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Optimisation of characteristics of a chemical HF laser operating by using a new method for oxidising-gas production

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Abstract. **The energy parameters of an HF laser operating by using a new method for oxidising-gas production, which is based on the principle of two-region mixing, are optimised. The total amount of the inert diluent (helium) supplied to the laser was varied during experiments by varying its relative fraction only in the second mixing region. For an optimal relative fraction of the diluent in the second mixing zone and for an optimal position of the optical axis of the cavity under a constant pressure in the gas generator, the laser radiation power and the specific power output could be increased by 50 % and 60 %, respectively, compared to the laser operation regime realised in our previous experiments. In this case, the inert diluent amount decreased by 35 % and the length of the generation region increased by 20 %.**

Keywords: *chemical laser, oxidising gas, two-region mixing, active medium.*

1. Introduction

An original design of a self-contained supersonic cw chemical HF laser with a modified radial expansion nozzle block using nozzle–injector–injector cycle for reagent mixing (referred to as the A type laser in the following) was proposed in our paper [1]. The modified nozzle block was equipped with a special injector for spraying the cold inert diluent at the nozzle inlet. This made it possible to supply atomic fluorine and the inert diluent separately to the nozzles, and also ensured a two-region mixing of reagents and the subsequent low-temperature flow of the oxidising gas in the supersonic parts of the nozzles. The engineering approach proposed in [1] was patented as a new method for oxidising-gas production [2].

Experimental studies of an A type HF laser [1] confirmed its operational capability and gave its output parameters during redistribution of various amounts of helium from the first mixing region (of the combustion chamber of the gas generator with a primary dilution degree ψ_1) to the second mixing region (adjoining the nozzles) with a secondary dilution degree ψ_2. The total dilution degree ψ_Σ of the fuel mixture remained constant during the experiment: $\psi_\Sigma = \psi_1 + \psi_2 = \text{const}$. It was assumed in these experiments that the mass flow rate m_F of atomic fluorine or the pressure p_c in the combustion chamber of the gas generator were maintained constant. The distance x_c between the optical axis of the resonator and the nozzle block section was also kept constant. It was shown that for an almost complete transfer of helium from the first mixing region to the second one (which corresponds to $\psi_1 \sim 0.7$ and $\psi_2 \sim 13.5$), the laser radiation power increased by 70 % for $p_c = \text{const}$ and by 14% for $m_F = \text{const}$, while the specific energy output increased by 40%. Because the position of the optical axis of the resonator was fixed, no information was obtained about the variation in the lasing region length.

The secondary dilution degree chosen by us ($\psi_2 = 13.5$) is very close to its optimal value required for achieving the maximum radiation power in the operating regime (for $\psi_\Sigma = \psi_1 + \psi_2 = 0.7 + 13.5 = 14.2$) for the initial (basic) model of the HF laser (called the B type laser in the following) [3], whose nozzle block was subjected to modification. However, it does not mean that the same dilution degree should be also optimal for A type lasers. If this is the case, the optimal position of the optical axis of the resonator and the lasing region length may be different for different secondary dilution degrees. Moreover, it is interesting to estimate the effect of the mass flow rate of the reagents on the absolute laser radiation power N and the specific energy output N_Σ.

In accordance with the above considerations, the aim of this study, which is a continuation of our earlier work [1], is to optimise the energy parameters of an A type HF laser by varying the relative fraction of the secondary inert diluent supplied to the second mixing region, the position of the optical axis of the resonator relative to the nozzle block section, and the total mass flow rate of the reagents.

2. Experimental

Experiments were carried out using a test setup consisting of an A type HF laser, a system for supplying the working reagents (F_2, D_2, H_2, He) and for recording working parameters, a system for exhaust of waste reaction products, and an optical measurement scheme. Because all the elements used in the setup have been described in detail in [1], we consider only the peculiarities of the laser used in this study.

