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Supersonic oxygen – iodine 1.4-kW laser with a 5 cm gain length and a nitrogen-diluted active medium

M V Zagidullin, V D Nikolaev, M I Svistun, N A Khvatov

Abstract. A compact chemical oxygen – iodine laser with a jet generator of singlet oxygen and a nitrogen-diluted active medium was developed. The maximum chemical efficiency equal to 24.1% was achieved for a chlorine flow rate of 39.2 mmol s^{-1}, and the maximum output power equal to 1.4 kW was obtained for a chlorine flow rate of 75 mmol s^{-1}. The following specific energy characteristics of laser radiation were obtained: output power of 5 kW per one litre of the reactor volume of the jet generator of singlet oxygen, paraxial intensity of 100 W per one square centimetre of the cross sectional area of the stream of the active medium in the resonator, and an output power per unit volume evacuation rate of 2.7 W (litre s^{-1})$^{-1}$.

1. Introduction

Currently, there is a rebirth of interest in the feasibility of developing an oxygen – iodine laser (OIL) for various technological applications [1, 2]. There is special interest in harnessing OILs with an output power of 10 – 30 kW for dismounting and disassembling the elements of thick-walled steel structures of nuclear reactors. According to experts estimates, the demand for dismantling nuclear reactors will increase sharply in the beginning of the next century, when reactors constructed in the 1960 – 70s become obsolete [3]. An OIL can be useful in such areas as cutting thick-walled steel in ship building, welding of aluminium constructions, and underwater welding and cutting. High transmission of the OIL radiation by glass fibre makes it possible to robotise laser complexes on its basis.

The cost of laser energy and investments will play an important role in whether OILs will be accepted as industrial equipment. To reduce investments and OIL energy costs, it is important to decrease the required volume rate of flow of the active medium and reduce the cost of the initial chemical components and the buffer gas [4].

The gas of choice for diluting the active medium is nitrogen, which is much cheaper than helium and is easy to transport in a condensed state. As shown earlier, the use of gaseous nitrogen as a diluent at a temperature of about 100 K makes it possible to attain in a supersonic OIL a chemical efficiency comparable with that obtained with a helium-diluted active medium [5]. As a diluent of the laser active medium, nitrogen can be delivered directly from vessels containing liquid nitrogen, which significantly reduces the mass-size characteristics of a mobile laser complex. Moreover, in this case, it is no longer necessary to accomplish the deep gas-dynamic cooling of the active medium by accelerating it to high supersonic velocities, at which losses in the total pressure become inevitable.

The most important technical characteristic of an OIL is its chemical efficiency η, which is defined as the ratio between the number of photons emitted by the laser and the number of chlorine molecules introduced into the generator of singlet oxygen. The expression for η can be represented as

$$\eta = \frac{W}{90.6 G_{\mathrm{Cl}}},$$

where W is the total output laser power (in W) and G_{Cl} is the flow rate of chlorine (in mmol s^{-1}) in the generator of singlet oxygen. Until now, the question of whether high chemical OIL efficiency can be obtained with a nitrogen-diluted active medium and a high pressure in the resonator had remained an open question. Carroll et al. [3] obtained an efficiency of $\sim$15% for a chlorine flow rate of 70 mmol s^{-1} in an OIL with a 5-cm gain length.

What distinguishes the operation of a laser with a nitrogen-diluted active medium from that with a helium-diluted medium is a reduction of the volume flow velocity in the gas-transport laser part, resulting in the increase in all the pressures and the $O_2(^1\Delta)$ transport time. This is accompanied by losses of $O_2(^1\Delta)$ upon its quenching and by an increase in its partial pressure in the region of mixing with iodine vapour. Given this, the requirements for the arrangement of the elements of an OIL of this type and for the mixing unit become extremely stringent. There arises the necessity of increasing the area of the critical section of the supersonic nozzle to lower the pressure in front of it and to shorten the oxygen–nitrogen mixing time for reducing $O_2(^1\Delta)$ losses. However, the increase in the area of the critical section of the nozzle with retention of the degree of expansion of the supersonic flow is limited by the attainable volume evacuation rate.

