PARAMETRIC STUDIES OF JET TYPE SINGLET OXYGEN GENERATOR

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Since the discovery of the Chemical Oxygen Iodine Laser (COIL) in 1978 by Dr. William McDermott and co-workers, the development of COIL has progressed very fast because of its wide industrial and military applications. It is the only chemical laser with electronic transition and hence has high efficiency with shorter wavelength (l =1.315m m). With the introduction of supersonically flowing (Supersonic COIL) laser gas (i.e., Singlet oxygen and Iodine gas mixture) there is a large potential for power scaling possibility. This potential has led to the use of COIL in various military and civilian applications during the last decade. The possibility of carrying high power beams via optical fibers makes it extremely useful for decommissioning and dismantling of dangerous structures like obsolete nuclear reactors through remote control.

This laser operates on the $^2P_{1/2}$ ® $^2P_{3/2}$ transition of iodine atom at 1315 nm and is pumped by the reaction scheme

$O_2(^{1D}) + I(^2P_{3/2})$ Û $O_2(^{3S}) + I^*(^2P_{1/2})$

$I^*(^2P_{1/2})$ + nhn ® $I(^2P_{3/2})$ + (n+1) hn

In COIL, the electronically excited singlet oxygen molecules mainly serves as a pumping source with a near resonant energy transformation and is also helpful in dissociating the Iodine molecules into the atomic form for excitation. Different mechanisms for the production of this $O_2(^{1D})$ have been studied and demonstrated, which includes Chemical, Electrical (DC, microwave and RF) discharges and Photo-sensitizer method. Out of them, Chemical method is the only one till date that has been successful for power scaling up. The chemical method is based on chemical reactions between Chlorine gas and Basic Hydrogen Per-oxide solution (BHP),

$$2KOH + H_2O_2 + Cl_2 \text{ ® } 2KCl + 2H_2O + O_2(^{1D})$$

A large number of researches have already been done in chemical singlet oxygen generators with various techniques. But the Jet type Singlet Oxygen Generators (JSOG) has attracted the COIL community for its ability in high throughput production with minimal water vapor and continuous stable operation.

The transport of the singlet oxygen molecules with minimum loss and proper COIL operation requires dilution of the singlet oxygen. Most of the research works have used Helium and Argon as the buffer gas. Due to the limited availability and high cost of these gases, the present day research has turned towards nitrogen based COIL operation. But very limited studies have only been carried out on SOGs employing nitrogen as buffer gas. Efficient operation needs to overcome all these deficiencies thus adding further complexity to the reaction chemistry thereby involving optimized preparation and handling of hazardous BHP solution. The way of singlet oxygen extraction from the generator also makes the system unique and plays an important role in macroscopic carryover of BHP droplets into the exit. Keeping this mind, here a new SOG is designed and operated where output is at 40^o, which is extremely flexible as horizontal system, at the same time, there is no carry over of BHP droplets towards the cavity as like a verti – flow system.

Chapter I present: a brief introduction on COIL, singlet oxygen molecules is discussed along with a review of various singlet oxygen generation methods. This chapter also briefly discusses various research works already carried out in JSOGs and finally discusses the motivation and aim of this present research work. Chapter II discusses mainly about the design philosophy and method adopted for the design of the present JSOG so as to be suitable for 500W class COIL application. Further, a theoretical analysis is also given in this chapter to emphasis the importance of the angular exit of the generator with regards to droplet carryover. The design parameters of SOG have also been evaluated numerically for its optimum function, based on an analytical model based on the theory given by Zagidullin.

Chapter III discusses the entire experimental system in full details. The individual subsystems like the reaction chamber, BHP preparation, receiving tanks, BHP injection plate, chlorine supply system, buffer gas feed system, chlorine trap, vacuum pumps etc. are explained. The system description also include the details of the diagnostics systems used for the characterization of the system along with the Data Acquisition and Control System (DACS) used for the entire operation of the system.

In Chapter IV, the parametric studies of the angular JSOG for various experimental conditions carried out with nitrogen buffer gases are discussed. The experiments are conducted to study the performance of the singlet oxygen generator under variation conditions such as effect of gaseous fuel (Cl_2), BHP composition, BHP temperature, specific surface area, jet lengths and diameter were also discussed in this chapter. In each case, the singlet oxygen yield, chlorine utilization and water vapor fraction in important case are observed for a range of operational parameters and are analyzed with the theoretically expected values. Chapter V discusses the parametric studies carried out with the SOG using helium buffer gas. The results of COIL power extraction experiments with the incorporation of the present angular JSOG are also discussed in this chapter for both nitrogen and helium buffer mixed SOG conditions. The experimental limits for the hydro dynamically stable operation of the singlet oxygen generator are also arrived by setting various experimental situations inside the generator using both helium and nitrogen buffer diluted along with chlorine through the generator.

Chapter VI presents the conclusions: The proposed and developed angular geometry of JSOG is found to be successful and equivalent to a vertical JSOG. More than 99% of the demonstrated runs (more than 600 runs) were successful without any carryover problem [1-5]. A complete parametric study was carried out with the angular JSOG by testing its performance. The results in each experimental condition were interpreted with the theoretically expected values and properly discussed. The generator is found to operate at more than 60 % yield and 95% chlorine utilization for a chlorine flow rate up to 22 mmol/s and gas velocity of about 15 ms^{-1} and generator pressure about 30 torr [1,5]. The SOG performance is studied for various BHP composition and temperature. The suitable BHP composition is worked out from the water vapor determination under various BHP composition and temperature [6]. The effect on SOG performance under different generator length and specific surface area is also studied. The effect of different buffer gas dilution and nature on SOG performance is also studied [6]. The measurements of water vapor fraction gives the conclusion that it is very close to the saturated water vapor corresponds to the BHP system, i.e composition and temperature [1-2]. Helium buffer is found to provide much better hydrodynamic stability of jets as compared to the Nitrogen buffer, since the momentum of the flowing gas is less in the earlier case as compared to the later. It is concluded that for any configuration of generator operation, unstable operation is seemingly a twin function of the momentum ratios (liquid to gas) inside the generator and in the local region of gas injection. The experiments with the present system showed that, for better stable operation of SOG, the liquid to gas momentum ratio inside the generator region should be more than about 70 and the minimum local momentum ratio at the gas exit point is about 7 [6]. The power extraction experiments with the incorporation of this angular JSOG with the other subsystems of COIL has given very good results [2,3,5, 6]. It is able to produce a maximum stable power of about 350W with this SOG for a chlorine flow rate of 22 mmole/sec resulting in a overall COIL efficiency of 17.5%. The COIL power is found to be in linear with chlorine flow rate and reveals that it is proportional to the singlet oxygen production. The future scope of the presented thesis work is also given in this chapter VI.

Publications in International Journal / International Conferences

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3. *Supersonic COIL with Angular Jet Singlet Oxygen Generator*, R.K. Tyagi, R. Rajesh, Gaurav Singhal, Mainuddin, A. L. Dawar and M. Endo, ***Journal of Optics and Laser Technology,*** Vol. 35 (5) (2003), 395-399
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