Figure 1 shows the modified nozzle block of the A type HF laser. Nozzle block (*2*) with slotted nozzles (*3*) consists

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of two symmetric (upper and lower) halves held together by bolts (*7*). The combustion chamber of gas generator (*1*) and the input part of slotted nozzles (*3*) of nozzle block (*2*) were connected through special injector (*4*) in the form of a stainless steel tube of diameter 6 mm perforated with holes of diameter 0.5 mm and intended for injecting secondary inert diluent (He^* atoms) into each slotted nozzle (*3*) of width 3 mm. The holes were drilled in three rows (the distance between the rows was 1.3 mm) with a step of 5 mm in each row, which corresponds to the step between the nozzles (the injector contains 108 holes). The angle between the axes of two adjacent holes was 25°. The plane of the output sections of the holes in the middle row was at a distance of 4.5 mm from the plane of critical nozzle sections. The secondary fuel (H_2 molecules) is supplied through an attached collector formed by 37 injector tubes (*5*) (only two end tubes are shown in Fig. 1) having an outer diameter of 2 mm and perforated by holes of diameter 0.35 mm (each tube contains 20 holes). The holes are arranged in a staggered manner with a step of 4 mm in each row. The injector tubes are fastened to the edges of nozzles (*3*), and the axes of the holes form an angle of 20° with the direction of the flow of oxidising gas mixture ($F-He-DF-He^*$) flowing from the slotted nozzles. The presence of nozzle (*3*) and two injectors (*4*) and (*5*) led to the term 'nozzle–injector–injector' for the realised scheme of reagent mixing. The output section of the nozzle block had a size of 180 mm × 39 mm. The nozzle block was cooled with water supplied through channels (*6*).

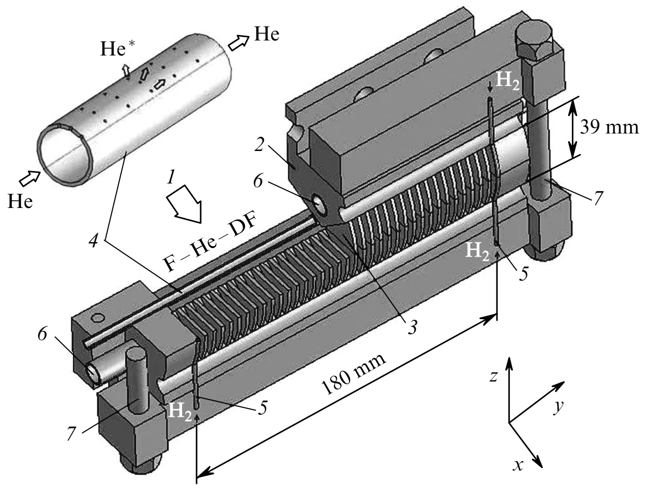

Figure 1. Design of the modified nozzle block of an A type HF laser: (*1*) flow of combustion products from the gas generator chamber; (*2*) nozzle block; (*3*) slotted supersonic nozzle; (*4*) special injector for injecting secondary inert diluent (helium); (*5*) injector tube for supplying secondary fuel (hydrogen); (*6*) coolant (water) channel; (*7*) bracing bolt.

A closed type two-mirror spherical resonator was used in the experiments. The laser beam was extracted through a hole of diameter 2 mm drilled in one of the mirrors. The parameters of the resonator are presented in [1].

Gaseous fluorine (oxidant F_2), deuterium (primary fuel D_2), helium [primary (He) and secondary (He^*) diluents] and hydrogen (secondary fuel H_2) in molar ratio $D_2 : F_2 : He : H_2 : He^* = 1 : \alpha : \psi_1(\alpha-1) : \alpha_2(\alpha-1) : \psi_2(\alpha-1)$, were used as the working reagents, where $\alpha = n_{F_2}/n_{D_2}$; $\psi_1 = n_{He}/n_{F_2}^{free}$; $\alpha_2 = n_{H_2}/n_{F_2}^{free}$; $\psi_2 = n_{He^*}/n_{F_2}^{free}$; $n_{F_2}^{free} = n_{F_2} - n_{D_2}$; and n_i is the number of moles of the corresponding reagent.