In this paper, we made an attempt to fully take into account these factors, which are related to the operation of an OIL with a nitrogen-diluted active medium, under conditions of limited volume transport. The jet generator of singlet oxygen (JGSO) allows a nearly complete utilisation of chlorine and makes it possible to obtain oxygen at pressures of several tens of Torr with a high content of $O_2(^1\Delta)$ [6]. Most

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versatile, especially from the scaling standpoint, is the JGSO design involving the outlet of the oxygen stream upward through the central hole in the nozzle grid, through which the alkaline solution of hydrogen peroxide is supplied to the reactor [7].

In this work, we pursue parametric investigations and optimisation of the output power of an OIL with a gain length of 5 cm based on a JGSO with a vertical stream exhaust. The gas-transport part of this laser, which comprises the JGSO, the buffer gas – $O_2(^1\Delta)$ mixing chamber, the iodine vapour mixer, and the nozzle, can be treated as a separate part. The gas-transport part of a high-power OIL can consist of a set of similar sections.

2. Experimental setup and measurements

A schematic diagram of the OIL facility is shown in Fig. 1. Singlet oxygen $O_2(^1\Delta)$ forms in the interaction of a chlorine stream with jets and droplets of an alkaline solution of hydrogen peroxide in a countercurrent-type reactor 1 with a cross section measuring 34 by 50 mm. The alkaline solution of hydrogen peroxide was prepared from 5 litres of 50% hydrogen peroxide and 5 litres of 46% KOH. At a temperature of –15 °C and a total pressure of 1 to 3 bar, the solution was supplied to the prechamber of a nozzle grid 2 and injected through its openings to the reactor. Gaseous chlorine was blown in the reactor through an injector 3, which was made up of perforated tubes built into the reactor walls.

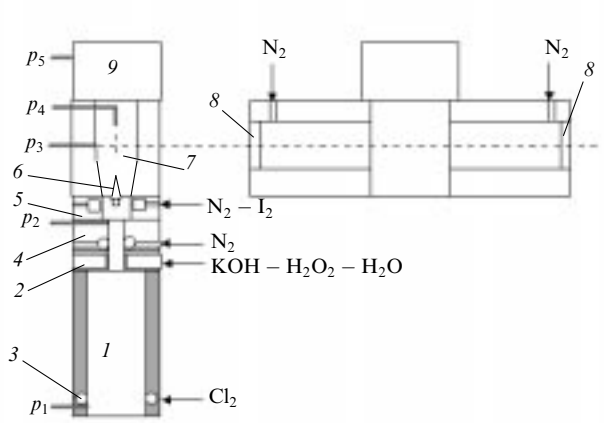

Figure 1. Schematic diagram of an oxygen – iodine laser indicating the location of pressure pickups in its gas-transport part: (1) jet generator of singlet oxygen; (2) nozzle grid; (3) injector of chlorine; (4) mixing chamber; (5) iodine mixer; (6) nozzles; (7) slot channel; (8) resonator mirrors; (9) exhaust pipe.

The oxygen stream was expelled from the reactor through the central slot opening in the nozzle grid. The injector of chlorine was located at a distance of 165 mm from the nozzle grid. The nitrogen buffer gas (primary nitrogen) was added to oxygen through the system of holes drilled in two nickel tubes, which were built in the walls of a mixing chamber 4 measuring 10 by 50 mm in cross section and 60 mm along the flow direction. To pre-cool the $O_2 - N_2$ mixture, primary nitrogen was passed through a copper helix immersed in liquid nitrogen. In front of an iodine mixer 5, the height of the mixing chamber increased from 10 to 20 mm. The $O_2 - N_2$ mixture flows into the iodine mixer, which has two throats of 7.5 by 50 mm cross section each. The iodine vapour with the carrying nitrogen gas (secondary nitrogen) is added to the $O_2 - N_2$ stream through a system of holes drilled in the side walls of the iodine mixer and in the central tube located between the throats. The flow rate of iodine was measured accurate to 5%. The two flows of the active medium diverge in nozzles 6 and, on merging together in a slot channel 7, enter the active resonator region measuring 45 mm along the flow direction and 50 mm along the optical axis. The walls of the slot channel 7 are turned by an angle of $\sim 2.5^\circ$ relative to the flow axis to compensate for the effect of boundary layers on the gas flow.

