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13. ABSTRACT (Maximum 200 words)

This report describes the experimental and basic theoretical work that was performed for the evaluation of a jet generator simulator for a Chemical Oxygen Iodine Laser (COIL) system. Chorine gas reacts with liquid **Basic Hydrogen Peroxide (BHP) in the generator to produce excited oxygen,** $O_2(^1\Delta)$. The jet generator for a chemical oxygen iodine laser system has to provide a large reaction surface. This is accomplished in the generator by providing many small orifices through which the liquid BHP will flow and form liquid jets. The liquid jets should be as long and stable as possible to provide a maximum reaction surface. This experiment deals with a finite set of orifice diameters and lengths which allow for convenient scalability procedures in the future.

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Chemical Oxygen Iodine Laser
Jet Generator Characterization

Quarterly Report
December 1993

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Introduction

This report describes the experimental and basic theoretical work that was performed for the evaluation of a jet generator simulator for a Chemical Oxygen Iodine Laser (COIL) system. Chlorine gas reacts with liquid Basic Hydrogen Peroxide (BHP) in the generator to produce excited oxygen, $O_2(^1\Delta)$. The jet generator for a chemical oxygen iodine laser system has to provide a large reaction surface. This is accomplished in the generator by providing many small orifices through which the liquid BHP will flow and form liquid jets. The liquid jets should be as long and stable as possible to provide a maximum reaction surface. This experiment deals with a finite set of orifice diameters and lengths which allow for convenient scalibility procedures in the future. When these BHP jets come in contact with chlorine gas, singlet delta oxygen, $O_2(^1\Delta)$ is produced. The rapid transfer of electronic energy from the singlet delta produced excites the upper state for lasing. In principle, a jet generator which produces extremely stable jets with low water content in a chlorine gas flow environment will produce high yields of singlet delta and therefore high laser power. Liquid jets are naturally unstable and break up into drops. The size and formation of these drops may be analyzed to give insight as to the characteristic requirements for jet formation. It is very hard to match the surface tension of liquids. However, it is possible to match the viscosity coefficient of BHP to that of a particular liquid. In this case glycerin was chosen because it is a high viscosity liquid (Table 1). Hence, the characterization and properties of water jets and 65% glycerin/water solution jets were analyzed to develop new procedures for an improved jet generator that will produce singlet delta oxygen, $O_2(^1\Delta)$. The stabilization of the fluid jets will also be discussed. Russian literature has presented superior results with high efficiencies in this area. A future experimental set-up is presently under development which may provide insight as to the techniques required for these results.

A description of the experimental set-up of a jet generator simulator which was used to observe the jet breakup characterizations and jet flows of water and a 65% glycerin/water solution through 5.0mm, 8.0mm and 3.0mm thick brass plates with 0.3mm, 0.5mm and 0.7mm jet orifice diameters in each plate is also provided. Information such as, tables of liquid properties, jet lengths, effective velocity and diagrams used for jet characterization are included along with future experimental configurations for clarification.

Jet Breakup Theory

Breakup of a liquid jet flow may be defined as the result of disruptive internal and external forces which eventually exceed the constricting forces of surface tension. Internal forces such as surface tension and viscosity exert a stabilizing behaviour. Aerodynamic forces exert external forces which may distort the surface of a liquid and contribute to breakup of the jet into droplets.

In studying the behaviour of liquid jet flows and droplet formation it is necessary to discuss some of the critical elements that are used to define such behaviour. It is important to note that a cylindrical column becomes unstable when its length exceeds its perimeter. The breakup that was observed in the following experiment is known as *Rayleigh Breakup* or viscous breakup. This type of breakup produces drops with a diameter of approximately two times the jet orifice diameter. Early breakup or *First Wind Induced Breakup* is a result of amplified lift forces of uneven or bulging liquid streams. When the liquid flow oscillations are observed to be *sinusoidal* this indicates that there are strong external forces present just before the jet breaks up known as *Second Induced Breakup.* (ref. 1)

Velocity, density, viscosity and surface tension contribute to the characterization of droplet formation and define the breakup modes for a liquid jet flow. Parameters for liquid jet flow breakup have been developed to aid in behaviour characterization. The *Reynolds number* of a liquid is a value that describes the ratio of the momentum to the viscous force for a specific jet orifice diameter. The *Weber number* which is used to describe the influences of aerodynamic forces is the ratio of the aerodynamic force to the surface tension and takes into account the relative velocity at the surface. The Reynolds number and the Weber number can be used to derive another useful parameter known as the *Ohnesorg number* which describes the effect of the viscosity and the surface tension and is used to classify the various breakup modes. Another useful parameter is the Discharge Coefficient which is defined as the ratio of the actual measurable mass flow to the ideal mass flow through an orifice. The Discharge Coefficient was used in this case to determine the actual jet velocity as compared to the ideal velocity.