We planned to perform three series of tests. The first two series were aimed at obtaining the dependence of the HF laser parameters on the secondary dilution degree ψ_2, the total mass flow rate m_Σ of the reagents, and the position x_c of the optical axis of the resonator relative to the nozzle block section. As mentioned in the Introduction, the total dilution degree ψ_Σ of the fuel mixture remained constant during the experiment and was close to its optimal value required for the initial (B type) model of the HF laser [3]: $\psi_\Sigma = \psi_1 + \psi_2 = 13.5$; the maximum power of laser radiation was achieved for an almost complete transfer of helium from the first mixing region to the second one, i.e., for $\psi_1 \sim 0.7$ and $\psi_2 \sim 13.5$, and for the position $x_c = 17.5$ mm of the optical axis of the resonator, which was kept constant. However, it does not mean that the secondary dilution degree $\psi_2 \sim 13.5$ should be also optimal for the A type laser. It is also possible that it can be higher or lower, which is bound to affect the position of the optical axis of the resonator. To find an answer to this question, the first two series of experiments were carried out in two regimes and the position of the optical axis of the resonator was fixed in each series relative to nozzle block section (for a variation of x_c in the range 13–32 mm in each series), while the secondary dilution degree ψ_2 assumed values of 10, 15 and 21. On the one hand, such an approach increases the reliability of the obtained results, because two regimes are juxtaposed in each series of experiments. In one of the regimes (called the nominal regime), we have $\psi_2^{nom} \sim 15$ (close to the regime in which $\psi_2 \sim 13.5$). On the other hand, it becomes possible to obtain the dependences $N = f(\psi_2, x_c)$ and $N_\Sigma = f(\psi_2, x_c)$ in a minimum number of trials.

The dimensionless coefficients characterising the chemical composition of the medium in the combustion chamber of the gas generator were fixed ($\alpha \sim 2.5$ and $\psi_1 \sim 0.7$) under the condition $m_F = \text{const} \sim 9$ g s^{-1}. As the secondary dilution degree ψ_2 was increased from 10 to 21, the pressure p_c in the gas generator and the total mass flow rate m_Σ of the reagents were varied from 1.13 to 1.30 kg cm^{-2} and from 30 to 40 g s^{-1}, respectively.

The aim of the third series of tests was to study the effect of the secondary dilution degree ψ_2 on the HF laser parameters under the condition $p_c = \text{const}$. This series consisted of several tests in which the pressure p_c in the combustion chamber of the gas generator was ~ 1.2 kg cm^{-2} (which corresponds to a nominal secondary dilution degree $\psi_2^{nom} \sim 15$). Tests were performed for the optimal positions x_c^{opt} of the optical axis of the resonator obtained from the dependences $N = f(\psi_2, x_c)$ and $N_\Sigma = f(\psi_2, x_c)$ for the coefficients $\psi_2 = 10$, 15 and 21. In all three series of experiments, the secondary fuel excess coefficient α_2 was kept constant and equal to ~ 8.

3. Experimental results

3.1 Spatial energy parameters of laser radiation

The results of the first two series of experiments are presented in Fig. 2 in the form of two groups of dependences $N = f(\psi_2, x_c)$ and $N_\Sigma = f(\psi_2, x_c)$. These dependences are constructed for three (minimal, nominal and maximal) values of the secondary dilution degree ψ_2 in a rather broad range of positions x_c of the optical axis of the resonator. All the dependences demonstrate a monotonic increase in the energy parameters of laser radiation with increasing the distance between the optical axis of the resonator and the nozzle block section, but only to a certain extent determined by the optimal value x_c^{opt} that depends on the dilution degree ψ_2: $x_c^{opt} = 21$ mm for $\psi_2^{min} \sim 10$, $x_c^{opt} = 25$ mm for $\psi_2^{nom} \sim 15$, and $x_c^{opt} = 26$ mm for $\psi_2^{max} \sim 21$ (Fig. 3a).