The optical resonator consisted of two mirrors 8 with diameter of 50 mm and a radius of curvature of 5 m spaced at 63 cm. The height of the channel of the active resonator region at the optical axis was 28 and 30 mm for respective distances of 55 and 80 mm between the throat of the iodine mixer and the optical resonator axis. Nitrogen was supplied to the so-called resonator sleeves to keep the mirrors free of the aerosol of the alkaline solution of hydrogen peroxide. The flow of nitrogen also serves to force the stagnant gas out of the sleeves, in which resonance absorption of radiation could occur. The gas mixture escapes from the resonator through a slot opening of 30×50 mm cross section to enter an escape pipe 9 of diameter 100 mm. The active medium was removed by an AVZ-125 pump. To provide a high short-term evacuation rate, the gas escaped in parallel to a vacuum receiver with a volume of 4 m^3. The gas-transport part was blown with nitrogen, which showed that the volume evacuation rate behind the resonator was 630 litre s^{-1} during the first second. In five seconds, it dropped to 520 litre s^{-1} due to the growth of counterpressure in the receiver.

The egress of oxygen through the central opening in the nozzle grid 2 has several advantages that favour augmenting the output of the jet generator of singlet oxygen and enable its geometric scaling. A JGSO with an egress of oxygen through a side opening in the reactor wall was investigated previously [6]. It was found that the gas flow entrained the film of the solution from the reactor walls, which was one of the causes of the enhancement of the content of solution droplets in the resonator with an increase in the chlorine flux.

When oxygen escapes through the central opening in the nozzle grid, the appearance of solution droplets is possible only through generating these droplets in the reactor and carrying them away by the volume gas flow. The formation of small solution droplets entrained by the gas flow can occur both when the solution film at the reactor walls destructs and when jets and large drops disintegrate. Consequently, a lower content of solution droplets in the emergent oxygen flow is expected for a JGSO design with a central opening in the nozzle grid. This laser arrangement eliminates many OIL scaling problems that arise with the use of traditional JGSO designs that involve the egress of the gas flow through the opening in the side reactor wall.

The $O_2(^1\Delta)$ yield and the residual content of chlorine in the gas stream exiting the JGSO depend on the chlorine-solution contact surface area, the pressure, and the duration of stay of gas in the reactor. The pressure and the velocity of gas in the reactor are determined by the geometric dimensions of the central opening in the nozzle grid and by the counterpressure in the mixing chamber. The counterpressure in the mixing chamber depends both on the quantity of primary and secondary nitrogen consumed and also on the cross sectional area of the nozzle throat. In turn, the variation of the consumption of primary and secondary nitrogen affects the mixing mode and the dissociation of iodine vapour in the

iodine mixer and also affects the degree of gas-dynamic cooling of the active medium. Therefore, in the absence of gas-dynamic decoupling between the JGSO and the iodine mixer, as was the case in Ref. [5], the OIL optimisation problem becomes considerably more complex.

The pressures in the reactor (p_1) and in the mixing chamber (p_2), the static pressure in the resonator (p_3), the pressure in the pressure tube at exit from the resonator (p_4) and in the gas-evacuation channel (p_5) were measured employing 'Sapfir' pressure pickups during laser operation. The pressure measurements had an accuracy of 1%. To estimate the character of the flow of the active medium, the Mach number M in the axis of the gas flow in the resonator was calculated by the formula [8]

$$\frac{p_4}{p_3} = \frac{166.7M^7}{(7M^2-1)^{2.5}} .$$

Chlorine was transferred from a vessel with liquid chlorine to an elastic plastic bag residing at atmospheric pressure, which in turn delivered gaseous chlorine to the JGSO. The consumption of chlorine and nitrogen was controlled by calibrated orifices and measured with an accuracy of 6%.

The output laser power was measured by an LPM-905 meter, which has a time constant of 0.5 s, an upper limit of power measurements of 30 W, and an accuracy of 5%. Upon passing through the higher-transmittance mirror, the laser beam was successively reflected from two plane-parallel plates and then two lenses focused the beam on the sensitive element of the power meter. For the maximum possible dimension of the output laser beam, the optical system ensured a total interception of the beam by the sensitive element of the LPM-905 meter.