The following liquid flow states were observed during this experiment: *Turbulence* which is usually associated with high flow velocity, large orifice diameter, surface roughness and any perturbations present in the jet flow stream. Turbulent flows are characterized by transverse velocity components of the liquid particles which cross each other randomly. *Laminar* behaviour was observed for the 65% glycerin/water solution and is usually associated with high viscosity liquids. Rounded or chamfered entrance to the jet orifice and liquid flow undisturbed by perturbations also contribute to a laminar flow. Laminar flows are characterized by liquid particles which flow parallel to the axis of the jet during a laminar jet flow.

Experimental Set-up

The final experiment set-up is shown in figure 1 using a previously designed rectangular plexiglass jet generator simulator. The generator´s physical dimensions are given in reference (2). The jet generator simulator has two chambers. An *upper chamber* which holds the liquid to be evacuated through an orifice plate (which separates the two chambers) and a *lower chamber* which contains a scale for measuring the jet lengths observed. In this set-up there are three vacuum lines, each controlled by its own valve, which are connected as follows: the main line from the vacuum pump, the line from the generator to the vacuum pump and the line from the fluid collecting vessel to the vacuum pump. These vacuum lines are identified in figure 1 as (1) green for the main vacuum pump valve; (2) red for the generator to pump line which maintains a certain degree of vacuum and is also used for clearing the generator viewing area after a "run" for video recording; line (2) will be used in the future to remove entrained gas from the system; and (3) blue for the line from the fluid collecting vessel which removes liquid from the generator and prevents the tank from filling up. The physical set-up also has color coded tubing connections as described above for visual clarification during the experiment.

Splattering occurs on the walls of the generator simulator tank during an experiment. The splattering builts up on the generator walls slowly throughout the experiment. So, it is necessary to clear the tank, using a special procedure, before the next run. Additional collecting vessels are provided to prevent fluid from getting into the vacuum pump and the pressure gauge. Drying vessels are also provided to prevent any moisture from entraining the pump. The additional ports provided will be used for future experiments involving various gas flow techniques.

The video set-up used for this experiment is shown in figure 2. A CCD Sony Video Camera Recorder 8 model W200E, a Sony model KV-M14D/Trinitro Color television, and a Bauer Bosch model CVP110 photo print recorder were used in the configuration shown. Not shown is an Omnichrome 400mW argon laser (457-514 nm) which was used to provide backlighting of the jet flows. Various camera shutter speeds and lighting configurations were recorded and studied. The shutter speed of 1/10,000 seconds with an aperture of 1.4 was found to be optimum for observing droplet formation. An expansion lens was also added in front of the laser beam to provide a wider illuminated area for observation and recording. A lighting configuration that consisted of the laser in combination with two flood lamps, one in front of the generator and one in back proved to provide the best contrast for recording the jets and droplet formation. An optical blooming effect which is an artifact of the CCD camera was periodically observed and appeared as white parallel vertical lines. This effect depended on the angle of the generator with respect to the camera and the laser and was observed to be reflections off of the droplets that remained on the walls of the generator as a result of splatter. A filter it is not expected to eliminate this effect since it is based on excess charge at the pixel level of the camera. However, it may provide some improvement. Other cameras do not exhibit this phenomenon.

Jet Characterization

The experimental set-up described above was used to characterize the jet flow and droplet formations of water and a 65% glycerin/water solution. The *upper chamber* of the generator was filled with the liquid while the *lower chamber* was evacuated between 50 to 70 mbar. A screen was used in the bottom of the generator to aid in decreasing splatter and a thin strip of rubber was used to cover the orifices. The rubber strip was removed to start the experiment. Each liquid was tested first with the 5.0 mm plate and then the 8.0 mm plate. Both plates had three sets of orifice diameters, 0.7 mm, 0.5 mm, and 0.3 mm each consisting of four holes as shown in figure 3.

