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Research paper

Procedure to optimize the performance of chemical laser (CCLs) using the genetic algorithm optimization

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Abstract

This work presents details of the study of the entire flow inside the facility where the exothermic chemical reaction process in the chemical laser cavity is analyzed. In our paper we will describe the principles of chemical lasers where flow reversal is produced by chemical reactions. We explain the device for converting chemical potential energy laser energy. We see that the phenomenon thus has an explosive trend. Finally, the feasibility and effectiveness of the proposed method is demonstrated by computer simulation.

Keywords: *Gas; Chemical; Reactive Flow; Mach Number; Genetic Algorithm.*

1. Introduction

Chemical compounds are able to store large
amounts of energy that may be partially released in exothermal chemical reactions, i.e. the ones proceeding with liberation of energy. It has been rather attractive to convert this energy into coherent optical radiation. The chemical lasers are exactly the systems where such a conversion has been realized. The current chemical lasers oscillate on the vibrational (more exactly, on vibrational-rotational) transitions of molecules. The chemical laser to a device for the conversion chemical potential energy into laser energy. It is based on the use of simple reactions the type:

$$A + BC \rightarrow AB^{*} + C$$

AB * means that the AB molecule is vibrationally excited. When the atom A approaches the BC molecule, the atoms A and B attract, BC link breaks and there create a new molecule AB * which has an energy equal vibration a more or less important fraction of the energy released. The total energy released is equal to the sum of the translational kinetic energy and energy Vibration and rotation. The theory shows that this fraction depends strongly on the interaction potential and the relative masses of the atoms. The most well known reactions involve halogen and hydrogen. The reactions involved are the following:

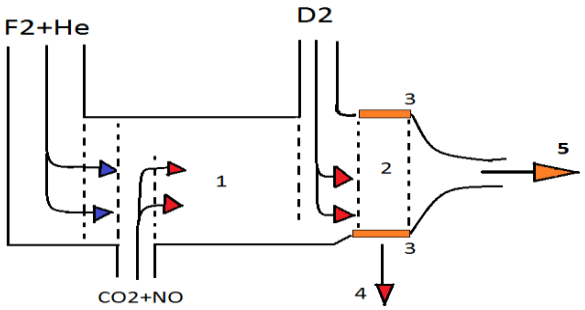


Fig. 1: Schematic of HF-DF Chemical Laser. 1 Chemical Reactor Chamber, 2 Resonator Volume, 3 Output Mirror, 4 Laser Output.

- Initiation of the reaction by creating fluorine atom

$$NO + F_2 \rightarrow NOF + F \quad (1)$$

- Production of molecules DF and Chain reactions for chemical lasers

$$F + D_2 \rightarrow DF^* + D; D + F_2 \rightarrow DF^* + F; F + D_2 \rightarrow DF^* + D; \tag{2}$$

- Production of HF molecules

$$F + H_2 \rightarrow HF^* + H\left(+\frac{30kcal}{mole}\right);$$

$$H + F_2 \rightarrow HF^* + F(+130kcal/mole); \tag{3}$$

Transfer of the vibration energy of DF au mode CO2

$$DF(v) + CO_2(000) \rightarrow DF(v-1) + CO_2(001) \tag{4}$$

The first reaction initiates the phenomenon, the following three (2) (3) lead to the production of vibrationally excited molecules DF and more fluorine atoms than those who were injected for the initiation reaction. The phenomenon thus has an explosive trend. The latter reaction indicates the vibrational energy transfer of the DF molecule than CO2. it is not possible to observe the stimulated emission continues directly on the DF transitions because the population inversion is low. By cons, the long life of the level (001) of CO2 can store energy on this level and to obtain a high population inversion between the levels (001) → (100) and levels (001)→(020). DF molecule plays the same role as the nitrogen molecule in electrical CO2-N2-He laser (laser GDL). The upper laser level is state (001), the lower laser level is provided by states (020) and (100). The transition (001) → (100) yields a line at the wavelength λ= 10.6 μm, whereas the (001 → (020) yields a line at λ= 9.6 μm.

