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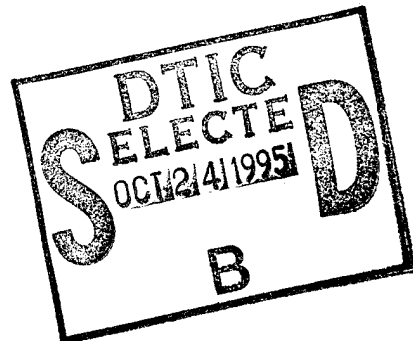
EVALUATION OF PERFORMANCE OF DF CHEMICAL LASER WITH NITROGEN DILUENT

by

*Yao Cuiyue, Sun Chaojun, Guo Jianzeng, Li Huiying, Jin Hui, Zhang
Youfu, Sui Xiping and Hu Shiheng*



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ABSTRACT

This article explores avenues for the practical applications of DF chemical lasers, conducts an analysis and study of experimental output capabilities, and compares these results with ordinary nitrogen diluent DF laser capabilities. The results illustrate that for the output capabilities of the device itself, the nitrogen diluent is somewhat inferior to helium diluent. However, considering overall capabilities, nitrogen diluent DF chemical lasers continue to be one of the ideal candidates for a practical model.

1. FOREWORD

For a DF laser to be of practical value, the key technology is the high density stockpiling of the laser reactant gas. At the same time, chemical methods must be used to treat the laser exhaust gasses. Using nitrogen as the diluent for chemical lasers is seen as a realistic feasible means to achieve this.

With N_2 as the diluent for a DF chemical laser, we selected $NF_3/H_2/D_3/N_2$ as the reaction series. After several hundred tests, the laser output capabilities had reached a fairly high level. Figure 1 is a block diagram of the DF chemical laser system. The reactant gas and tail gas treatment technology is a major component in rating its overall capabilities. This article will critique this laser in the three aspects of the stockpiling of the laser gas, the treatment of the tail gasses and the properties of the laser itself.