Characteristic *turbulent flows* for water were observed. Early breakup of the jet flow appeared to be attributed to a sinusoidal modulation of the jet stream itself. While the jet flows were longer for the 0.7 mm diameter orifices, they were still turbulent and consistantly shorter in flow length for each of the smaller orifices, respectively. These results were observed for both the 5.0 mm plate and the 8.0 mm plate. The jet lengths for the 5.0 mm plate appeared longer than for the 8.0 mm plate, yet still turbulent for each orifice diameter. This indicated that a smaller length-to-diameter ratio would result in longer jet lengths. This was verified later with the 3.0 mm thick plate. The drop formations of the 3.0 mm plate also appeared significantly more round and evenly spaced upon breakup in comparison to the 5.0 mm and the 8.0 mm thick plates.

Laminar flows were observed for the 65% glycerin/water solution for each plate. Again the flow lengths were longer for the the larger diameter jet orifices. However, the lengths for the 0.7 mm diameter orifice appeared to be up to 14.5 cm in some cases as compared to only 9.0 cm for the water flows for the same diameter. The flow lengths appeared to be increased significantly for the 65% glycerin/water solution. The drop formations were evenly distributed, consistant in size, and the breakup took place at the flow constrictions, which is characteristic of *Rayleigh* breakup. The various breakup lengths for water and the 65% glycerin/water solution for the 8.0 mm, 5.0 mm, and 3.0 mm thick plates are shown in Table 2.

Velocity Flow Measurements and Results

The flow velocity for water and glycerin were calculated by measuring the time for 250 ml of solution to flow through each set of orifice diameters for each plate thickness. The other two sets of orifices were covered with tape during the time measurement. This also allowed for a simple division by 4 of the effective velocity calculation which took into account the four orifices for each diameter. The effective velocity was calculated to be the flow rate (ml/s) multiplied by 10^{-6} (m^3/s) and then divided by the area (m^2), for each orifice diameter, to give the correct units of meters per second for velocity. The equations for jet flow theory were used along with the equations for ideal velocity to calculate the Discharge Coefficient defined above. The mass flow is the density of the liquid multiplied by the ideal velocity for a specific area. The effective velocities of water for the 3.0 mm thick plate were 12.0 m/s, 11.5 m/s and 9.4 m/s for the 0.7 mm, 0.5 mm, and the 0.3 mm orifice diameters, respectively as compared to the 65% glycerin/water solution velocities which were calculated to be 9.6 m/s, 8.4 m/s and 7.1 m/s for each orifice diameter, respectively for the 3.0 mm thick plate. The various velocities calculated are shown in Table 3. The glycerin/water solution jet flows at 20°C proved to be laminar and therefore longer. The discharge coefficient calculated for water and the 65% glycerin/water solution were between 0.63 and 0.81 for water and between 0.42 and 0.65 for the glycerin/water solution. Again showing a significant difference. When compared to the Weber Stability Diagram plot shown in figure 4(a) this experimental set-up comfirmed the water breakup as sinusoidal and the glycerin/water solution as Rayleigh breakup behaviour (ref. 2). The length of the water and the glycerin/water solutions improved for the 0.3 mm plate for each orifice diameter, as expected. A Significant improvement in length was seen for the glycerin/water soulution as shown in Table 2.

The limitations of this experiment were also studied using a Jet Length Limitation Diagram for various pressures, which took into account the Weber number, the Ohnesorg number, and the Reynolds number. Recall that the Ohnesorg number describes the dynamics of the liquid using its density, surface tension and viscosity for a specific size jet, as a value which indicates when any disturbances in a flow will damp out. Figure 4(b) shows these limitations as a function of length and driving pressure. Each diameter has a length and driving pressure which is also limited by an atomization factor that should be considered when designing the actual jet dimensions. These limitations factors will be validated in experiments utilizing higher pressure techniques.

Interpretation of Results

This experimental set-up confirmed the breakup characterization and droplet formation as defined in the technical literature for the 5.0 mm and 8.0 mm thick orifice plates. Initially the results for the 3.0 mm plates was not as significant as expected. For example, the effective velocity for the 3.0 mm orifice plate was only slightly increased for both the 65% glycerin/water solution and water. At this point in the experiment several screw holes in the plexiglass plate on which the orifice plate was fixed had been stripped. A variation in the vacuum pressure was observed and is likely to have contributed to this observation. Although, a significant improvement for the smaller diameter orifices for the glycerin/water solution was observed. Testing with the 3.0 mm plate was repeated with the repaired plexiglass plate using nylon screws to prevent further damage. A significant improvement in the effective velocity for the 3.0 mm plate for the Glycerin/water solution is shown in Table 3. In all cases the experimental observations confirmed the Reynolds numbers and stability diagrams of the characterization effects. Temperature was also found to be an important factor during the characterization of the glycerin/water solution. A variation of one degree proved to give significantly different results. A better way for maintaining the temperature during the experiment should be investigated. The limitation of the orifice length-to-diameter dimensions were also observed and verified. These results will be considered for determining the jet lengths and pressure parameters for the future jet generator simulator which is expected to improve jet stability.

