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HIGH-PRESSURE DISCHARGE FOR CO2 LASERS, (U)
MAY 77 R MCLEARY, P J BECKWITH
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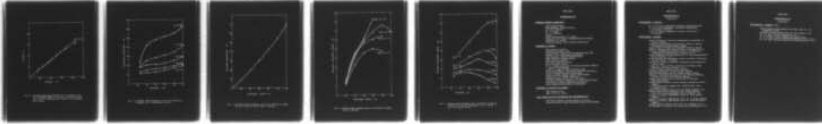
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HIGH-PRESSURE DISCHARGE FOR CO₂ LASERS

R. McLeary and P.J. Beckwith

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R. McLeary and P.J. Beckwith

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ABSTRACT

This report describes the characteristic of continuous electric discharges stabilised by the plasma-injection technique. The gases investigated are N₂ and mixtures of N₂ and CO₂ that are suitable for use in CO₂ lasers. Discharge characteristics are presented for wide ranges of pressure, discharge length and gas mixture. Stable discharges in N₂ have been achieved at power densities up to 200 MW/m³ (200 kW/litre) at atmospheric pressure.

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16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

This report describes the characteristics of continuous electric discharges stabilised by the plasma-injection technique. The gases investigated are N₂ and mixtures of N₂ and CO₂ that are suitable for use in CO₂ lasers. Discharge characteristics are presented for wide ranges of pressure, discharge length and gas mixture. Stable discharges in N₂ have been achieved at power densities up to 200 MW/m³ (200 kW/litre) at atmospheric pressure.

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HIGH-PRESSURE DISCHARGE FOR CO₂ LASERS

INTRODUCTION

The development of the plasma-injection technique (1) for stabilising continuous electric discharges in CO₂ lasers has resulted in the construction of a multi-kilowatt laser (2) which operates at the relatively high pressure of 30 kPa. This laser is compact and reliable but is based on a discharge configuration which is difficult to scale, and output powers above about 10 kW are not easily achieved.

This report describes the electrical characteristics of discharges that can be scaled indefinitely in cross-sectional area and which may be extended to at least 120 mm in length. The discharges are stabilised by the injection of plasma from an array of subsidiary arc discharges (pin discharges) which originate on pin electrodes located near the apertures of a perforated (pin-hole) plate (Fig. 1). The gas in which the discharge is to be excited is injected at sonic velocity through these pin-holes, and the ionised or otherwise excited species which form in the pin discharges disperse over the main discharge volume. The injection of these excited species provides a background level of ionisation in the main discharge volume and inhibits the formation of discharge instabilities.

It has been found that the conductivity of such discharges is nearly independent of area. The results presented in the following section may therefore be extended to apply to discharges of larger area by appropriate scaling.

APPARATUS

The apparatus used in this investigation is shown in Fig. 2. The discharges were excited in a rectangular Perspex box with an internal cross-section of 20 mm x 50 mm, in which the discharge length could be varied up to a maximum of 120 mm by means of a movable mesh electrode. The box contained thirteen regularly spaced pins corresponding to a pin density of $1.3 \times 10^4 \text{ m}^{-2}$. A number of aluminium pin-hole plates were available with pin-hole diameters in the range 1.5 to 3.0 mm. The total pin current could be varied from 0.8 to 3.4 A, and the pressure in the main discharge region from 20 to 120 kPa by means of an adjustable restriction between the discharge region and the dump tank.

The apparatus was operated quasi-continuously, the gas being supplied from a "blow-down" reservoir and the electrical input from capacitor banks. Operating times were of the order of 100 ms, which was considerably longer than the maximum gas transit time of 11 ms (corresponding to a discharge length of 120 mm, a pressure of 120 kPa and a flow rate of 15 gs^{-1}). The main discharge voltage and current, the total pin current and the pressures upstream of the pin-hole plate and in the main discharge region were monitored during each run. These waveforms were essentially constant over the 20-ms monitoring time.

RESULTS

The discharge characteristics presented here were obtained with a pressure of 240 kPa upstream of the pin-hole plate. The flow rate was varied by the use of pin-hole plates having different pin-hole diameters.