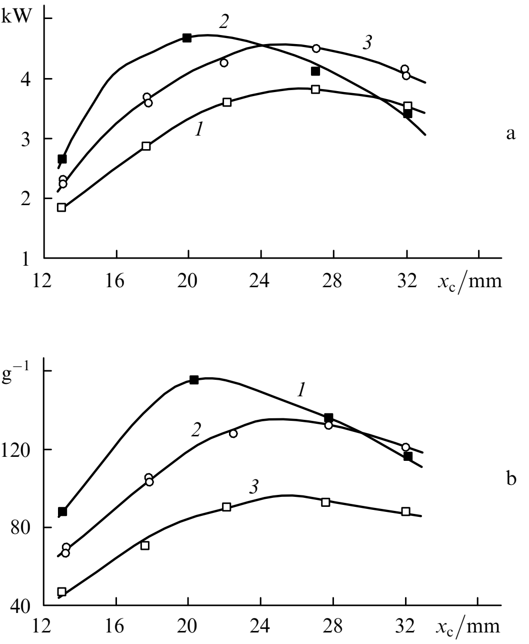

Figure 2. Dependences of (a) laser radiation power and (b) specific energy output on the distance x_c between the optical axis of the resonator and the nozzle block section for $\psi_2 \sim 10$, $p_c \sim 1.13$ kg cm^{-2} (*1*), $\psi_2 \sim 15$, $p_c \sim 1.21$ kg cm^{-2} (*2*) and $\psi_2 \sim 21$, $p_c \sim 1.30$ kg cm^{-2} (*3*).

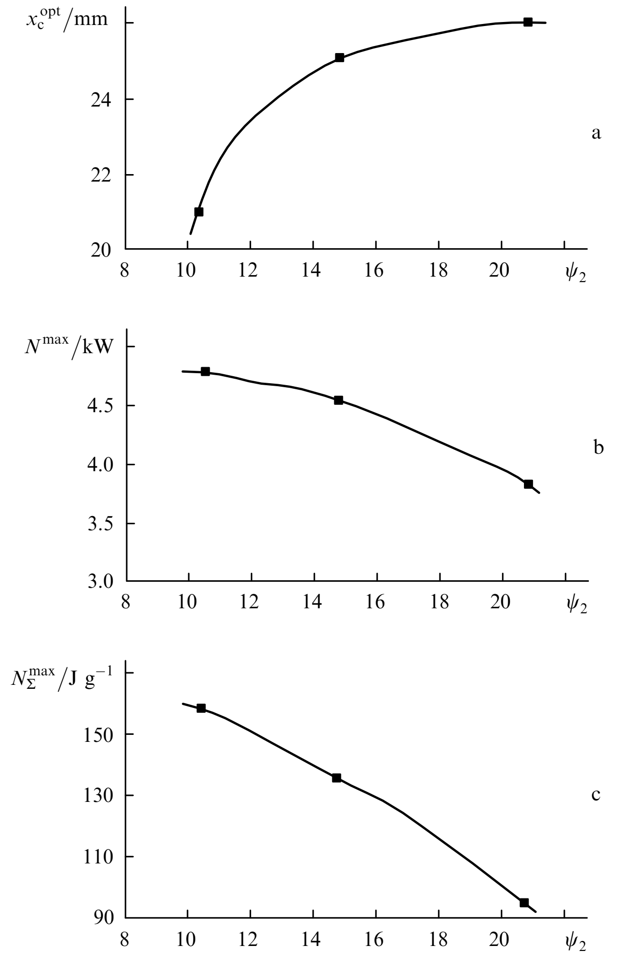

Figure 3. Dependences of (a) the optimal distance between the optical axis of the resonator and the nozzle block section, (b) the maximum laser radiation power, and (c) the specific energy output on the secondary dilution rate.

The data presented in Fig. 2a were used for constructing the dependence $N^{max} = f(\psi_2)$ (Fig. 3b) of the maximum values of laser power (corresponding to the optimal positions x_c^{opt} of the optical axis of the resonator shown in Fig. 3a) on the secondary dilution degree ψ_2. One can see that the function $N^{max} = f(\psi_2)$ does not have a maximum in the investigated range of variation of the dilution degree ψ_2 ($10 \leqslant \psi_2 \leqslant 21$). On the whole, the laser radiation power displays a weak dependence on the secondary dilution degree. The smooth dependence $N^{max} = f(\psi_2)$, especially in the region of small values of ψ_2, can be used to determine the probable position of its maximum which should lie in the region of $\psi_2^{opt} = 9 - 10$.

As for the maximum specific energy output N_Σ^{max}, one can see from Fig. 3c that its dependence on ψ_2 is manifested more strongly due to the influence of the total mass flow rate of the reagents (the flow rate increases with increasing ψ_2 more rapidly than the laser power).

