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Oxygen – iodine ejector laser with a centrifugal bubbling singlet-oxygen generator

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***Abstract*.** **It is shown that if a supersonic oxygen – iodine ejector laser is fed by singlet oxygen from a centrifugal bubbling generator operating at a centrifugal acceleration of $\sim 400g$, the laser output power achieves a value 1264 W at a chemical efficiency of 24.6 % for an alkaline hydrogen peroxide flow rate of 208 cm^3 s^{-1} and a specific chlorine load of 1.34 mmol s^{-1} per square centimetre of the bubble layer.**

Keywords: *singlet oxygen, oxygen – iodine laser*

Singlet oxygen $O_2(^1\Delta)$ is the source of energy in a gas-flow oxygen – iodine laser (OIL). The primary gas flow with $O_2(^1\Delta)$ is formed in a singlet-oxygen generator (SOG) based on the reaction of chlorine with an alkaline solution of hydrogen peroxide. Introduction of iodine molecules into the primary gas flow results in their dissociation into atoms in a chain of reactions whose mechanism has not been understood fully so far. Amplification in the active medium of the OIL occurs at the fine structure transition of the iodine atom because of the energy transfer in the reaction

$$I(^2P_{3/2}) + O_2(^1\Delta) \leftrightarrow I(^2P_{1/2}) + O_2(^3\Sigma) + 402\,\mathrm{K}. \quad (1)$$

The first SOG for the OIL was based on a mass-exchange bubbling devices [1] in which chlorine bubbles are passed through a layer of an alkaline solution of hydrogen peroxide. The $O_2(^1\Delta)$ molecules are formed in a thin surface layer of the solution as a result of the reaction $Cl_2 + 2HO_2^- \rightarrow 2Cl^- + H_2O_2 + O_2(^1\Delta)$ and enter the bubbles. As the bubble rises, chlorine is consumed and the bubble is filled with oxygen. Under the conditions of terrestrial gravity, the optimal specific load m_c in bubbling SOGs is 0.1 mmol s^{-1} per square centimetre of the bubbling layer under an oxygen pressure of several Torr over the solution layer [2]. Any further increase in m_c and pressure leads to a deterioration of the chlorine utilisation, a lowering of the fraction of $O_2(^1\Delta)$, and a rapid removal of the solution aerosol [2]. Bubbling SOGs have not been used widely for pumping supersonic OIL due to a low oxygen pressure under which they operate.

Counterflow or transverse jet-droplet generators of singlet oxygen have been used much more extensively for this purpose [3, 4]. However, it is well known that the efficiency of bubbling mass-exchange devices increases considerably if the bubbling layer is located in the field of strong centrifugal accelerations ($G \sim 10^3 - 10^4$ m s^{-2}) [5]. In this case, one can expect a sharp decrease in the diameter of the bubbles, a considerable increase in the floating-up speed, an intensification of the mass-transfer process, and a decrease in the rate of carry-over of the solution aerosol [6]. These circumstances are especially favourable for developing high-efficiency and high-productivity SOGs. In this paper, we shall demonstrate the potentialities of using centrifugal bubbling SOGs (CBSOGs) for supplying energy to an OIL with an ejector-type nozzle bank.

Figure 1 shows the scheme of an OIL with an ejector-type nozzle bank and a CBSOG. The CBSOG consists of rotor (*1*) in the form of a perforated cylinder of inner diameter 93 mm inserted into casing (*2*). An electric motor is used to run the rotor. The alkaline solution of hydrogen peroxide is supplied to the inner surface of the rotor through channel (*3*). The solution is drained through a system of holes (*4*) and pumped into the receiver tank. The chlorine –

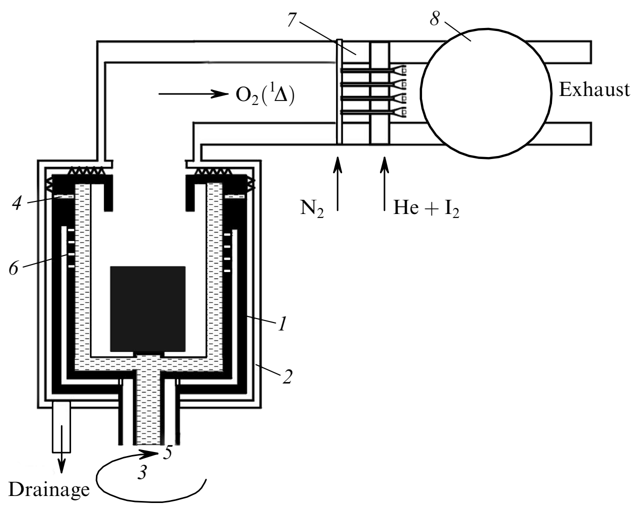

Figure 1. Scheme of an ejector OIL with a centrifugal bubbling singlet-oxygen generator: (*1*) rotor; (*2*) casing; (*3*) solution inlet channel; (*4*) solution drainage hole; (*5*) gas inlet channel; (*6*) gas supply nozzles; (*7*) nozzle bank; (*8*) optical cavity.

