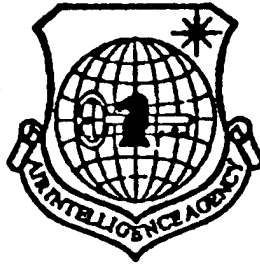


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FORMULA FOR ESTIMATING THE OUTPUT POWER OF SUBSONIC
(CHEMICAL OXYGEN-IODINE LASER) COIL

by

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FORMULA FOR ESTIMATING THE OUTPUT POWER OF SUBSONIC
(CHEMICAL OXYGEN-IODINE LASER) COIL.

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ABSTRACT: By analyzing the experimental data of subsonic COIL in different working conditions, we obtained the experimental formula for estimating the output power of subsonic COIL.

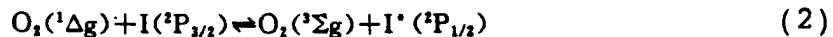
KEY WORDS: Chemical oxygen iodine laser, output power.

1 Introduction

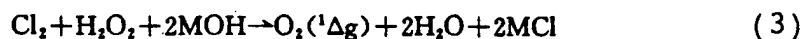
So far, the chemical oxygen iodine laser (COIL) is the first chemical laser to adopt atomic electron transition. It has a working wavelength $1.315\mu\text{m}$ and is based on transition of iodine atoms $\text{I}^*(^2\text{P}_{1/2}) \rightarrow \text{I}(^2\text{P}_{2/3})$.



The energy of iodine atoms in an excited state comes from the near-resonance transmission energy of iodine atoms and $\text{O}_2(^1\Delta\text{g})$



while the generation of $\text{O}_2(^1\Delta\text{g})$ results from a chemical reaction between Cl_2 and H_2O_2 alkaline solutions as follows:



$\text{M} = \text{K}, \text{Na}, \text{Li}$

A COIL has the following features: (1) High energy output: its ratio power is extremely high, and the energy density of $O_2(^1A_g)$ as an energy giver is as high as 100kJ/mol[1]; (2) Highly efficient operations: the conversion of the chemical energy of reacting substances to laser output is extremely efficient[2]; (3) Short wavelength: its output wavelength is the shortest wavelength among all the chemical lasers realized to date; in addition, its wavelength, located at the atmospheric window, possesses ideal atmospheric propagation properties; (4) Its laser wavelength coincides with the optimum optical fiber transmission waveband and therefore, enjoys excellent optical fiber transmission properties. Furthermore, while interacting with metallic materials, it can provide a large absorption coefficient[3], which leads to some unique advantages in its multifunctional applications.

In recent years, with the successful development of the $O_2(^1A_g)$ generator of the circulating reaction liquid as well as the realization of a kilowatt-level COIL featuring long and stable operations, interest has been growing in the prospects of COIL in industrial applications[5,6].

By analyzing the experimental data of subsonic COIL under different working conditions, we derived an experimental formula for estimating the output power of laser devices. With this formula and some working parameters, it is possible to conduct quantitative estimation of the output power of COIL and provide a support for COIL design.

2. Experimental Formula

To facilitate an overall assessment of the working performance of COIL, Watanabe[7] introduced chemical efficiency

η_c , energy extraction efficiency η_e and Cl_2 utilization rate η_c , which are defined, respectively, as:

$$\eta_c = P_L / \dot{m}_{\text{Cl}_2} E \quad (4)$$

$$\eta_e = P_L / \dot{m}_{\text{O}_2} (\eta - \eta_{th}) E \quad (5)$$

$$\gamma = \dot{m}_{\text{O}_2} / \dot{m}_{\text{Cl}_2} \quad (6)$$

where m_i is the molar flow rate of component i ; η is the content percentage of $\text{O}_2(^1\Delta_g)$; P_L is laser device and output power; E is deactivation energy of $\text{O}_2(^1\Delta_g)$, which is approximately $9.43 \times 10^4 \text{ J/mol}$; η_{th} is the lowest content percentage of $\text{O}_2(^1\Delta_g)$, needed for causing a counter-revolution of the number of iodine atomic particles. Theoretically[2],

$$\eta_{th} = (1 + 1.5 \exp(402/T))^{-1} \quad (7)$$

When $T=300\text{K}$, $\eta_{th} \approx 17\%$.

In another paper[8], an analysis of the working parameters η_e and η_c of a supersonic COIL operating under different conditions revealed a relationship of chemical efficiency η_c depending on η , the content percentage of $\text{O}_2(^1\Delta_g)$ as follows:

$$\eta_c = 0.5(\eta - 0.17) \quad (8)$$

The accommodation of concrete experimental data and formulas are shown in Fig. 1.