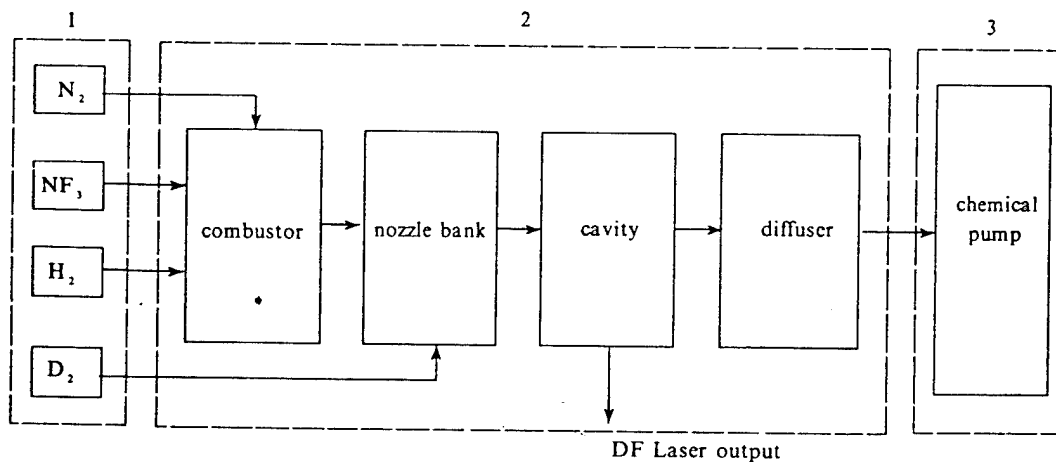


Fig. 1. Block diagram of the chemical laser system

1. The densified laser reactant gases, 2. DF chemical laser device .

3. Disposing device of exhausted laser gases by chemical absorption.

2. HIGH DENSITY STOCKPILING OF LASER GAS

For chemical lasers to become high energy devices and to achieve a practical level a great deal of gas will be required. Currently, the gas is commonly stored in ordinary pressurized steel cylinders. As the laser uses an increased amount of gas, more and more cylinders will be required, thus limiting the device from becoming practical. In order to alter this gas cylinder stockpiling mode, it is necessary to a reaction system with a gas which can be stored at high density, such as $\text{NF}_3/\text{H}_2/\text{D}_2/\text{N}_2$. In this system, the oxidizing agent NF_3 can be stored as a liquid. At -129°C , NF_3 has a specific gravity of 1.537 g/cm^3 , 16 times that of bottled NF_3 . The fuels H_2 and D_2 are isotopes, H_2 is a new energy source, with much work being done around the world on its development, application and storage. In 1984, the British MPD Corporation already had 14 different Hydrogen storage metal alloy products, forming a product series. The Japanese Chuanqi [translator's note: phonetic] Heavy Industries Corporation has developed the world's largest hydrogen container which can store

175Nm³, the equivalent to the contents of 25 high pressure hydrogen cylinders. The container itself is 0.4m³, which can reduce the weight by 30 percent over similar gas storage high pressure steel bottles, one-seventh the former volume^[1].

The diluent N₂ can be stored in high density through two different methods. One is liquification, and the other is to use hydrazine as the raw material. N₂ is the most common gas. There is an abundance of this gas in the natural world. Liquified N₂ technology is already fairly well developed in China. Liquified nitrogen storage has attained one percent or less evaporation per day. Liquified nitrogen has a specific gravity of 0.898 g/cm³, 4.3 times that of the gas under high pressure. Using hydrazine as the raw material in order to store N₂ and H₂ is one other avenue. The chemical formula for the hydrazine molecule is N₂H₄. One hydrazine molecule contains two nitrogen atoms and four hydrogen atoms. Once broken down, there are two of the raw material gasses used in the chemical laser system. Furthermore, hydrazine is stored as a liquid at ordinary temperatures which makes it easy to store and use.

When raw material gasses are stored at high densities they are not vulnerable to vibrations, and do not present the danger of explosion of high pressure gas bottles. They also do not leak as easily. If helium is used as the diluent, its critical temperature is -268° C and it is fairly difficult to liquify. Therefore, high density storage is difficult to achieve in engineering applications.

3. CHEMICAL METHODS OF TAIL GAS TREATMENT

Tail gas treatment in chemical lasers is ordinarily done through either mechanical vacuum pump or a jet pump. These two methods are feasible and effective in laboratory or test bases. If it is necessary to have rapid start up of a high energy chemical

laser, these pumps cannot meet the requirements. The mechanical vacuum pump treatment method requires a vacuum tank as well as a power supply. With the current device levels in China, a hundred watt level gas flow requires a one cubic meter vacuum tank, and a thousand watt device would require a 100 cubic meter tank. This exhaust gas system is several dozen times as big as the laser itself. Although vacuum jet pump technology is more advanced than mechanical vacuum pump technology, the jet operating medium is more than ten times that of the jetted gasses^[2], further increasing the amount of exhaust gasses. These two methods are both open mode, exhausting the laser noxious high temperature gasses directly into the air, which not only is harmful to oneself and ones friendly troops and machines, but can easily expose oneself as a target.

In 1980, the United States magazine "Aviation Week and Space Technology" reported that the United States Army was at that time testing a small DF laser. Its fuel could be stored in a metal container. The exhaust gasses it generated were absorbed into another canister. A United States Defense Department official stated that a chemical pump designed for this purpose had demonstrated through calcium consumption during laser power output and during operation that it had very effective properties^[3]. With N₂ as the diluent, it would be possible to match together the chemical pump and the DF chemical laser, basically eliminating the disadvantages of the mechanical vacuum pump and the jet pump. The greatest advantage of the chemical pump is its safety. The exhaust gasses given off by the DF laser are completely absorbed within the sealed calcium pump shell. Other advantages are its small size, light weight, rapid start up, and noiseless operation. One United States source describes the use of a calcium pump with a high power laser as "we estimate requiring a cubic foot of calcium pump volume for every giga joule"^[4]. Such a small volume and weight beyond comparison for mechanical vacuum pump and jet pump treatment methods.