Future Experimental Considerations

The future experiment will involve lower vacuum pressures in the 1 mbar range in the *lower chamber* of the jet generator simulator; reduced orifice plate thicknesses between 1.2 mm to 3.0 mm; the addition of a *high pressure chamber* of up to 4 bar; and introduction of *gas flow* techniques. The intended improvements should increase the the flow velocity which will also increase the Discharge Coefficient. This is accomplished by the decrease of vacuum pressure and increase high pressures as well as reducing the plate thickness. An increase in driving pressure will be accomplished by the addition of an other chamber connected above the present *upper chamber* as shown in figure 5. In doing so the jet characteristics and stability are expected to improve. Some control of these flows may also be possible. Counter-flow *gas* techniques will be investigated. It is suspected that varying the gas flow velocity will allow control of the breakup lengths.

In addition, preparation techniques are presently under development which involve the precision machining and post polishing of surgical stainless steel tubes between 1 cm to 3cm in length. This technique for varying the orifice length will be performed to verify the results obtained by Russian researchers.

The parameter limitations which involve the aerodynamic forces and their effect on the jet flows will be studied. A geometrical analysis of the jet generator simulator dimensions will be performed. As a result of this analysis it may be necessary to modify the jet generator simulator's physical dimensions or reconfigure the experimental set-up as required. The improvement of Jet stability is expected.

References

1. "Atomization and Sprays", Arthur H. Lefebvre, Hemisphere Publishing Corporation, New York, 1989.

2. "Fluid Mechanics of Liquid Jet $O_2(^1\Delta)$ Generators", W. O. Schall and B. Tisch, IB 441 15/93. DLR- Deutsche Forschungsanstalt für Luft- und Raumfahrt.