Fig. 2: (A-B)-Analogical Approach-Rate-Controlling Processes in CO2 Laser. Groups 1 and 2 Represent the Collective Lower and Upper Laser Levels. Group 3 Represents the Excited Metastables Such as HF-DF.

The flow can bring other benefits that the evacuation of and the heat of the reaction products:
It may "freeze" in a very fast supersonic expansion Energy certain levels to be the essential agent of setting out of balance and of the population inversion. This will be the "gas dynamic laser" (GDL) discovered in 1969 and the other lasers of the same type that followed.
It can also allow the rapid mixing of two components gas by mixing two supersonic flows. These components then react in an exothermic chemical reaction and chemical lasers will flow alone can operate continuously, The foregoing reactions are of great interest because if for example we calculate the energy required dissociation of the molecule F ,, there is that the energy required to produce an atom Fluorine is the same as the vibrational energy produced during the first of the preceding reactions. We can say that it is possible convert chemical energy into vibrational energy with a yield of about 100%. Experiences made to extract the laser energy over the first reaction lead to reports conversion between the vibrational energy and energy laser 5% and perhaps even 20% after results that have been communicated. It appears therefore possible to convert chemical potential energy laser energy with a fairly good yield. There seems to be that in some cases the reaction of atoms and molecules provides an efficient conversion of chemical energy into vibrational energy. So the problem often leads to a search a production of atoms in favorable conditions

2. Flow conditions through the nozzle

The following hypotheses are considered for the nozzle problem formulation: two-dimensional equilibrium flow, in viscid flow (where the dissipative transport phenomena of viscosity, mass diffusion, and thermal conductivity are neglected), there is no body force acting on the fluid and there is no heat addition.
The development of the following equations is detailed in Anderson (1995) and the main steps are described below. The classical governing equations can be written in the conservation form as : continuity equation (mass conservation equation), momentum equations and Energy equation. The velocity components in the x and y directions are defined as u and v respectively and t is the time. Conservation of species equation and equation of state. the other hand, nitrogen acts as a reservoir of energy because its first vibrationally excited level (HF-DFV = 1) is in near resonance (it has almost the same energy) that the upper level (100) and CO2 its energy is quickly transferred to the CO2 level. In this system the excited states to establish the top level the laser transition (see references. 1), are populated by thermal processes at thermodynamic equilibrium, either by shock wave, by combustion or by electrical means (ref. 1). These states excited are then frozen in the flow by means of a process extremely fast adiabatic expansion speed aerodynamics supersonic. In this expansion, the gas cooling rate is too fast for the kinetic processes to follow. At the same time, of course, the flow transports energy to degraded downstream of the cavity. The devices used were originally very simple. Inversion population was sought on the vibrational transition (001-100) the CO2 molecule in its ground electronic state (see fig.3 detailed presentation of the principle of the laser). FIG. 3 shows a block diagram of the device as well as the evolution of energy in the environment and the population of the vibrational states of CO2 during the relaxation. In such a system, the first levels 001 and 100 of the vibrational CO2 have their "frozen" population so substantially equal by relaxation, when using pure CO2; it generally has no population inversion. Steam is added water or helium which have the property of selectively disabling by collisions lower CO2 level (100) of the transition. In parallel, one also flows the secondary flow of hydrogen that reacts with the fluorine atoms to produce the vibrationally excited HF and the associated heat of reaction. The addition of heat tends to

drive the flow toward Mach 1 conditions, or the so-called thermal choking case. Avoiding this condition is a major concern in chemical laser designs. Thermal choking of supersonic flows leads to a variety of unfavorable behaviors, such as reduced velocity, increased density and pressure, higher temperatures, large optical path difference (OPD) effects associated with density variations, and feedback of flow behavior into upstream flow regions. To avoid thermal choking, an inert, diluent gas, such as helium or, more infrequently nitrogen, is used to increase the flow mixture's heat capacity, thus minimizing the effects of heat release. Alternatively, one can mitigate heat release through area expansion; however, this increases vacuum pumping demands. Figures 3. to 4. Show the Mach number, temperature, and pressure dependence of the gas mixture as a function of position in a typical laser cavity with and without the addition of heat due to the secondary flow.