Because the gain coefficient in the medium was low, we had to resort to mirrors with a transmittance of 1 – 2% to maximise the output laser power. Under these conditions, the radiation power inside the resonator was about 100 kW, and nontransmitting mirrors with transmittances below 0.1% were quickly damaged, because these mirrors have, as a rule, higher absorption and light scattering. For this reason, it was quite often advantageous to employ the second mirror with transmittance T_2, which was comparable with that of the output mirror. The total output power was taken as $W = W_1(T_1 + T_2)/T_1$, where W_1 is the measured power of the radiation transmitted by the mirror with the transmittance T_1.

3. Results

The following sequence was involved in starting up the laser for short time (about 5 s). The transport laser part was evacuated by an AVZ-125 pump, then the blowing on the mirrors was started, the primary and secondary nitrogen were admitted, the consumption of iodine vapour was set, and the alkaline solution of hydrogen peroxide and chlorine were supplied to the reactor in succession. After this, the vacuum receiver was opened. Provided that the subsonic or supersonic flow of the active medium in the resonator was stable, stationary pressures (p_1, p_2, p_3, p_4) and the output power were established in two seconds and remained invariable untill the end of the laser operation. The duration of laser operation (equal to 5 s) was limited only by the stock of the alkaline solution of hydrogen peroxide in the feeding reservoir.

The optimum ratio of molar flow rates of chlorine (G_{Cl}), primary (G_{NP}), and secondary nitrogen (G_{NS}), determined in our previous studies [5] of an OIL with a single nozzle and injection of iodine vapour near the nozzle throat, was $G_{Cl} : G_{NP} : G_{NS} \approx 1 : 2 : 1$. When the stream with the above flow-rate ratio and with nitrogen in lieu of chlorine was blown through the gas-transport part of the laser with a flow rate of 39.2 mmol s^{-1} in this experiment, the Mach numbers of the flow in the resonator were 1.72 and 1.8 for respective distances of the optical axis to the nozzle throat $d = 55$ and 80 mm. For an ideal isentropic expansion, the respective Mach numbers of the flow should have been 2.18 and 2.25. The distinction between the resultant values and the calculated ones can be attributed to the nonideal nozzle profiling, the existence of friction forces, and the effect of admitting the secondary flow to the primary one in the vicinity of the critical nozzle section.

Initially, our experiments were performed for $d = 55$ mm and the ratio $G_{Cl} : G_{NP} : G_{NS} \approx 1 : \sqrt{2}$, as in Ref. [5]. The flow rate of chlorine was 39.2 mmol s^{-1}. In this case, the pressure in the reactor was 35 Torr. The flow rate of nitrogen through each resonator sleeve was 1.36 mmol s^{-1}. Fig. 2 shows the pressures being measured and the Mach number for the flow in the resonator as functions of the iodine flow rate G_I. By the end of the fifth second of laser operation, the pressure p_5 exceeded the static pressure in the resonator by 1 – 1.5 Torr. The weak dependence of p_2 on G_I testifies to the absence of significant heat release in the region where iodine vapour is added (where $M < 1$).

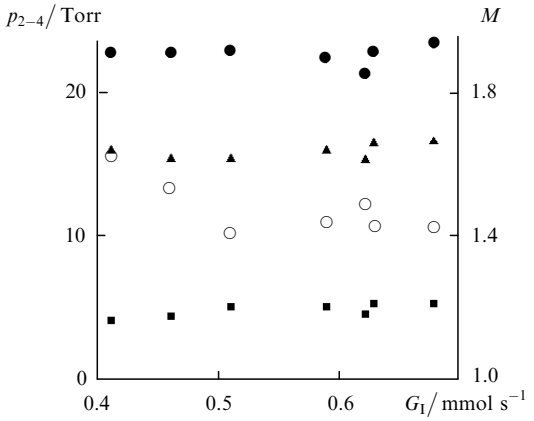

Figure 2. Pressures in the gas-transport laser part p_2 (●), p_3 (■), p_4 (▲) and the Mach number (○) of the flow in the resonator as functions of the iodine flow rate G_I for the ratio of gas flow rates $G_{Cl} : G_{NP} : G_{NS} \approx 1{:}2{:}1$.