A typical voltage-current characteristic for N_2 is shown in Fig. 3: the discharge length was 60 mm and the discharge pressure was 96 kPa, the total pin current was 2.5 A, and the N_2 flow rate was 34 gs^{-1} . This flow rate was obtained by the use of 2.3-mm diameter pin-holes. The characteristic is essentially a straight line through the origin up to an input power of approximately 14 kW, above which value the discharge becomes unstable. The positive slope of the line gives the discharge resistance which in this case is $20 \text{ k}\Omega$. The discharge resistances obtained in this way are plotted in Fig. 4 as a function of pressure for various values of the total pin current, a N_2 flow rate of 34 gs^{-1} and a discharge length of 60 mm. Fig. 5 shows the resistance as a function of discharge length for a total pin current of 1.3 A and a N_2 flow rate of 34 gs^{-1} at a pressure of 100 kPa. The maximum discharge power as a function of length is shown in Fig. 6 for a N_2 pressure of 100 kPa, and for the pin currents and gas flow rates indicated. Fig. 7 shows the maximum power as a function of discharge pressure for a number of mixtures of N_2 and CO_2 and a total pin current of 1.3 A, a discharge length of 60 mm and a flow rate of 34 gs^{-1} .

It is to be noted from Figs. 6 and 7 that in the case of N_2 there is a difference of about 20% in the power density for similar discharge conditions ($I_p = 1.3 \text{ A} - 1.4 \text{ A}$, $\dot{m} = 34 \text{ gs}^{-1}$, $L = 60 \text{ mm}$ and $P = 100 \text{ kPa}$). This may be due to the use of different gas cylinders in these two cases. It has been found that, in general, discharge characteristics are sensitive to impurities (especially O_2) in the gas mixtures.

The voltage on each pin electrode is in the range 1.0 to 1.5 kV, depending on the pin current. The total power dissipated in the pin discharges is therefore at most about 20% of the main discharge power.

DISCUSSION

The main emphasis in this investigation was on discharge performance over a range of operating conditions relevant to CO_2 lasers. Some general conclusions may be drawn from the data presented.

Discharge power densities of approximately 200 MW/m^3 may be achieved in N_2 at atmospheric pressure. The addition of 2% CO_2 decreases the maximum power density by a factor of two at this pressure. One reason for the decrease of power density with increasing CO_2 content is likely to be the rise in temperature of the gas caused by the depopulation of the vibrational energy states of N_2 by collisions with CO_2 . At least 80% of the discharge energy goes into producing vibrationally excited N_2 molecules at the values of E/N (ratio of electric field to gas number density) obtained in these experiments (3). The addition of CO_2 provides a relatively fast means ($\sim 1 \text{ ms}$ for 1% CO_2 at 100 kPa) of channelling this vibrational energy into translational energy in the gas.

It can be seen in Figs. 4 and 5 (which show discharge resistance as a function of pressure and discharge length) that the slopes of the curves are increasing at pressures approaching 120 kPa (Fig. 4), and at discharge lengths above about 100 mm (Fig. 5). This may be due to life-time processes associated with the excited species mentioned previously. The decrease in resistance at low pressures seems to be a result of a "jetting" action of the pin discharges. At low pressures the plasma jet from each pin-hole extends a significant distance across the main discharge region thereby decreasing the effective discharge length.

The precise mechanism underlying the operation of the plasma-injection technique has not so far been resolved. The role of the direct transportation of ions and electrons is likely to be small owing to the fast ion-electron recombination rates (4). A secondary ion-electron production process involving long-lived metastable species created in the pin discharges (5,6,7) appears to be the explanation for the observed conductivity of the gas.

APPLICATION TO HIGH-POWER LASERS

It is seen in Fig. 7 that the highest input powers are obtained with low CO_2 concentrations, at pressures of about 100 kPa. These conditions, however, give rise to problems of low gain and high saturation flux which make it difficult to extract optical power efficiently (8). The optimum operating conditions are consequently a compromise between the requirements of the discharge and the resonator. A laser with discharge dimensions of 20 mm x 60 mm x 1000 mm has been constructed and has been found to have an optimum operating pressure of about 30 kPa; quasi-continuous (10 ms duration) output powers of 8 kW have been achieved at this pressure with an efficiency (defined as the ratio of output power to the sum of the pin and main discharge powers) of 7%.

In applications where there is no requirement for the use of pre-mixed gas, the compactness and gain of a laser using this type of discharge can be significantly improved by the adoption of a mixing-laser configuration. The discharge can then be operated in pure N_2 at 100 kPa, allowing input power densities above 200 MW/m^3 to be attained, and the CO_2 and He can be mixed with the excited N_2 in a lower pressure region in which the optical power is extracted. When the laser mentioned earlier was operated in this way with a resonator pressure of 20 kPa, output powers of 30 kW were obtained at an efficiency of 12%.

It has been found that good overall performance is provided by a pin density of 10^4 m^{-2} , pin-hole diameters of 2 mm, individual pin currents of 100 mA, and a flow rate per pin-hole of 2 gs^{-1} . These parameters may however be varied widely to satisfy individual requirements.