The third series of tests was intended for obtaining the dependences $N^{max} = f(\psi_2)$ and $N_\Sigma^{max} = f(\psi_2)$ for a constant pressure $p_c \sim 1.2$ kg cm^{-2} in the combustion chamber of the gas generator. The values of N^{max} and N_Σ^{max} for nominal secondary dilution degree $\psi_2^{nom} \sim 15$ and nominal pressure $p_c^{nom} \sim 1.2$ kg cm^{-2} were obtained directly from Fig. 2 [curves (*2*)]. For the maximum secondary dilution degree $\psi_2^{max} \sim 21$, the values of N^{max} and N_Σ^{max} correspond to a pressure $p_c^{max} \sim 1.3$ kg cm^{-2} [curves (*3*), Fig. 2]. Hence these quantities were recalculated for the nominal pressure by the expressions

$$N(p_c^{nom}) = N(p_c^{max}) \frac{p_c^{nom} N_\Sigma(p_c^{nom})}{p_c^{max} N_\Sigma(p_c^{max})}, \tag{1}$$

$$N_\Sigma(p_c^{nom}) = N_\Sigma(p_c^{max}) \frac{1 - 0.51(p_c^{nom} - 1.3)}{1 - 0.51(p_c^{max} - 1.3)}, \tag{2}$$

where p_c^{nom} and p_c^{max} are measured in kg cm^{-2}. For a minimal secondary dilution degree $\psi_2^{min} \sim 10$ and nominal pressure $p_c^{nom} \sim 1.2$ kg cm^{-2}, the values of N^{max} and N_Σ^{max} were obtained in the present investigations. All these data are presented in Table 1. They allow a more correct comparison of the energy parameters of the A type HF laser working at a constant pressure $p_c^{nom} \sim 1.2$ kg cm^{-2} in the combustion chamber of the gas generator and at a fixed primary dilution degree $\psi_1 \sim 0.7$ of the helium fuel mixture in it, by varying the secondary dilution degree ψ_2 in the interval $10 \leqslant \psi_2 \leqslant 21$.

An analysis of the obtained experimental results leads to the following conclusions. Variations in the degree of the

Table 1. Results of testing of an A type HF laser for a constant pressure $p_c \sim 1.2$ kg cm^{-2} in the combustion chamber of the gas generator.

Laser operation regime	ψ_2	$N^{\max}$/ kW	$N_\Sigma^{\max}$/ J g^{-1}	$N_F^{\max}$/ J g^{-1}	m_Σ/ g s^{-1}	x_c/ mm
Optimal	10	5.19	161	536	32.2	21
Intermediate	15	4.56	133	528	34.2	25
Nominal	15	3.44	100	382	34.2	17.5
Post-nominal	21	3.71	100	445	37.2	26

secondary dilution of the active medium by helium in the range $10 \leqslant \psi_2 \leqslant 21$ considerably affect the energy parameters of the laser. As ψ_2 is decreased, both the laser power N and the specific energy output N_Σ increase, while the lasing region length Δx_L (related to the optimal position of the optical axis of the resonator by the condition $\Delta x_L \geqslant 2x_c^{\text{opt}}$) decreases. As ψ_2 is increased, the parameters N and N_Σ decrease but the lasing region length increases considerably. Hence, on the one hand, the nozzle block of the modified construction allows a control of the lasing region length due to the secondary dilution of the active medium by helium (we failed to demonstrate this earlier in [1]). On the other hand, the choice of an optimal secondary dilution degree should be made on the basis of a compromise between the energy parameters of the laser radiation and the spatial parameters of the active medium.

Optimisation of the parameters of an A type HF laser with respect to its nominal operation ($\psi_2 \sim 15$ and $x_c =$ 17.5 mm) realised in [1] led to the following results. For a nearly optimal value of ψ_2 ($\psi_2^{\text{opt}} \sim 10$) and for the optimal position of the optical axis of the resonator $x_c^{\text{opt}} = 21$ mm ($\Delta x_L = 42$ mm) corresponding to it under the conditions $p_c = \text{const} \sim 1.2$ kg cm^{-2}, the laser power N could be increased by 50 % (from 3.44 to 5.19 kW), the specific energy output N_Σ was increased by 60 % (from 100 to 161 J g^{-1}), and the specific power per unit flow rate N_F of free fluorine was increased by 40 % (from 382 to 536 J g^{-1}) (see Table 1).