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helium mixture is supplied to channel (*5*) and bubbled through nozzles (*6*) in the lateral wall of the rotor through a layer of the solution. The surface area occupied by the gas nozzles is 42 cm^2. The singlet oxygen flow formed as a result of bubbling in the helium mixture is passed to ejector nozzle bank (*7*) through a rectangular gas-flow channel having a volume of 100 cm^3. The construction of the nozzle bank used in our experiments is described in detail in [7].

Figure 2 shows a segment of the nozzle bank. The high-pressure nitrogen flow was formed by 52 conical nozzles (13 rows with four nozzles in each row). The nozzle axes were at a distance of 4 mm from one another. The initial and outlet diameters of the conic nozzle were 0.55 and 2.6 mm, respectively. The expanding part of the nozzle had a length of 3.3 mm. The flow of helium with molecular iodine was mixed with the gas flow through holes drilled in 12 rectangular tubes arranged between the conic nozzles. The edge of the conic nozzles was 5 mm downstream of the iodine injector flow. The gas flow from the CBSOG emerged through the gaps between nozzles for iodine-containing gas and the driver gas. The supersonic flow formed by the nozzle bank was let into the mixing chamber with the active zone of the cavity as an extension (height 20 mm, length 52 mm along the optical axis). The 113-cm-long optical cavity was formed by mirrors with radii of curvature equal to 2 m and transmission coefficients $T_1 \approx T_2 \approx 1.5\%$. The optical axis of the cavity was at a distance of 48 mm from the edge of the conic nozzles.

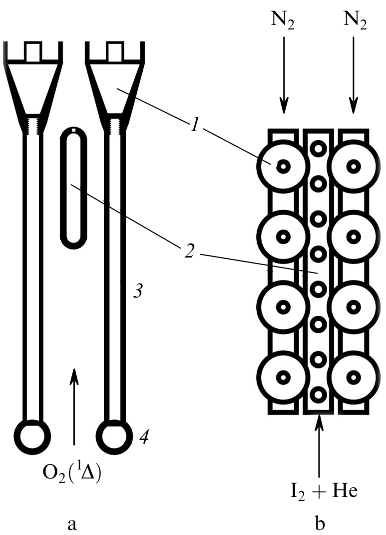

Figure 2. Nozzle block segment (a) top view and (b) view from the mixing chamber side: (*1*) conic nozzle for driver gas; (*2*) nozzle for helium with molecular iodine; (*3*) connecting pipes; (*4*) collector.

The laser radiation power emerging from both mirrors was detected with the power meters Ophir-300 (with an attenuator) and Ophir-1500. The gas from the mixing chamber was supplied to a gas-flow pipe of diameter 90 mm and pumped into a tank of volume 15 m^3 evacuated preliminarily to a pressure below 1 Torr. The chlorine flow rate was calculated using the values of its initial and final pressures in a closed 80-litre tank with chlorine gas (from where it was supplied to the CBSOG) and the time interval between the beginning and end of the laser operation.

The working parameters of a chemical OIL for which lasing took place are given below. The efficiency of chlorine utilisation in the CBSOG was about 95 %. No traces of the aerosol removed by the gas from the CBSOG were observed.

Rotational frequency of the rotor/s^{-1}	46
Flow rate of the alkaline solution of hydrogen peroxide/cm^3 s^{-1}	208
Concentration/mol L^{-1}	
KOH	6.5
H_2O_2	7.5
Initial temperature of solution/°C	−20
Flow rate of chlorine through CBSOG/mmol s^{-1}	56.5
Flow rate of helium through CBSOG/mmol s^{-1}	90
Flow rate of the driver nitrogen/mmol s^{-1}	250
Flow rate of helium through iodine nozzles/mmol s^{-1}	60
Flow rate of molecular iodine/mmol s^{-1}	1
Height of the solution layer over the rotor surface/mm	~8
Pressure at the bubbler nozzles/Torr	538
Pressure at the nozzle bank/Torr	26
Static pressure at the cavity walls/Torr	8.9.

For a rotational speed of 46 s^{-1} of the rotor, the solution layer was subjected to a centrifugal acceleration of 3.88×10^3 m $s^{-2} \approx 396g$ and created a pressure of ~ 300 Torr on the bubbler surface. The output power remained practically constant for a 7s-operation of the laser (a slight decrease in its value was due to a decrease in the chlorine pressure in the tank) and was equal to 623 and 641 W at the outlets of the mirrors. The total power (1264 W) corresponded to a chemical efficiency of 24.6 % for the laser. The ratio of the chlorine flow rate and output power to the flow rate of the solution was 0.27 mole L^{-1} and 6.1 kW L^{-1} s^{-1} respectively. The specific flow rate of chlorine through CBSOG per square cm of the working surface of the bubbler was 1.34 mmol s^{-1}. Thus, CBSOG is an efficient source of high-pressure singlet oxygen with a high rate of chlorine utilisation and a low concentration of the solution aerosol, and can be used for pumping supersonic OILs.

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