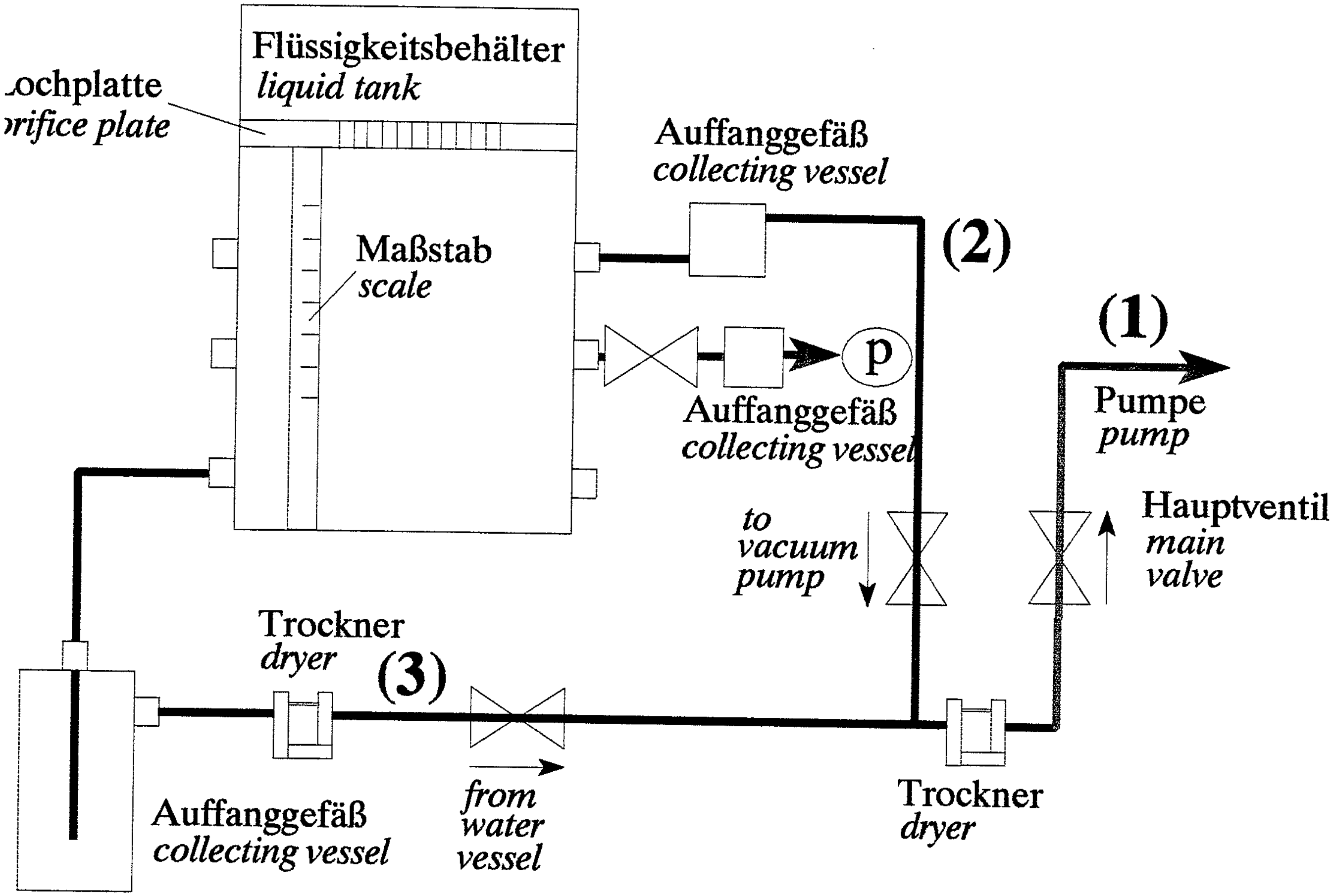


Fig.1 Experimental Set-Up

Video Set-Up

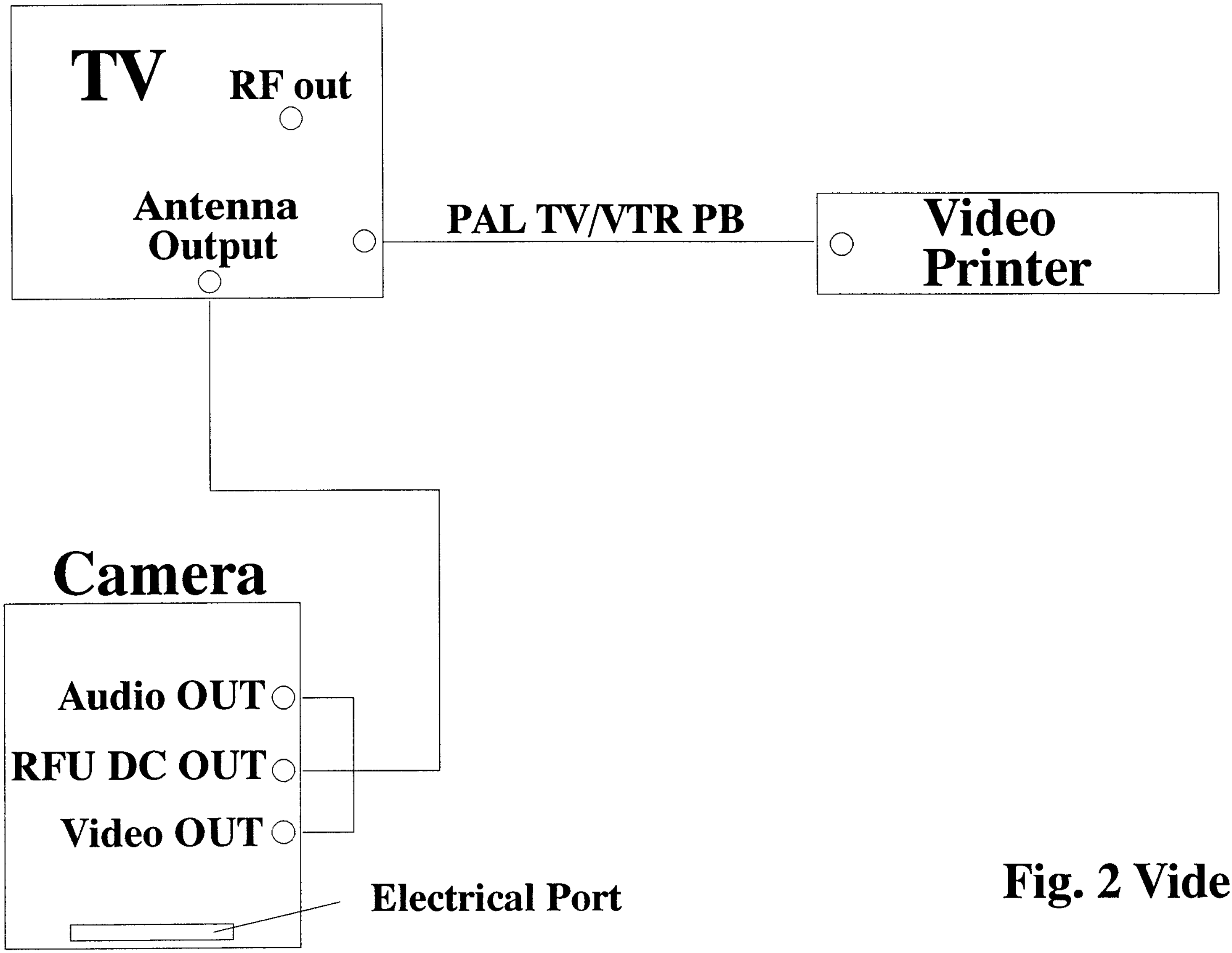


Fig. 2 Video Set-up

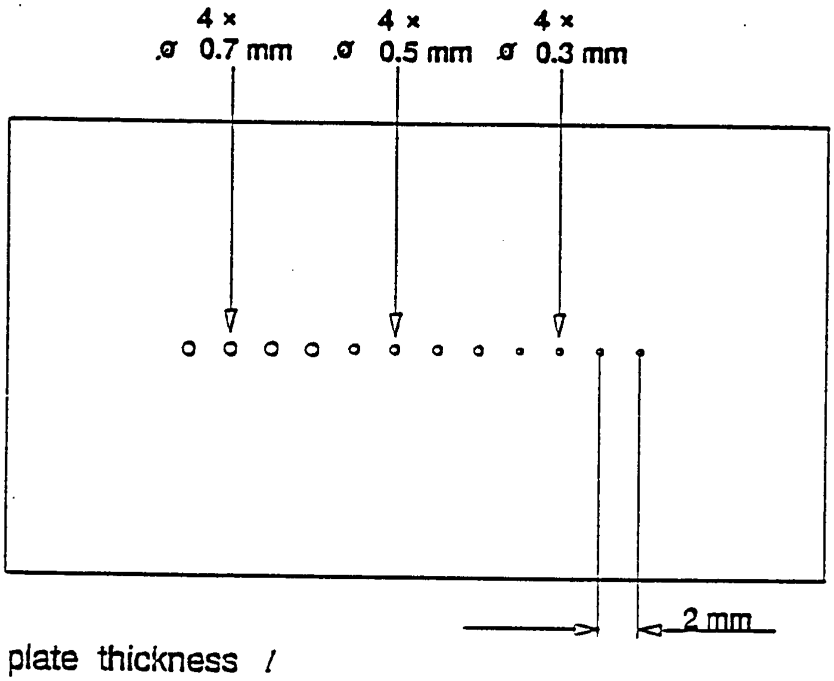


fig.3 Layout of Orifice Plate

liquid	density 10^3 kg/m^3	viscosity 10^{-3} kg/m s	surface tension N/m
water	1.000	1.005	0.073
65%wt glycerin	1.135	15.5	0.068
StdBHP (-10°C)	1.350	15.5	0.043

Table 1 Physical Properties of Compared Liquids

Table 2 Approximate Jet Lengths

Plate Thickness	Approximate Jet Lengths 0.3 mm	0.5 mm	0.7 mm
Water			
8.0 mm	2.0	4.0	9.0
5.0 mm	2.5	5.0	8.0
3.0 mm	3.5	4.5	6.0
Glycerin			
8.0 mm	2.5	8.5	14.5
5.0 mm	3.1	8.3	10.8
3.0 mm	6.0	15.0	>17.0

all measurements are in cm (+ or - 0.5 cm)

Table 3 Effective Velocity

Plate Thickness	Effective Velocity [m/s]		
	0.3 mm	0.5 mm	0.7 mm
Water			
8.0 mm	5.3	8.8	11.7
5.0 mm	7.1	9.1	11.7
3.0 mm	9.4	11.5	12.0
Glycerin			
8.0 mm	*	6.0	7.4
5.0 mm	2.1	6.9	8.1
3.0 mm	7.1	8.4	9.6

