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Test bed for a high throughput supersonic chemical oxygen – iodine laser

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***Abstract*. The paper reports the development of a test bed for a chemical oxygen – iodine laser based on a high throughput jet flow singlet oxygen generator (JSOG). The system provides vertical singlet oxygen extraction followed by horizontal orientation of subsequent subsystems. This design enables the study of flow complexities and engineering aspects of a distributed weight system as an input for mobile and other platform-mounted systems developed for large scale power levels. The system under consideration is modular and consists of twin SOGs, plenum and supersonic nozzle modules, with the active medium produced in the laser cavity. The maximal chlorine flow rate for the laser is ~ 1.5 mole s^{-1} achieving a typical chemical efficiency of about 18 %.**

Keywords: *chemical oxygen – iodine laser, jet singlet oxygen generator, supersonic flow.*

A supersonic-flow chemical oxygen – iodine laser (COIL) [1] can be scaled to large power levels, which are of interest for both industrial and defense scenarios. The laser wavelength (1.315 μm) allows efficient radiation transmission via optical fibres, thereby enabling remote operations essential in such applications as nuclear reactor dismantling [2].

This paper reports the results of tests of a high throughput supersonic-flow COIL system based on a jet singlet oxygen generator. The test-bed system (Fig. 1) provides maximal chlorine flow rates of ~ 1.5 mole s^{-1}. The overall length of the laser head is 2.5 m (up to supersonic diffuser exit), the width of the system is 1.8 m and the height of the optic axis from ground is 2.1 m. The uniqueness of the system lies in vertical extraction of singlet oxygen, which is then transferred to a horizontal COIL system in order to achieve a more uniform weight distribution. The present study focuses on the aspects of configuration modularity and flow organisation for a high throughput multi-kilowatt COIL system employing counter flow JSOGs.

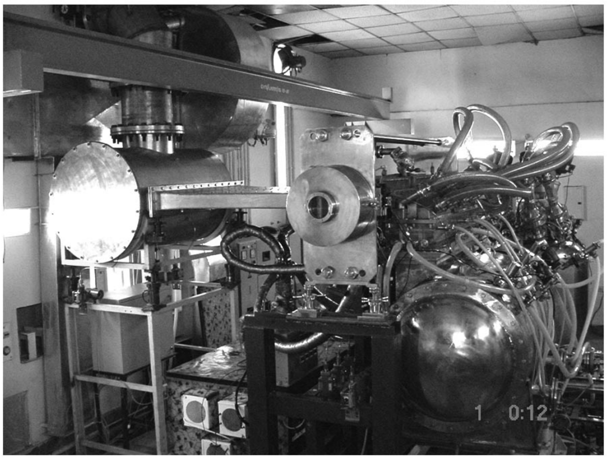

Figure 1. Test bed for a high throughput chemical oxygen – iodine laser.

A supersonic scheme was employed for mixing working gases viz., energy carrying [singlet oxygen (SO) with buffer nitrogen] and emitting (vapour mixture of iodine and nitrogen) [3, 4]. Iodine vapour mixed with the carrier gas (nitrogen) was supplied into the subsonic part of the nozzle. The supersonic nozzle with an exit size of 100×6.7 cm consisted of 46 nozzle blades divided into two modules (a design Mach number, $M = 2$). The amplifying medium had a length of 100 cm and output square cross section of 8×8 cm.

We used in experiments a modular jet singlet oxygen generator consisting of twin SOG modules. It employs four reaction zones of 50×3 cm with two zones housed in each module. The design of the JSOG module is described in detail in paper [5]. The experiments were performed employing the basic hydrogen peroxide (BHP) solution with molar concentrations $M_{\rm KON} = 6.5$ mole L^{-1} and $M_{\rm H_2O_2} = 7$ mole L^{-1}. In the mixing system with the internal diameter of 0.8 m and height of 1 m, ~ 300 L of solution was prepared. A Freon-based cooling system was coupled to the mixing tank to cool the solution during preparation and to maintain the BHP temperature in the range of -18 to $-20\,^{\circ}$C during operation. The total solution preparation time was of the order of three hours. The BHP solution was supplied into the reactor unit under the action of atmospheric pressure and collected in the receiving tank. The maximum running time was ~ 7 s. The working solution interacted with the flowing chlorine gas supplied from a