Let us estimate the integral effect resulting from a transfer of 95 % of helium from the first mixing region to the second one and optimisation of its total amount. For this purpose, we compare the energy parameters of the basic (initial) model of the laser whose nozzle block was subjected to modification (B type laser) with the modified model (A type laser).

The transfer of helium from the first mixing region to the second one for a constant total amount of helium ($\psi_\Sigma \sim$ 13.5), which was studied by us earlier in [1], led to an increase in the laser power by a factor of 1.7. Optimisation of the total amount of helium performed in the present study resulted in its decrease by 35 % (the value of ψ_2 decreased from 13.5 to ~ 10). It led to a further increase in the laser power N by a factor of 1.5, specific energy output N_Σ by a factor of 1.6, and specific power N_F by a factor of 1.4. The obtained value of $N_F = 875$ J g^{-1} is comparable with the value $N_F = 870$ J g^{-1} achieved in the testing of the basic model of the laser. This fact is a consequence of large ($\sim 40\,\% - 50\,\%$) losses of atomic fluorine due to high thermal losses of the small-scale model studied in this work and to a prolonged stay of combustion products in the gas generator chamber and a non-optimal construction of a special injector for injecting the secondary inert diluent into the second mixing region.

Thus, from the point of view of the energy parameters of the laser, the integral effect associated with a transition from the basic model of the laser to the modified model is estimated by us as an increase in the laser power by a factor of $1.7 \times 1.5 = 2.55$, and of specific energy output by a factor of 1.6. The lasing region length Δx_L increases in this case by a factor of 1.6 (from 26 to 42 mm).

3.2 Analysis of the results

What is the reason behind such a considerable integral effect? To elucidate this question, we perform a comparative analysis of the A type laser operating in the control regime and of the B type laser operating in the basic regime. In the basic regime (B type laser), the entire inert diluent is supplied through the spray head into the combustion chamber of the gas generator (first mixing region). In the control regime (A type laser), about 5 % ($\psi_1 \sim 0.7$) of the inert diluent is supplied to the first mixing region, while 95 % ($\psi_2 = 13.5$) is supplied through a special injector into the input sections of the oxidising nozzles (second mixing region). The following conditions correspond to both regimes: the temperature T_c in the first mixing regime is ~ 2400 K; the pressure p_c in the combustion chamber of the gas generator is maintained equal to ~ 1.36 kg cm^{-2}; and the total dilution degree of the fuel mixture varies in a narrow range ($\psi_\Sigma = \psi_1 + \psi_2 = 12.4 - 14.2$).

In the basic regime, the results were obtained for the optimal position $x_c^{\text{opt}} = 13$ mm of the optical axis of the resonator, while the results in the control regime were obtained for $x_c = 17.5$ mm, which differs from the optimal value $x_c^{\text{opt}} = 25$ mm. The results can be reduced to the optimal conditions, by using a correcting factor $k = N^{\text{nom}}(x = 25\text{ mm})/N^{\text{nom}}(x = 17.5\text{ mm}) = 1.33$ by which the energy parameters of the control regime should be multiplied. Table 2 presents the energy parameters of the control regime corrected in this way. These parameters exceed the corresponding values of laser power for the basic regime by a factor of $N^A/N^B = 7.51\text{ kW}/3.48\text{ kW} = 2.16$ and of specific energy output by a factor of $N_\Sigma^A/N_\Sigma^B = (226\text{ J g}^{-1})/(173\text{ J g}^{-1}) = 1.31$. The specific power per unit flow rate of free fluorine decreased by a factor of $N_F^A/N_F^B = (831\text{ J g}^{-1})/(870\text{ J g}^{-1}) = 0.955$.