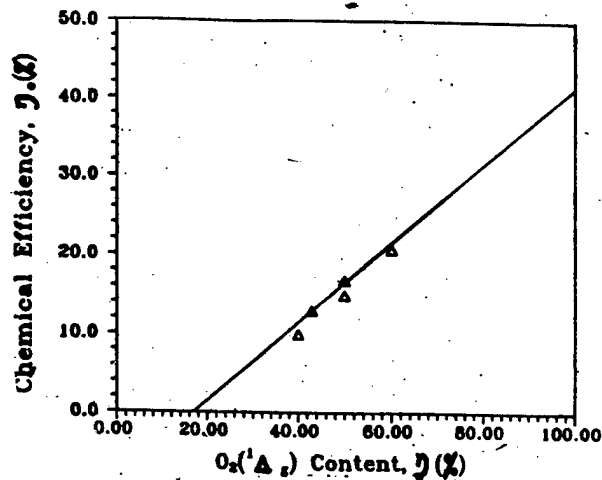


Fig. 1. Dependence of η_c on η

Besides, it is known from the definitions of η_c and η_e that they are in a relationship as follows:

$$\eta_c = \eta_e \gamma (\eta - \eta_a) \quad (9)$$

Since the supersonic COILs generally adopt bubbling $O_2(^1\Delta g)$ generators, in which the Cl_2 utilization rate is nearly 100% [9] in normal cases and the working temperature is 300K, for the supersonic COIL,

$$\begin{cases} \gamma \approx 1 \\ \eta_a = 0.17 \end{cases} \quad (10)$$

by introducing condition (10) in (9) and comparing it with (8), it can be concluded that in supersonic COILs adopting bubbling $O_2(^1\Delta g)$ generators, the extraction efficiency of converting $O_2(^1\Delta g)$ to laser output is roughly a constant that is approximately equal to 50%.

Based on the above conclusion, i.e., in an actually operating supersonic COIL, η_e can be approximately regarded as a constant. From the definition formula of η_e and condition (10), the following can be derived:

$$P_L / \dot{m}_{Cl_2} (\eta - 0.17) = \text{const} \quad (11)$$

This suggests that if in two laser devices, the molar flow rate of Cl_2 , the content percentage of $O_2(^1\Delta g)$ and the laser output power, respectively, are \dot{m}_{Cl_2} , η , P_L and \dot{m}'_{Cl_2} , η' , P'_L , the following can be derived from Eq. (11):

$$P_L / P'_L = \frac{\dot{m}_{Cl_2}}{\dot{m}'_{Cl_2}} \cdot \frac{\eta - 0.17}{\eta' - 0.17} \quad (12)$$

To verify the correctness of Eq. (12), we carried out simulation calculations of the experimental results of the supersonic COIL under different working conditions as listed in Table 1, and defined

$$\begin{cases} X = P_L / P'_L \\ Y = \frac{\dot{m}_{Cl_2}}{\dot{m}'_{Cl_2}} \cdot \frac{\eta - 0.17}{\eta' - 0.17} \end{cases} \quad (13)$$

TABLE 1. Typical Working Parameters of COIL

Ref	\dot{m}_{Cl_2} (mmol/s)	excitation efficiency, η (%)	P_L (W)
10	19	40	180
11	80	50	1080
12	6.9	50	105
13	2.1	43	25
14	1.8	60	35

The simulation calculations are shown in Fig. 2, where the solid line is a straight line of $X=Y$, and the independent dots are simulated values. The simulation results in Fig. 2 demonstrated the correctness of the inferred conclusion (12), based on which the experimental relationship of the output power of the supersonic COIL depending on the molar flow rate of Cl_2 and \dot{m}_{Cl_2} , the content percentage of O_2 ($^{1\lambda}g$) as follows:

$$P_L = K \dot{m}_{Cl_2} (\eta - 0.17) \quad (14)$$

where K is a ratio constant. From the experimental data listed in Table 2, we calculated the experimental value of K as of around $43.8J/mmd$ (see Table 2). And based on this, we obtained the experimental formula for estimating the output power of supersonic COIL as follows:

$$P_L = 43.8 \dot{m}_{Cl_2} (\eta - 0.17) \quad (15)$$

Using Eq. (15), the possible output power of laser devices can be estimated as long as the working parameters \dot{m}_{Cl_2} and η of the designed COIL system are determined.

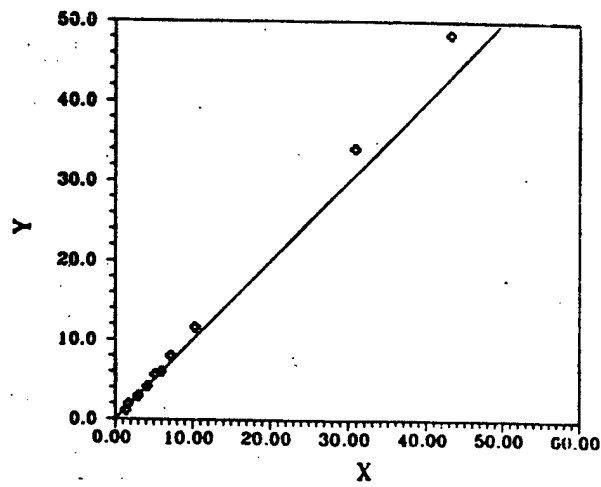


Fig. 2. Dependence of Y on X

TABLE 2

\dot{m}_{a_2} (mmol/s)	η (%)	P_L (W)	K
19	40	180	41.2
80	50	1080	40.9
6.9	50	105	46.1
2.1	43	25	45.8
1.8	60	35	45.2
			43.8

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