CONCLUSION

The characteristics of continuous high-pressure discharges in N_2 and in N_2/CO_2 mixtures have been described, and the use of these discharges in CO_2 lasers has been discussed. Power densities of about 200 MW/m^3 have been obtained in a N_2 discharge at a pressure of 100 kPa, although the maximum power density decreases as CO_2 is added, and is reduced by a factor of about 2 by a CO_2 concentration of 2% at this pressure. Lasers based on these discharges have the advantages of being simple, rugged and reliable, and may be readily scaled to higher powers.

APPLICATION TO HIGH-POWER LASERS

It is seen in Fig. 7 that the highest laser powers are obtained with low CO_2 concentrations, at pressures of about 100 kPa. These conditions, however, give rise to problems of low gain and high absorption for which it is difficult to extract optical power efficiently (8). The operating conditions are consequently a compromise between the requirements of the discharge and the resonator. A laser with discharge diameter of 10 cm x 50 cm x 1000 mm has been constructed and has been found to have an output power of about 10 kW at 10.6 μm (9). The laser resonator was a four-mirror output mirror of 5.5% gain was achieved at this pressure with an efficiency (defined as the ratio of output power to the sum of the pin and wall discharge powers) of 5%.

In applications where there is no requirement for the use of pre-tilted gas, the construction and gain of a laser using this type of discharge can be significantly improved by the addition of a mixing-laser configuration. The discharge can then be operated at pressures of 100 kPa, allowing laser powers similar to those (10 kW) to be attained, and the CO_2 gas can be mixed with the output in a lower pressure region to which the optical power is extracted. When the laser mentioned earlier was operated in this way with a resonator pressure of 50 kPa, output powers of 30 kW were obtained at an efficiency of 1%.

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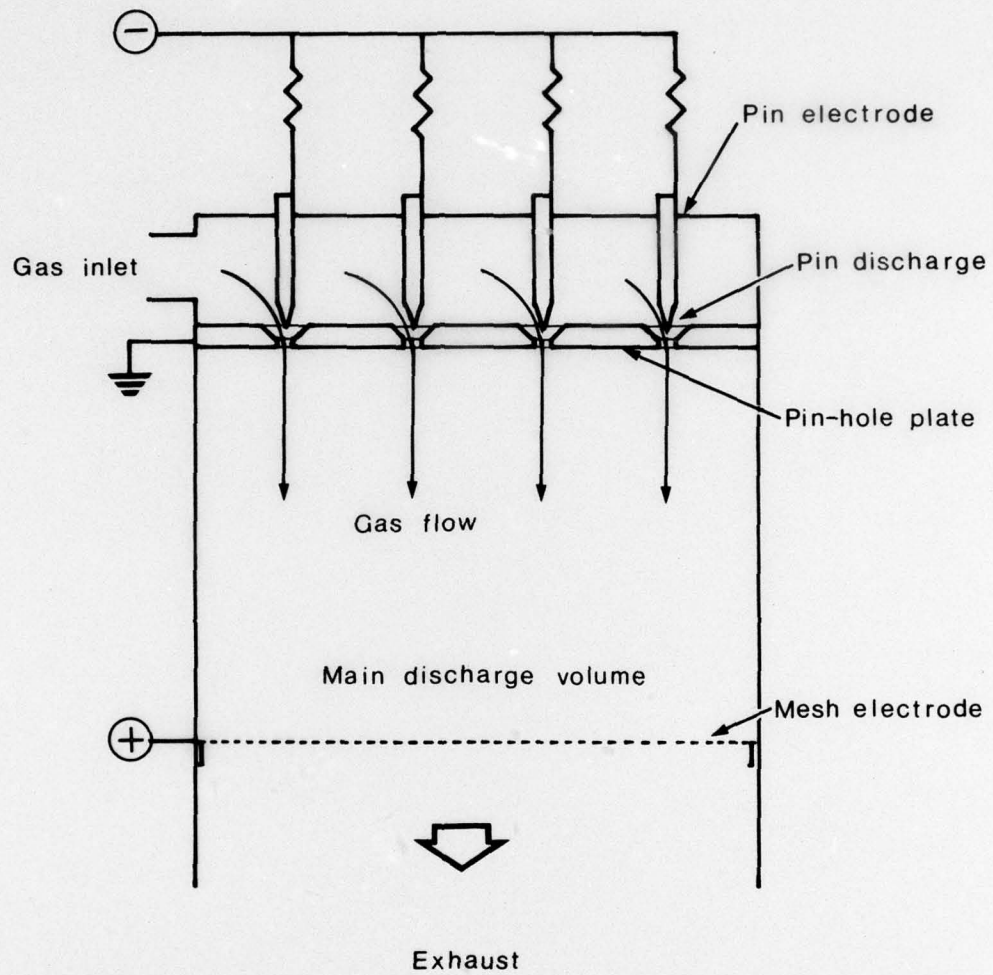


FIG. 1 - Basic arrangement for production of a plasma-injection-stabilised discharge.