A characteristic feature of the laser operation regimes being compared in this study is that the ratio of the mass flow rates of free fluorine $m_F^A/m_F^B = (9\text{ g s}^{-1}) \times (4\text{ g s}^{-1})^{-1} = 2.25$ is quite close to the ratio $N^A/N^B =$ 2.16 of laser powers. Considering that each fluorine atom

Table 2. Comparative data on the energy parameters of the HF laser.

Laser operation regime	α	ψ_1	ψ_2	m_c/g s^{-1}	m_Σ/g s^{-1}	p_c/kg cm^{-2}	x_c/mm	N/kW	N_Σ/J g^{-1}	N_F/J g^{-1}
Corrected control regime (A type laser)	2.45	0.67	13.5	29.4	33.2	1.36	17.5	7.51	226	831
Basic regime (B type laser)	1.52	12.4	0	18.0	20.1	1.36	13	3.48	173	870

Note: m_c is the mass flow rate of the gas-generating fuel.

in the A type laser 'realises' 0.955 of the energy released in the B type laser, the actual increase in the radiation power of the A type laser is equal to the ratio of mass flow rates of free fluorine after taking into account the factor 0.955, i.e., $0.955(m_\mathrm{F}^\mathrm{A}/m_\mathrm{F}^\mathrm{B}) = 0.955 \times 2.25 = 2.15$. This ratio coincides almost exactly with the ratio $N^\mathrm{A}/N^\mathrm{B} = 2.16$ of laser powers. The ratio of the specific energy outputs in the corrected regime coincides with their ratio $N_\Sigma^\mathrm{A}/N_\Sigma^\mathrm{B} = (N^\mathrm{A}/N^\mathrm{B})\times (m_\Sigma^\mathrm{B}/m_\Sigma^\mathrm{A}) = 2.16 \times [(20.1\ \mathrm{g\ s^{-1}})/(33.2\ \mathrm{g\ s^{-1}})] = 1.31$ in the basic regime.

Thus, the increase in the output power of the A type laser completely follows the increase in the amount of free fluorine entering the region of formation of the active medium under the condition that the pressures in the gas generator lasers of both types are equal.

For an almost complete transfer (~ 95 %) of helium to the second mixing region at input sections of oxidising nozzles, a cold helium jet (at $T_\mathrm{He} \sim 290$ K) mixes with a hot flow (at $T_\mathrm{c} \sim 2400$ K) of equilibrium combustion products from the gas generator. Rough estimates of the parameters of the completely mixed mixture performed for the control regime using the theoretical model of instantaneous mixing, showed that the temperature of the completely mixed mixture in the control regime ($\psi_2 = 13.5$, A type laser) decreases to $T_\mathrm{mix}^\mathrm{A} \sim 870$ K (by a factor of 2.8) compared to the basic regime temperature $T_\mathrm{mix}^\mathrm{B} = T_\mathrm{c} \approx 2400$ K (B type laser).

A decrease in temperature causes a lowering of pressure proportionally to the ratio $(T_\mathrm{mix}^\mathrm{A})^{1/2}/(T_\mathrm{mix}^\mathrm{B})^{1/2} = (870\ \mathrm{K})^{1/2}\times (2400\ \mathrm{K})^{-1/2} = 0.6$. If the inert diluent is not heated to the desired temperature $T_\mathrm{c} \sim 2400$ K, the concentration of the initial reagents $\mathrm{F_2}$ and $\mathrm{D_2}$ (whose combustion ensures such a heating) will decrease. If the amount of recovered free fluorine is kept unchanged ($m_\mathrm{F} = 4\ \mathrm{g\ s^{-1}}$ in the basic regime), the concentration of the equilibrium combustion products in the gas generator will decrease and hence the pressure in it will drop. In the basic regime of laser operation (B type laser), the recovery of one gram of atomic fluorine requires an expenditure of $m_\mathrm{c}/m_\mathrm{F} = (18\ \mathrm{g\ s^{-1}})/(4\ \mathrm{g\ s^{-1}}) = 4.5$ relative units of gas-generation fuel, while the corresponding amount required in the control regime (A type laser) is just $(29.4\ \mathrm{g\ s^{-1}})/(9\ \mathrm{g\ s^{-1}}) = 3.27$. Therefore, a transition from the basic regime to the control regime leads to a decrease in the consumption m_c of the gas-generating fuel by a factor of $3.27/4.5 = 0.726$. The pressure in the combustion chamber also follows this decrease. As a result of the decrease in the combustion chamber temperature and the concentration of the initial reagents, the pressure in the chamber drops by a factor of $(0.6 \times 0.726)^{-1} = 2.3$.