On the other hand, the growth of pressure p_3 in the resonator with an increase in the iodine flow rate indicates that the flow is heated in the supersonic domain of the nozzle. The dependence of the output power on G_I is given in Fig. 3 for different conditions. One can see that the output power strongly depends not only on the total transmittance of the mirrors mounted in the resonator, but also on their quality. The maximum output power was attained with the use of mirrors with $T_1 = 1\%$ and $T_2 = 0$ and was 858 W ($\eta = 24.1\%$) with primary nitrogen cooled to 80 K or 798 W ($\eta = 22.4\%$) with primary nitrogen at room temperature.

To reduce the pressure p_1 and increase the velocity of gas in the reactor, the counterpressure p_2 was lowered by reducing the flow rate of primary nitrogen G_{NP} to G_{Cl}. In this case, p_1 decreased from 35 to 28 Torr, but the supersonic flow mode became unstable. Increasing the flow rate of iodine would first result in a monotonic growth of the output power,

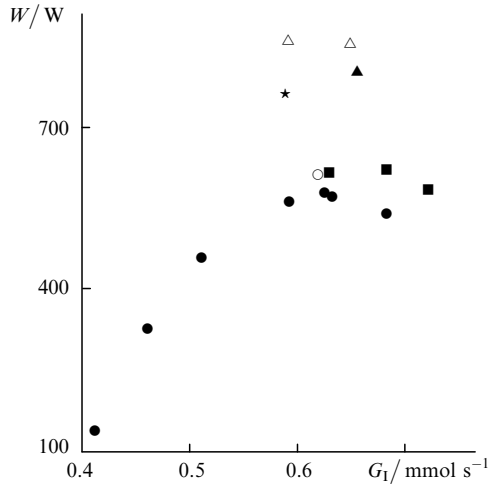

Figure 3. Output laser power W as a function of the iodine flow rate G_I for the flow-rate ratio $G_{Cl} : G_{NP} : G_{NS} \approx 1{:}2{:}1$ and different transmittances of the resonator mirrors [(●) $T_1 = 0.9\%$, $T_2 = 0$; (○) $T_1 = 0.9\%$, $T_2 = 0$ (cooled primary nitrogen); (■) $T_1 = 1.3\%$, $T_2 = 0$; (▲) $T_1 = 1\%$, $T_2 = 0$; (△) $T_1 = 1\%$, $T_2 = 0$ (cooled primary nitrogen); (★) $T_1 = T_2 = 0.7\%$].

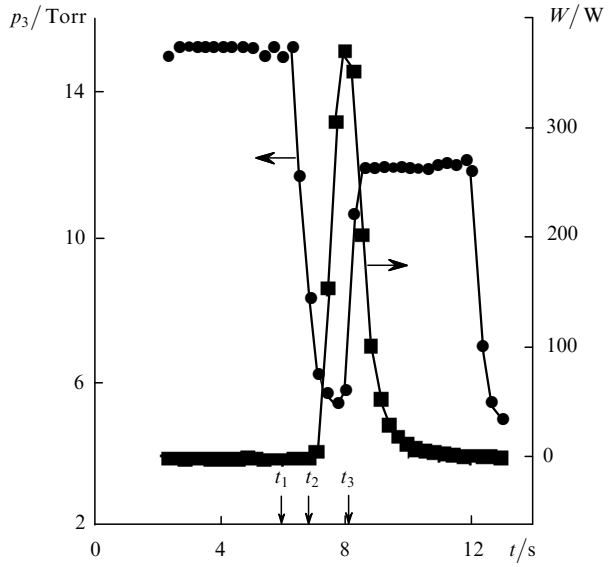

Figure 4. The diagram that demonstrates the transition from the supersonic mode of the flow of the active medium in the resonator to the subsonic one.

but later lasing would terminate short of reaching the maximum intensity and the flow in the resonator would become subsonic with the Mach number $M = 0.66$.