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chlorine system. The chlorine system represented a vertical evaporator with a bayonet-type mount in which steam was used to vaporise chlorine liquid. The pressure of the generated chlorine gas was then brought down to below the atmospheric pressure for safety purposes prior to supplying it to the laser source. Figure 2 shows the time dependence of chlorine pressure in the system. The pressure of ~ 680 Torr corresponds to the desired chlorine gas flow rate controlled using choked flow orifices. To provide the lasing duration of about 3 s, chorine should be supplied fora duration of 5 s.

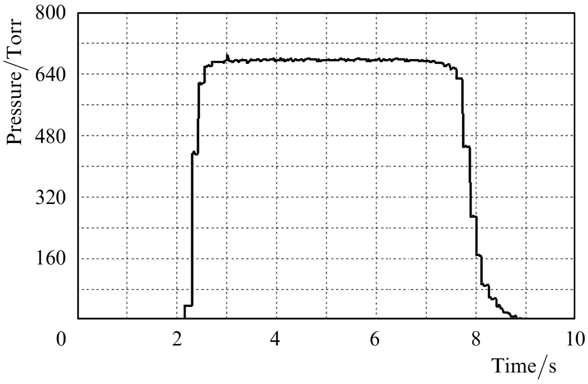

Figure 2. Time dependence of the chlorine pressure.

The gas pressures at various points of the system were measured employing Metran low pressure sensors. Figure 3 shows the time dependences of pressure at critical locations of the system viz., SOG, plenum, pitot, cavity and dumps. The measured pressures are in close agreement with the calculated values.

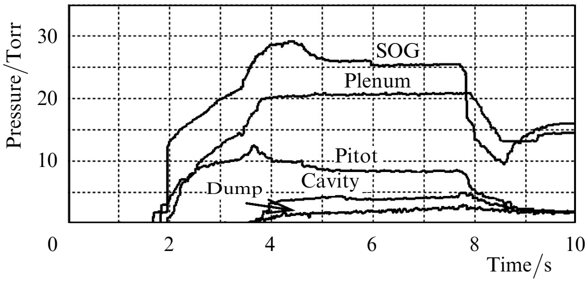

Figure 3. Time dependences of pressure at various locations inside the COIL.

The Mach number in the supersonic flow of the laser was determined from the known relations for the isentropic gas flow using the method reported in [6]. The time dependence of the Mach number, calculated by using the measured pressures in the cavity and pitot (Fig. 3) is shown in Fig. 4. One can see from the figure that the Mach number drops from its highest value $M = 2$ to nearly 1.5 during the iodine supply when power extraction takes place. The decrease is expected since during lasing a large amount of heat is dumping inside cavity, which leads to a boundary layer growth causing a drop in the Mach number.

The iodine supply system consists of four iodine evaporators [each of size: 45 cm (length) × 25 cm (width) × 7 cm (height)] filled with crystalline iodine maintained at a

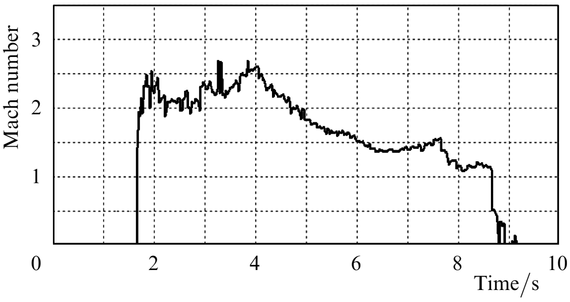

Figure 4. Time dependence of the Mach number.

temperature of 350 K using electrical heating arrangements. The iodine concentration was measured using absorption spectroscopy [7] at 499.5 nm employing a system of tungsten lamp, interference filters, collimating and collecting optics and Si photodetector.