* out of limits

Fig. 4(a) Weber Stability Diagram

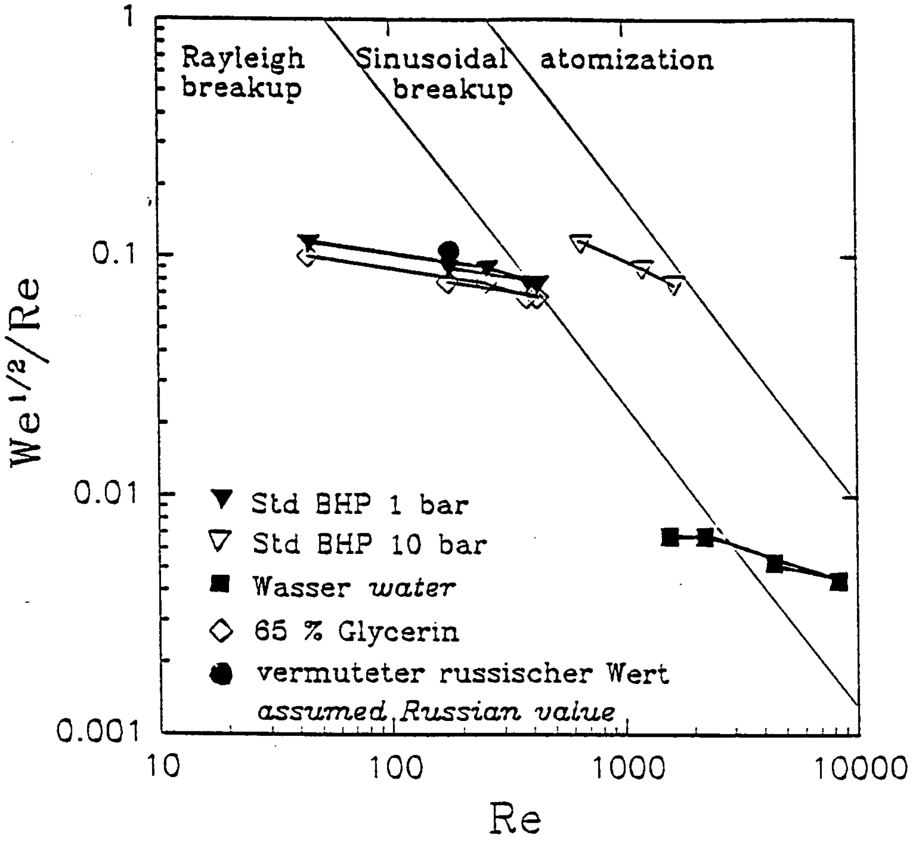
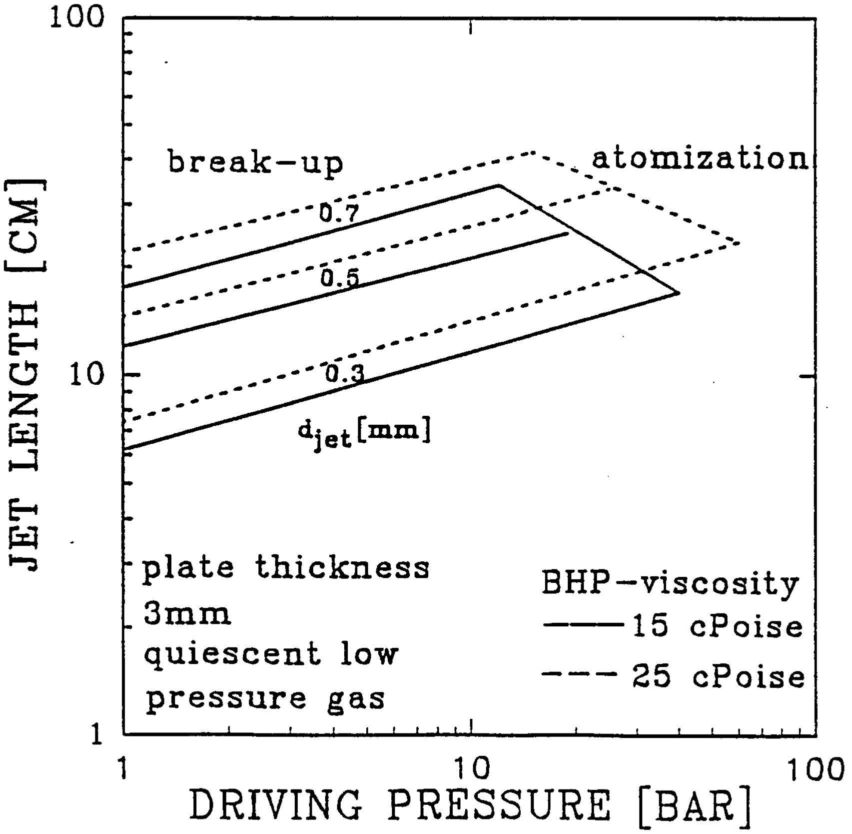