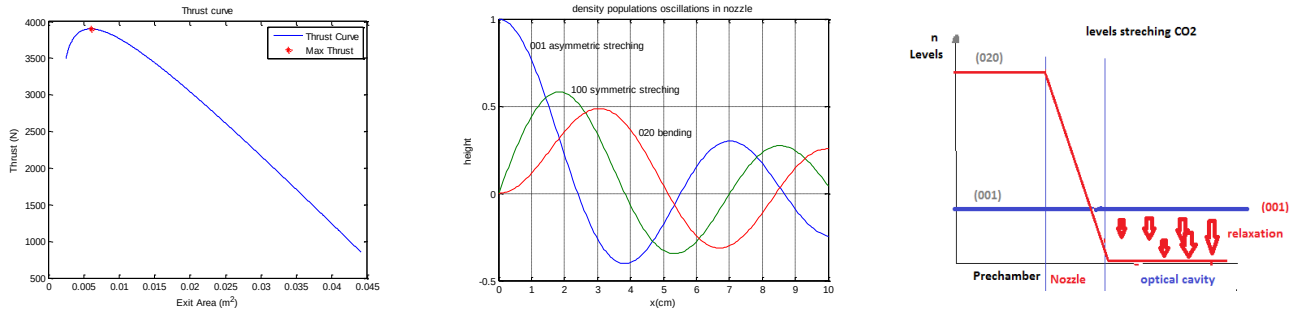


Fig. 3: The Vibrational State of the HF-DF Molecules and State (001) of the CO2 Molecules Named "Frozen".

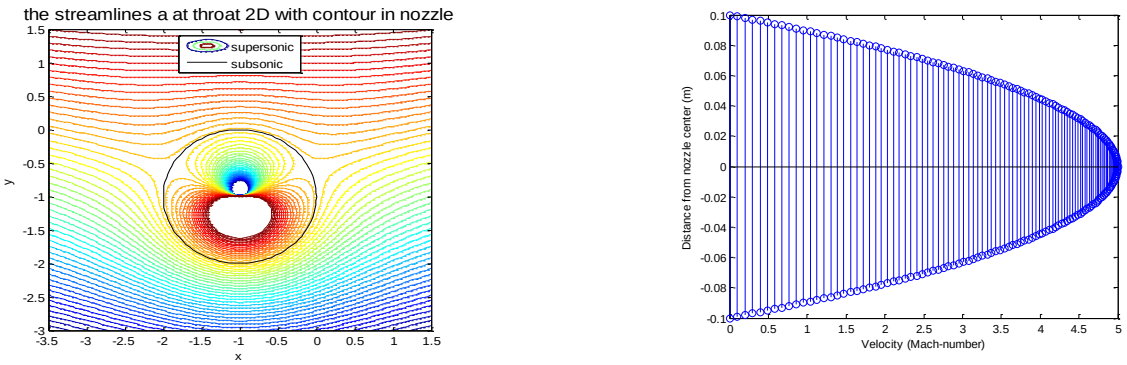


Fig. 4: Mach Number with and without Reaction Heat as A Function of Position in the Laser Cavity.

$$\frac{\partial n_1}{\partial t} = \omega(n_2 - n_1) - \omega_p(n_1 - n_3) + \frac{n_2}{\tau} + \frac{n_3}{\tau_{31}}$$

$$\frac{\partial n_2}{\partial t} = -\omega(n_2 - n_1) + \frac{n_3}{\tau_{32}} - \frac{n_2}{\tau}$$

$$\frac{\partial n_3}{\partial t} = \omega_p(n_1 - n_3) - \frac{n_3}{\tau_{32}} - \frac{n_3}{\tau_{31}}$$

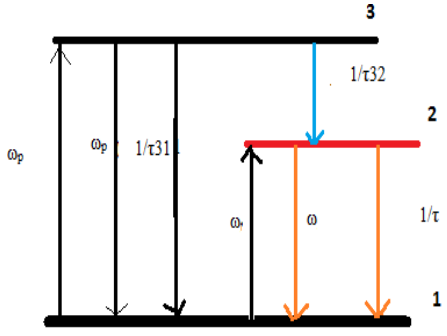
$$\partial n_1/\partial t + \partial n_2/\partial t + \partial n_3/\partial t = 0$$