Upon increasing d to 80 mm, the transition of the flow in the resonator to the subsonic mode also became observable for a higher heat capacity of the gas. For the mirror set with $T_1 = 0.9\%$ and $T_2 = 0$, the ratio $G_{Cl} : G_{NP} : G_{NS} \approx 1 : 2 : 1$, and an iodine flow rate of 0.47 mmol s^{-1}, the output power was 467 W and was found to be higher than that for $d = 55$ mm. In this case, the Mach number of the flow in the resonator was $M = 1.43$. However, increasing G_I even to 0.54 mmol s^{-1} caused the flow in the resonator to transit to the subsonic mode and caused the termination of the laser oscillation.

During some of the 5-s-long runs, it was possible to observe the transition from the supersonic flow of the active medium to the subsonic one (Fig. 4). Prior to the point in time t_1, the gas-transport part was evacuated only by the AVZ-125 pump. At the point in time t_1, the valve of the vacuum receiver was open. During the time interval from t_2 to t_3, the supersonic mode with $M = 1.4$ was realised and oscillation set in. Then the pressure in the resonator increased sharply, the oscillation terminated, and the flow in the resonator transited to the subsonic flow with the Mach number $M = 0.64$. This behaviour points to the instability of the supersonic flow of the active medium. The 25-mm increase in the length of the supersonic portion of the nozzle is likely to lead to additional heat release, and the gas flow in the nozzle proceeds near the state of thermal crisis.

The rate of heat release in the active medium depends on the densities of iodine and water vapour, through which the deactivation of $O_2(^1\Delta)$ eventually proceeds. A small increase in the density of these components is enough to bring about the thermal crisis with formation of a pseudo-shock wave of the density in the nozzle. The transition to the subsonic flow results in the growth of relaxation losses of $O_2(^1\Delta)$, even greater heating of the active medium, and the termination of lasing. In addition, it may be that the p_3-pressure jump causes the gas to flow over to the resonator sleeves, in which there appears a region of resonance radiation absorption by ground-state iodine atoms and there evolve stagnant circulation regions responsible for quenching $O_2(^1\Delta)$. On the contrary, in other laser operation runs under similar conditions, the subsonic flow without lasing was initially realised upon opening the receiver. Subsequently, the flow transited to the supersonic mode when lasing commenced.

Subsequently, the laser was tested for $d = 55$ mm. For a chlorine flow rate of 68 mmol s^{-1}, the tests were run for the ratio $G_{Cl} : G_{NP} : G_{NS} \approx 1 : 2 : 1$. The pressures in the gas-transport laser part were as follows: $p_1 = 54$ Torr, $p_2 = 36$ Torr. Changing the total rate of nitrogen flow through the resonator sleeves from 4.5 to 10.3 mmol s^{-1} for a fixed iodine flow rate of 0.71 mmol s^{-1} was found to increase the output laser power from 890 to 1035 W, the mirror set with $T_1 = 0.94\%$ and $T_2 = 0.9\%$ being employed. Simultaneously, the pressure in the resonator rose from 7.6 to 9.7 Torr, and the Mach number of the flow in the resonator dropped from 1.49 to 1.39.

The change of parameters of the gas flow in the resonator and the growth of the output power with an increase in the rate of nitrogen flow through the resonator tunnels are supposedly related to exclusion of the stagnant regions with the resonantly absorbing medium from the sleeves and 'contraction' of the principal flow. The output power as a function of the total transmittance of the mirrors is shown in Fig. 5. A threshold mirror transmittance of $\sim 6\%$ can be estimated from this dependence.

An increase in the flow rate of chlorine in the reactor results in a pressure increase in it and a reduction of the yield of singlet oxygen. There is a concurrent increase in the content of solution droplets in the gas flow emerging from the JGSO. A further increase in the chlorine flow rate may disturb the stable flow in the reactor and could result in a catastrophic ejection of the solution into the resonator. In our work, the maximum flow rate of chlorine did not exceed 75 mmol s^{-1} despite the fact that the JGSO operation was stable for a nitrogen flow rate up to 100 mmol s^{-1}. The utilisation of chlorine in the JGSO was 85 – 90% when the JGSO was operated at a maximum flow rate of chlorine of 75 mmol s^{-1} and a pressure of 65 Torr in the reactor.

