quantity α grows almost linearly as the distance increases from the first row of electrodes and reaches the maximum at 2 cm from the cathode, which is related to the free gas stream drift in the discharge zone. Therefore, the gain grows in the discharge zone, reaches a maximum at the boundary of the discharge domain and then starts its rapid drop downstream because of intensely progressing relaxation processes. Let us note that the location of the maximum α is substantially independent of the quantity P_e, which indicates the stability of the spatial arrangement of the stimulation zone of the medium for a fixed gas pumping rate.

One of the possible reasons for the abrupt degradation of the gain characteristics of an active medium outside the discharge zone ($x > 0.10$ m) is heating of the working medium both because the gas tempeature grows due to volume heat liberation in the discharge and because of heat transfer from the hot cathode surface. In order to verify the hypothesis of working gas heating, an attmept was made to restore the temperature T_3 of the upper lasing level and the translational temperature T of the medium by recording the spectral distributions of the gain in the R-branch of the 00°1-10°0 CO_2 band. This spectrum interval was selected for execution of the temperature measurements because of the weak influence of the "hot" transitions [8] on the gain characteristic being recorded, which permits most accurate restoration of the desired temperature. Finding the quantities T_3 and T was realized by minimizing the sum of the squares of the residuals between the experimentally measured values of the gain and their theoretical dependences. The results of measuring T_3 and T at diferent levels of medium stimulation in a section 13 cm away from the first row of stub cathodes are presented in Fig. 4. The accuracy of the restoration of the translational temperature of the medium was here ~30%, while the accuracy of finding T_3 was around 27% for a ~20% accuracy in determining the gain.

The practically linear growth of the vibrational temperature of the upper lasing level as P_e increases should also be noted, that indicates the possibility of realizing modes with large energy contributions because of the increase in the volume electrical discharge density. Meanwhile, attention is turned to the sufficiently significant, up to 500-600 K, heating of the working medium for power magnitudes above 50 kW in the discharge gap, which substantially reduces the efficiency of laser operation. Lowering the magnitude of heating the active medium at elevated values of the energy contribution can apparently be achieved by using a more efficient cathode cooling system as well as by changing the geometry of the gasdynamic channel in the discharge zone in order to compensate the process of heating the working medium by gasdynamic facilities.

Therefore, the data about the behavior of the translational and vibrational temperatures of a laser-active medium permit pointing out the path of perfecting the stimulation system in powerful electrical discharge lasers: this is increasing the number of stub cathodes to be cooled in order to raise the energy contribution during simultaneous lowering of the temperature of the stimulation system elements, and perfecting the working channel geometry.

The measured values of T_3 and T permit estimation of the efficiency of the resonator systems being utilized [9]. To this end, under the assumption that the resonator efficiency is 100%, the magnitude of the maximal generation power was estimated for specific modes by means of the magnitudes of T_3 and T. In particular, for the achieved values P_e = 55-60 kW of the pumping power, the generation power according to the estimates executed should not exceed 7 kW, which agrees well with the experimental results obtained. Thus, when using an unstable two-path resonator formed by a concave mirror with a R = 27 m radius of curvature, a convex mirror with R = −14 of smaller diameter and a flat mirror located in the side walls of the working chamber and having the reflection coefficient ~88%, the generation power was 5.8 kW in the mode mentioned. This indicates not only the possibility of estimating the limit energetic characteristics of lasers of a given type but also the reliability of measuring the temperatures of laser-active media by a laser method.

Therefore, laser diagnostics of a working medium by using the technique of rapidly tunable laser spectrographs in the generation spectrum can be used successfully to study the processes and to check the parameters of the medium in the working channels of electric discharge high power lasers. Information obtained as a result of investigations of the spectral distributions of the gain of the active medium of an electrical discharge CO_2 laser with a closed loop and a specific electrical stimulation system not only confirmed the high efficiency of this system but also permitted formulation of a number of recommendation on its further perfection.

NOTATION

P_e is the discharge power, W; P, I, U, $\bar{P}$, $\bar{I}$, $\bar{U}$ are local values of the discharge power, current and voltage along the stream and their average values, W, A, V, respectively; α, gain of the active medium, m^{-1}; T, translation temperature of the medium, K; T_3 is the vibrational temperature of the upper lasing level; R is the mirror radius of curvature, m; L, L_k, anode and cathode length, respectively, m; D is channel width, m; H is channel height, m; E_p is the magnitude of the interelectrode gap.

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CALCULATION OF A BOREHOLE SOIL HEAT EXCHANGER FOR STORING HEAT IN THE WATER-BEARING STRATUM TAKING INTO ACCOUNT FREE CONVECTION OF THE FORMATION FLUID

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A mathematical model of charging and discharging processes in a borehole soil heat exchanger for storing heat in a water-bearing stratrum is proposed. The model takes into account heat transfer owing to free convection of the formation fluid in a water-saturated porous medium and heat losses in the water-impermeable soil formation with reverse motion of the heat-transfer agent. The results of numerical calculations of the temperature distribution in the heat exchanger, performed by the integral balance method for some values of the parameters, are presented.

Introduction. In the last few years serious attention has been devoted to the problem of storing heat in natural and artificial water-bearing strata as one way to conserve energy and fuel [1, 2].

In traditional underground storage systems a pair or group of boreholes, some of which are used to extract underground water followed by heating or cooling in an intermediate heat exchanger while others are used to force water into the formation, are employed. Quite large amounts of heat can be extracted in such a scheme, but the pumping of highly mineralized impure underground waters, which are highly corrosive and have a tendency to deposit salts, has a deleterious effect on the heat-exchange equipment and the surrounding medium.

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