In order to demonstrate the effectiveness of chemical pumps and the feasibility of the "DF laser/Ca pump" formula, we used a hundred watt laser and a Ca pump testing apparatus to conduct hookup tests which provided initial success. The activated calcium in the chemical pump very quickly reacted to all the laser exhaust gasses, maintaining a fairly high vacuum within the system and ensuring the normal operation of the laser.

4. PROPERTIES OF THE LASER ITSELF

There have been some foreign reports of chemical lasers with nitrogen as the diluent. However, we have not seen any materials on thorough studies of nitrogen diluent systems and the development of their hardware (perhaps due to some undisclosed reasons). Over the past three years we conducted laser parameters of DF chemical lasers using N_2 as the diluent, building two devices, one of the hundred watt class and one of the thousand watt class. We performed hundreds of tests on these two devices, and compared them to DF laser output characteristics using He as the diluent, obtaining a good deal of useful data.

1. Characteristics of DF Lasers Using N_2 as the Diluent

The reaction systems of many chemical lasers use He as the diluent. Because N_2 has a lower specific heat than He, and because the molecules are larger, the jet port has a high static temperature and high static pressure, so it is difficult to achieve a fairly high Mach number, reducing the light chamber inner flow diffusion velocity, leading to a very short laser stimulation area. To overcome this, when designing the laser elements, we gave full consideration to the characteristics of N_2 as a diluent, designing a highly heat efficient combustion chamber and a high speed mixture N_2 diluent jet with a high F atom congealment and low F atom recombination. On this device, we used a planar parallel chamber (multiple hole array, with hole diameters of 1.4 millimeters and 3.3 millimeters between holes) for testing. The output results are

shown in Figure 2. Figure 2 is the pattern of holes burned in a lucite target face. We can clearly see that the N_2 diluent laser activity zone is larger than 44 millimeters. On this device we also obtained achieved multiple hole coupled output of 902 watts and single hole coupled output of 1422 watts and specific power of 70.5 J/g.

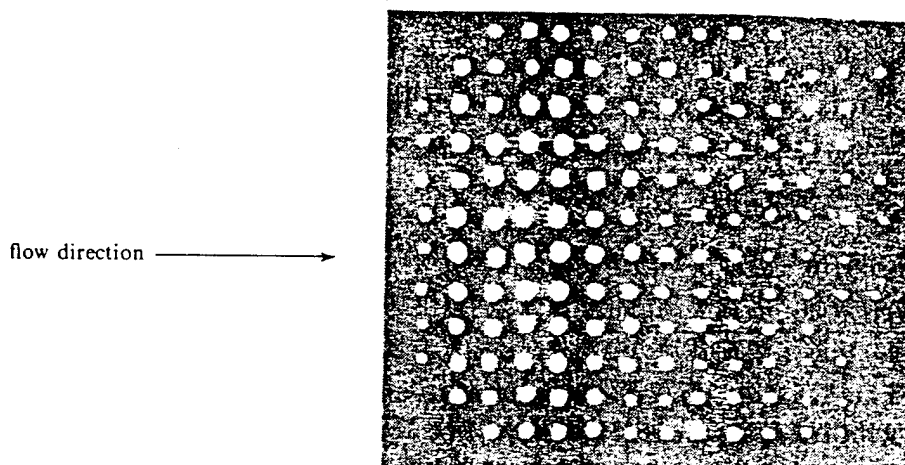


Fig. 2. Burned pattern of laser beam on a polished lucite board

2. Comparison with Characteristics of DF laser with He Diluent

He is a common diluent for chemical lasers. He is an inert gas. The atom is very small and it has a high specific heat ratio. It has been shown to be superior in improving chemical laser properties. We conducted comparative tests with a thousand watt class laser using N_2 and He as diluents. The conditions of the test were: The chemical agent was NF_3 with a flow of 0.12 mol/s. The excess coefficient was around 1.17. The intake gas dilution ratio was 1.5 (intake gas dilution ratio defined as $\psi = [\text{diluent}]/[NF_3]$). The results of the test were that the He diluent laser output was 1609 watts and the N_2 diluent laser output was 1393 watts, 13.4 percent lower. The He diluent achieved a chemical efficiency of 1244 J/g fluoride and the N_2 diluent achieved a

chemical efficiency of 1135 J/g fluoride, 8.8 percent lower. The He diluent had a mass flow specific power of 93.6 J/g and the N₂ diluent had a mass flow specific power of 70.5 J/g, 24.8 percent less.