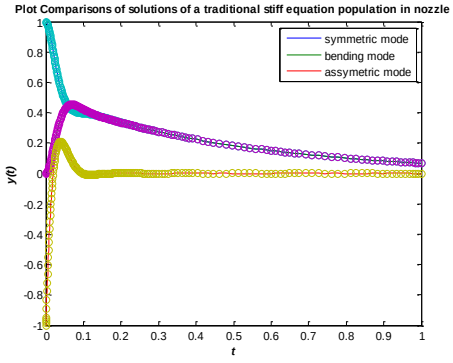
With $n_1 + n_2 + n_3 = n'$, (6)

This means creating the conditions $n_3 << n_1$

$$\frac{\partial n_3}{\partial t} \approx 0$$

$$\tau_{32} << \tau_{31}$$





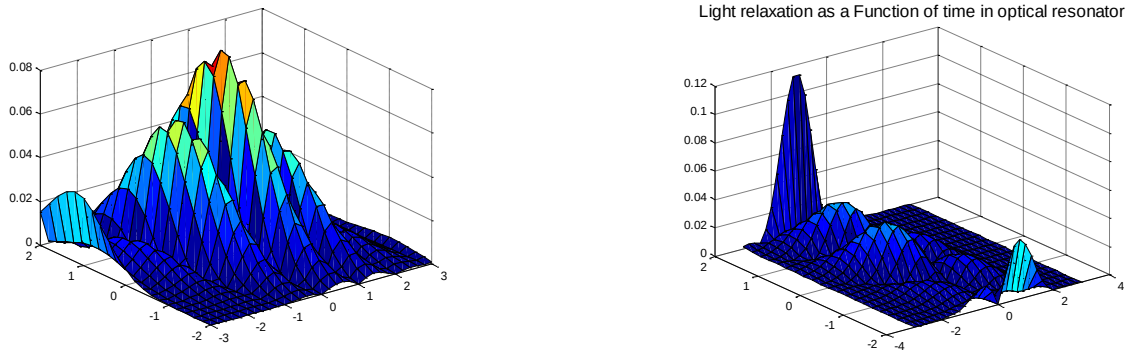


Fig. 5: The Error Surface with Reduced Spacing in Mesh Grids in Optical Resonator.

3. Using the genetic algorithm optimizations

Abbreviation this genetic algorithm technique to optimize the performance of any chemical laser as a function of any of the flow rates, mirror location, mirror size, nozzle configuration, injector sizes, and other factors. This modeling procedure can be used as a method to guide experiments to improve chemical laser performance. In fig.6 it is suggested that future use of the GA for this type of chemical laser modeling problem should include an investigation of the statistical effects of different random number seeds as a function of the GA scheme. Overall, the GA technique worked exceptionally well for this chemical laser modeling problem in a cost effective and time efficient manner. Because of a Gas population-based approach it is inherently parallel; therefore, further modifications could enhance this technique to be extremely fast at searching a large parameter space on a parallel processing computer. The first level constructs the CCLs through combinations of stoichiometric coefficients of all chemical species and optimized using genetic algorithm. Second level determines the best estimate for the reaction rate constants for each of the reactions using a standard non-linear optimization
algorithm. The process is repeated through a number of
generations where the genetic algorithm will successively
reduce the number of possibilities through elimination of poor CCLs and retaining and re-optimizing better CCLs. This modeling procedure could be used as a method to guide experiments to enhance chemical laser performance.