Fig. 4(b) Jet Length Limitation Diagram



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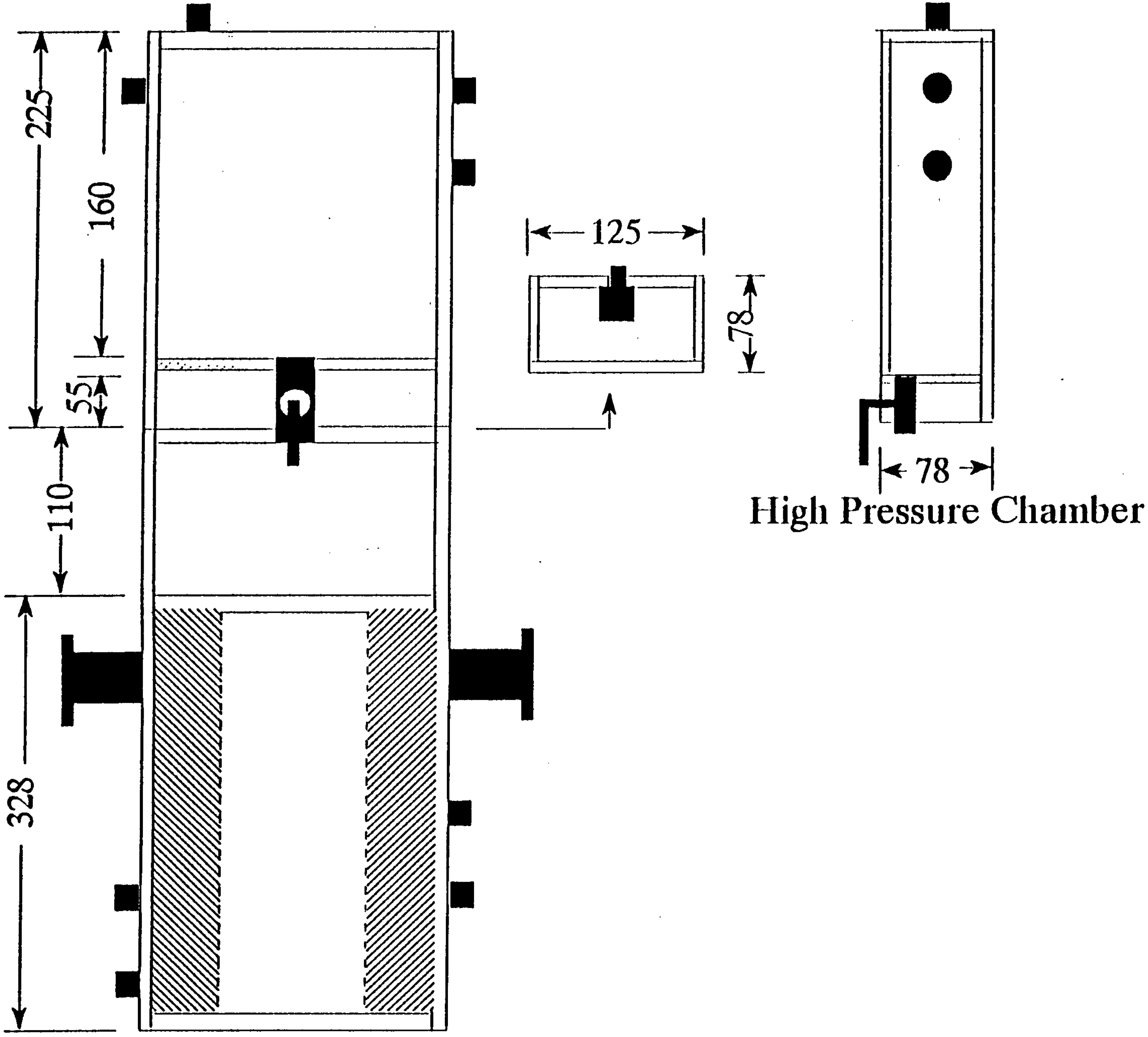

fig.5 Jet Generator Simulator High Pressure Configuration