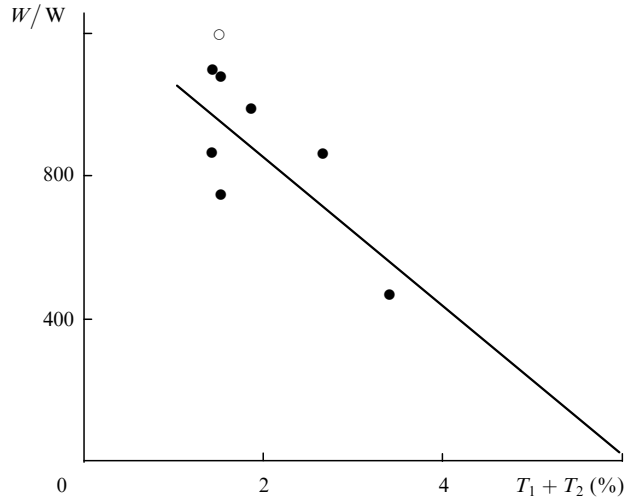

Figure 5. Output laser power W as a function of the summary transmittance of the mirrors for G_{Cl}=68 mmol s^{-1} and G_I=0.71 mmol s^{-1} when primary nitrogen resided at room temperature (●) or was pre-cooled (○).

When the laser was operated at a chlorine flow rate of 75 mmol s^{-1} and the ratio of $G_{Cl} : G_{NP} : G_{NS} \approx 1 : 2 : 1$, the respective pressures in the reactor and the mixing chamber were 67 and 42 Torr. When the nitrogen flow rate in transit through the resonator tunnels was 2.7 mmol s^{-1}, lasing terminated for an iodine flow rate of over 0.8 mmol s^{-1}, even though the flow of the active medium in the resonator was still supersonic ($M \approx 1.5$). Increasing the rate of flow of nitrogen in the resonator sleeves to 6.8 mmol s^{-1} resulted in stable lasing for iodine flow rates up to 0.9 mmol s^{-1}. The maximum output laser power of 1030 W was obtained for an iodine flow rate of 0.89 mmol s^{-1} employing the mirrors with $T_1 = 0.94\%$ and $T_2 = 0.9\%$.

The reduction of chemical laser efficiency with an increase in the chlorine flow rate from 68 to 75 mmol s^{-1} is evidently related to a higher pressure in the reactor and a lower $O_2(^1\Delta)$ yield. A reduction of the flow rate of primary nitrogen from 155 to 79 mmol s^{-1} caused the pressure in the reactor to drop from 67 to 53 Torr. However, in this case the flow in the reactor broke to the subsonic mode with pressure $p_3 = 14.4$ Torr and $M = 0.78$, and the lasing terminated.

The additional decrease in the flow rate of secondary nitrogen to 44 mmol s^{-1} did not enable a transition of the flow of the active medium to the supersonic mode. Increasing the flow rate of primary nitrogen to 96 mmol s^{-1} and of secondary nitrogen to 82 mmol s^{-1} reverted the flow of the active medium to the supersonic mode with $M = 1.5$. Under these conditions, the pressure was 55 Tor in the reactor and 40 Torr in front of the nozzle. When a new set of mirrors with $T_1 = 0.8\%$ and $T_2 = 0.7\%$ was mounted, an output power of 1408 W and a chemical efficiency $\eta = 20.7\%$ were attained.

4. Conclusions

Thus, we have developed the gas-transport part of a small-size chemical oxygen – iodine laser involving a JGSO of vertical design and a nitrogen-diluted active medium. This gas-transport part, which incorporates the buffer gas – $O_2(^1\Delta)$ mixing chamber, the iodine vapour mixer, and the nozzle, can be treated as a separate section. The gas-transport part of a high-power OIL can consist of several similar sections.

Fig. 6 and Table 1 review the testing of the chemical OIL, together with additional testing for $G_{Cl} = 23.2$ mmol s^{-1} and the ratio $G_{Cl} : G_{NP} : G_{NS} \approx 1 : 2 : 1$. In this case, the chemical laser efficiency is close to the efficiency of a mononozzle laser for the same gas flow rates [5].