Figures 5 and 6 show the time dependences of the iodine flow rates and iodine injection pressures. The average iodine flow rate during the laser pulse is ~ 29 mmol s^{-1}, corresponding to a titration ratio of I_2/O_2 close to 2 %. The initial surge on the curves is due to the opening of iodine valve carrying the entire developed iodine vapours along with the carrier gas under the effect of vacuum. The iodine cell pressure of 150 Torr was achieved, in agreement with the calculated value for achieving the required π-penetration parameter in the range of 0.8 – 1.0.

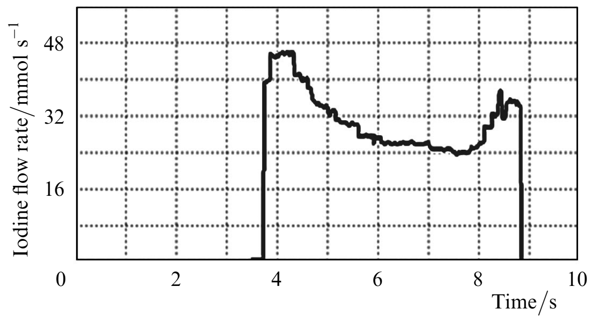

Figure 5. Time dependence of the iodine flow rate.

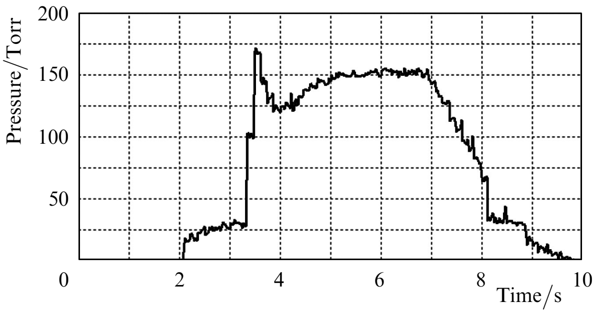

Figure 6. Time dependence of the injected iodine vapour pressure.

The laser gases were exhausted to 150-m^3 vacuum dumps via a modular straight diverging supersonic diffuser [8] recovering the pressure to 7 – 8 Torr. The gases were subsequently exhausted to atmosphere after neutralisation.

The COIL test-bed system was controlled using a customised data acquisition and control system (DACS) enabling remote operation. This system controls the actuating devices, monitors their state as well as records and processes the output signals of detectors and control devices. During the experiments it stores all the relevant experimental parameters for the post-run analysis.

The energy parameters of the supersonic COIL were studied by using a stable (plano-concave) resonator configuration. The mirror diameter was 125 mm with a radius of curvature of 10 m and coupling mirror transmission of 10 %. The shape of the laser pulses was measured using a Ge photodetector collecting the backscattered radiation from the reflecting mirror (Fig. 7). The laser power was measured using a beamsplitter for simultaneous power measurement as well as for evaluation of the effect of the laser pulse on a target. A cone type calorimetric method was used for power estimation. The observed chemical efficiency for nominal laser flow rates was typically 18 %.

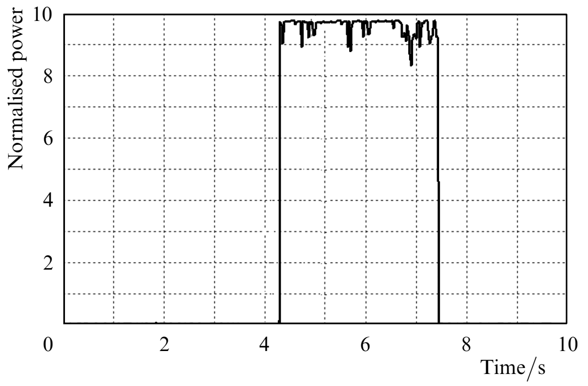

Figure 7. Time dependence of the COIL lasing power.

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