The energy parameters of a cw HF laser are usually determined and compared by specifying a pressure in the active medium and a gas generator. Obviously, the pressure p_c in the gas generator in the control regime should be increased in this case to the value $\sim 1.36\ \mathrm{kg\ cm^{-2}}$, which is typical for the basic regime. This can be done by increasing the mass flow rate of the reagents by a factor of 2.3. The concentration of free fluorine supplied to the active medium will increase in the same proportion. This fact was confirmed by us experimentally by comparing the parameters of lasers operating in the basic and control regimes: $m_\mathrm{F}^\mathrm{A}/m_\mathrm{F}^\mathrm{B} = 2.25$.

A 2.8-fold decrease in the temperature of the gas entering the oxidising nozzles in the control regime leads to a corresponding decrease in the translational temperature in the active medium. It was shown in [4] that the specific power N_F, calculated per unit flow rate of free fluorine, is inversely proportional to this temperature. Therefore the energy parameters of the laser will increase. According to the results of our previous studies [1], the increase is about 70 %.

Then, the expected calculated integral effect caused by a change in the energy parameters of the HF laser due to a decrease in the temperature in the combustion chamber of the gas generator and in the amount of initial reagents, as well as a decrease in the translational temperature of the active medium on passing from the basic model (B type laser) to the modified model (A type laser) will be manifested in the increase in the laser power by a factor of $N^\mathrm{A}/N^\mathrm{B} = 2.3 \times 1.7 = 3.9$. Naturally, the calculated value of the effect differs from that obtained directly in the experiments ($N^\mathrm{A}/N^\mathrm{B} = 2.16$) for the reasons mentioned above.

Thus, a comparative analysis of the A type laser operation in the control regime and B type laser operation in the basic regime reveals the physical factors responsible for the growth of energy parameters of the A type laser in which the new method proposed by us was used for oxidising-gas prduction. These factors include an increase in the concentration of free fluorine supplied to the region of active medium formation (under the condition that the pressure in the gas generators of both types of lasers is the same), and a decrease in the translational temperature of the active medium.

4. Conclusions

Experimental studies on optimising the energy parameters of self-contained HF lasers revealed the following facts. Variations in the secondary dilution degree ψ_2 in the investigated range ($10 \leqslant \psi_2 \leqslant 21$) lead to considerable variations in the spatial and power characteristics of laser radiation. As the coefficient ψ_2 is decreased, both the laser power and the specific energy output increase, while the lasing region length decreases. As ψ_2 is increased, the energy parameters decrease but the lasing region length increases considerably (up to $\Delta x_\mathrm{L} = 52$ mm). For a value of ψ_2 close to the optimal value ($\psi_2^\mathrm{opt} \sim 10$) and for a corresponding optimal position of the optical axis of the resonator $x_\mathrm{c}^\mathrm{opt} = 21$ mm under the conditions $p_\mathrm{c} = \mathrm{const} \sim 1.2\ \mathrm{kg\ cm^{-2}}$, the output power of the A type laser was increased by 50 % and the specific energy output N_Σ was increased by 60 % compared to their values in the nominal operating regime of the laser ($\psi_2^\mathrm{nom} \sim 15$ and $x_\mathrm{c}^\mathrm{nom} = 17.5$ mm) realised in our earlier investigations [1]. In this case, the total concentration of the inert diluent decreased by 35 % while the lasing length increased by 20 %.

A comparison of the energy parameters of the basic (initial) model of the laser (B type laser), whose nozzle block was subjected to modification, and the modified model (A type laser) shows that the integral effect resulting from a transfer of 95 % helium from the first to second mixing region and an optimisation of its total amount is manifested in an increase in the output power of the A type laser by a factor of 2.55, and of specific energy output by a factor of 1.6. The lasing region length increases in this case by a factor of 1.6. The physical reasons behind such an integral effect are revealed.

References

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