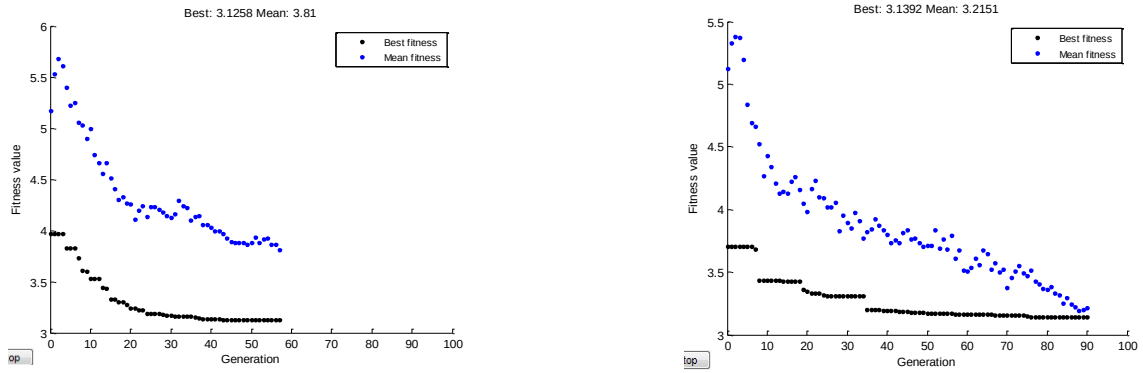


Fig. 6: Average Error as A Function of the Generation for Different Genetic Algorithm Schemes; Population Size for All Cases Was 100

4. CONCLUSION

At this point it is possible to answer the question of the utility of the GA technique. First, the genetic algorithm found a parameter set that was a better match than any that were determined by earlier trial-and-error calculations
An automated system that employs GA has been designed
to search and fit the best possible CCLs from concentration profiles of involved chemical species in a batch reaction. The system has been demonstrated to be able to model a CCLs even in the presence of unmeasured chemical species. Reversible reactions are also detected and can be evaluated by the system.
It may also be possible to use this modeling technique
for other types of chemical lasers, e.g., (COIL) chemical oxygen-iodine laser devices. This modeling procedure could be used as a method to guide experiments to enhance chemical laser performance

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References

[1] O. Svelto: Principles of Lasers (Plenum Press, New York 1982) https://doi.org/10.1007/978-1-4615-7667-9.
[2] D. C. O'Shea, W. R. Callen, W. T. Rhodes: Introduction to Lasers and Their Applications (Addison-Wesley Publ, Co., Reading, Massachusetts 1977).

[3] John D. Anderson Jr : Modern Compressible Flow, 2nd Edition, 1990.
[4] L. V. Tarasov: Lasers-Reality and Hope (Prosveshchenie, Moscow 1984).
[5] L. V. Tarasov: Optics Born by the Laser (Prosveshchenie, Moscow 1977).
[6] Basov, N. G., et al.: "Laser Operating in the Vacuum Region of the Spectrum by Excitation of Liquid Xenon with an Electron Beam," J. Exp. Theor. Phys. Lett., 12(S. 329), 1970.
[7] Rhodes, C. D.: Excimer Lasers—Topics in Applied Physics, Vol. 30, 2nd ed., Berlin, Springer-Verlag, 1984. https://doi.org/10.1007/3-540-13013-6.
[8] Polanyi, J. C., "On iraser detectors for radiation emitted from diatomic gases and coherent infrared sources," J. Chem. Phys., 34: 347, 1961;
[9] Valéria Serrano Faillace Oliveira Leite, NUMERICAL EVALUATION OF THE FLOW INSIDE THE TRANSONIC NOZZLE OF A DIRECT-CONNECT SUPERSONIC COMBUSTION RESEARCH FACILITY, November 6-11, 2005, Ouro Preto, MG.
[10] Pimentel, G. C., "The significance of chemical lasers in chemistry," IEE J. Quantum Electron, 6: 174, 1970. https://doi.org/10.1109/JQE.1970.1076416.
[11] Gross, R. W. F., and Bott, J. F., Handbook of Chemical Lasers, John Wiley & Sons, New York, 1976.
[12] P CHAKRAVARTY, N M REDDY and K P J REDDY, J. Phys., Vol. 34, No. 4, April 1990, pp. 333-345. 0 Printed in India. https://doi.org/10.1007/BF02845869.
[13] Anderson J D J.r 1976 Gas dynamic lasers: An introduction (New York: Academic Press.