Figure 3 shows the curve of the chemical efficiency versus the dilution ratio using the two different diluents. We can see from these figures that the different diluents have basically similar tendencies chemical efficiency versus change in dilution ratio. The best diluent ration range is between 1.0 and 1.5. These two graphs also reflect that the chemical efficiency of N₂ as a diluent is slightly inferior to that of he as a diluent.

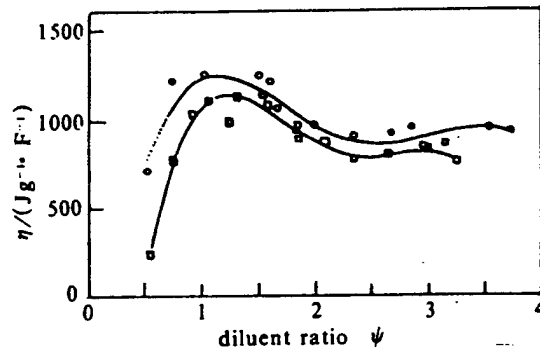


Fig. 3. Chemical efficiency of laser versus diluent ratio with two kinds of typical diluents

- represent the data with helium diluent and the dotted curve is the fitted.
- represent the data with nitrogen diluent and the solid curve is the fitted.

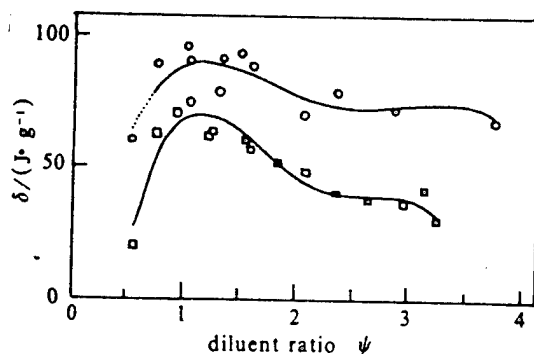


Fig. 4. The mass flow rate versus diluent ratio with two kinds of typical diluents

- represent the data with helium diluent and the dotted curve is the fitted.
- represent the data with nitrogen diluent and the solid curve is the fitted.

Figure 4 shows the graph of the mass flow specific power versus the diluent ratio using the two different diluents. The graphs indicate that there is a marked difference in how the mass flow rate specific power changes with intake gas dilution ratio in lasers using the two different diluents. The mass flow specific power of the laser using the N_2 diluent drops fairly rapidly as the dilution ratio increases. At the peak values of the two curves, the mass flow rate specific power of the laser using the N_2 diluent is 22 percent lower than that of the laser using the He diluent. Furthermore, the peak values of these two curves are between the dilution ratio of 1.0 and 1.3.

5. CONCLUSIONS

Summarizing the narrative above, we can see that DF chemical lasers using N_2 as a diluent are slightly inferior in output properties than the same lasers using an He diluent system.

However, by basing hardware designed on the different diluent characteristics for DF chemical lasers, it is completely possible for DF chemical lasers using N_2 diluent to achieve a high energy output. Furthermore, high density storage of the raw material gasses, chemical absorption of the waste gas can allow miniaturization of the laser system with a size efficiency, safety and concealment properties which He diluent systems cannot achieve. Our experiments show that to develop practical models of DF chemical lasers, the N_2 diluent laser system is one feasible formula.

We would like to thank all the other members of the team for the large amount of work they performed on these evaluation experiments.

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