A maximum output power of 1.4 kW was attained for a chlorine flow rate of 75 mmol s^{-1} while a maximum chemical efficiency of 24.1% for a chlorine flow rate of 39.2 mmol s^{-1}. The laser efficiency substantially depended on the transmittance and the quality of the cavity mirrors, which was noted earlier [9]. In this case, the mirrors that had already been operating at a high intracavity radiation density could not, as a rule, be validly used to obtain the same output power. This is supposedly due to the degradation of dielectric layers at radiation intensities of about 8 kW cm^{-2}.

The increase of heat release in the active medium or the reduction of its heat capacity results in the thermal crisis and the transition of the flow to the subsonic mode. This was clearly demonstrated by increasing the distance between the throat of the iodine mixer and the optical axis from 55 to 80 mm and reducing the flow rates of primary and secondary nitrogen. The termination of lasing in the subsonic mode can be attributed to the sharp increase in the intracavity densities of atomic and molecular iodine and of water vapour, and also to the growth of $O_2(^1\Delta)$ quenching rate and flow temperature.

Table 1. Results of testing an OIL.

G_{Cl}/ mmol s^{-1}	G_{NS}/ mmol s^{-1}	G_{NP}/ mmol s^{-1}	T_1 (%)	T_2 (%)	W/ W	η (%)	M
23	23.2	46.5	0.7	0.7	390 (●)	18.7	1.24
23	23.2	46.5	1	0	429 (■)	20.6	1.24
39.2	39.2	78.4	0.9	0	574 (○)	16.2	1.48
39.2	43	78.4	1	0	798 (■)	22.4	1.52
39.2	40	78.4	1.3	0	642 (★)	18.1	1.51
39.2	39.2	78.4	0.7	0.7	764 (●)	21.4	1.37
39.2	43	78.4*	1	0	858 (□)	24.1	1.38
68	66	66	0.8	0.7	1074 (▲)	17.4	1.51
68	66	66*	0.8	0.7	1183 (△)	19.2	1.43
75	65.7	135.5	0.7	0.7	1074 (●)	15.8	1.5
75	65.7	95.8	0.8	0.7	1303 (▲)	19.2	1.4
75	82.	95.8	0.8	0.7	1408 (▲)	20.7	1.5

*The data in the case of cooled primary oxygen.

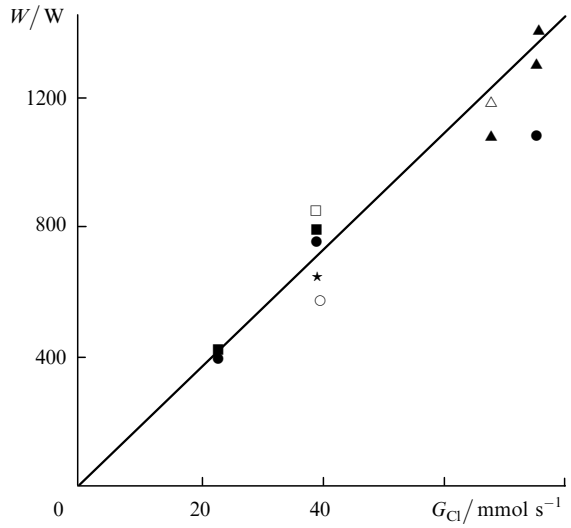

Figure 6. Output laser power W as a function of the chlorine flow rate G_{Cl}. The straight line corresponds to a chemical laser efficiency of 20%. The remaining conditions appear in Table 1.

We present several specific characteristics obtained during the trials of the OIL: an output power per unit area of the gas flow in the resonator of 100 W cm^{-2}, an output power per unit reactor volume of 5 kW litre^{-1}, and an output power per unit volume evacuation rate of 2.7 W (litre s^{-1})$^{-1}$. A maximum intensity of 400 W cm^{-2} and a maximum specific output power of 4.3 kW litre^{-1} reported to date were achieved by McDermott et al. [7] by increasing the linear gas velocity in the reactor and the resonator and diluting oxygen by helium. In our paper, the increase in the output power to 5 kW per one litre of the JGSO reactor volume was obtained by increasing the operating pressure in the reactor.

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