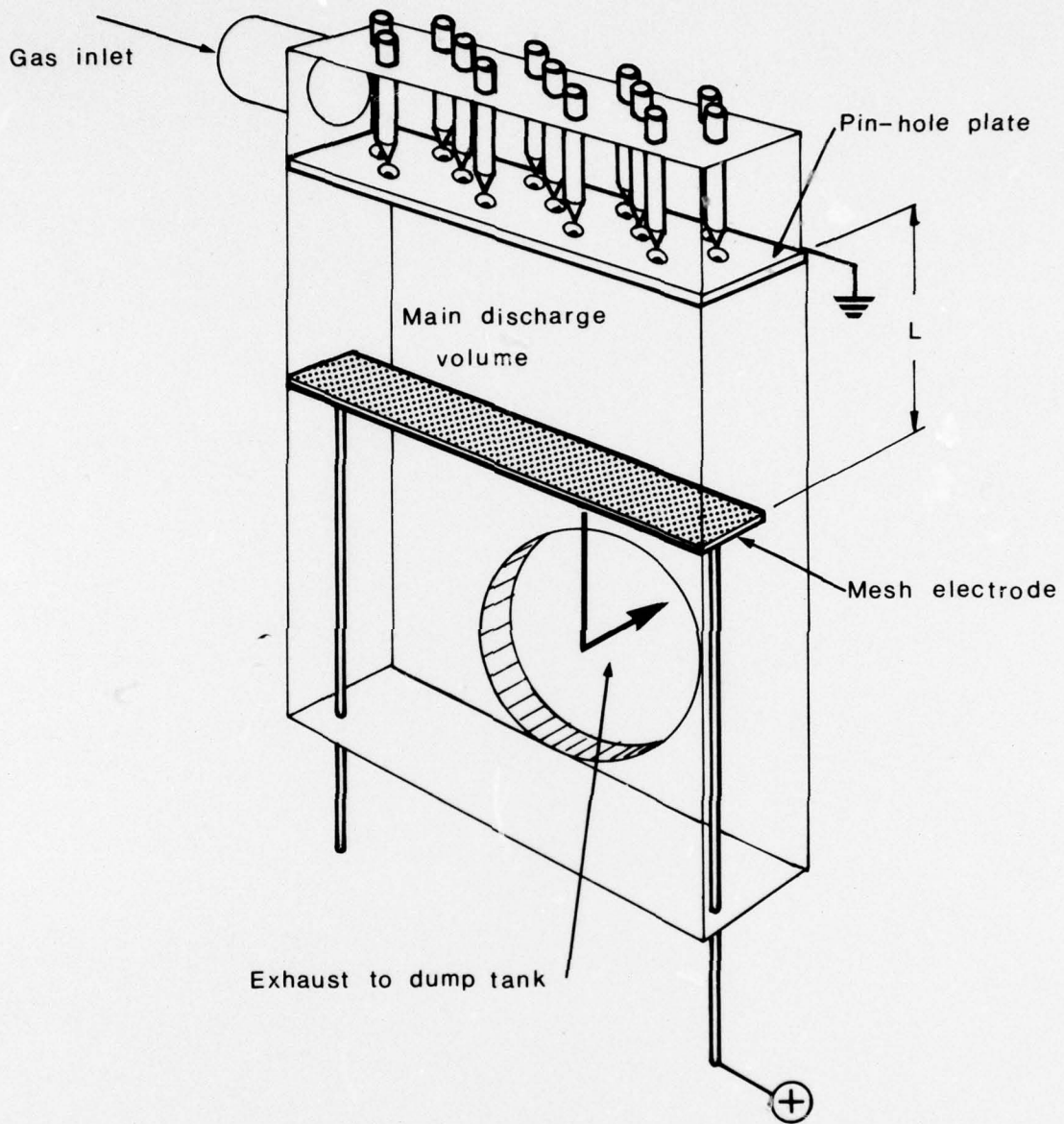


FIG. 2 - Diagram of experimental apparatus.

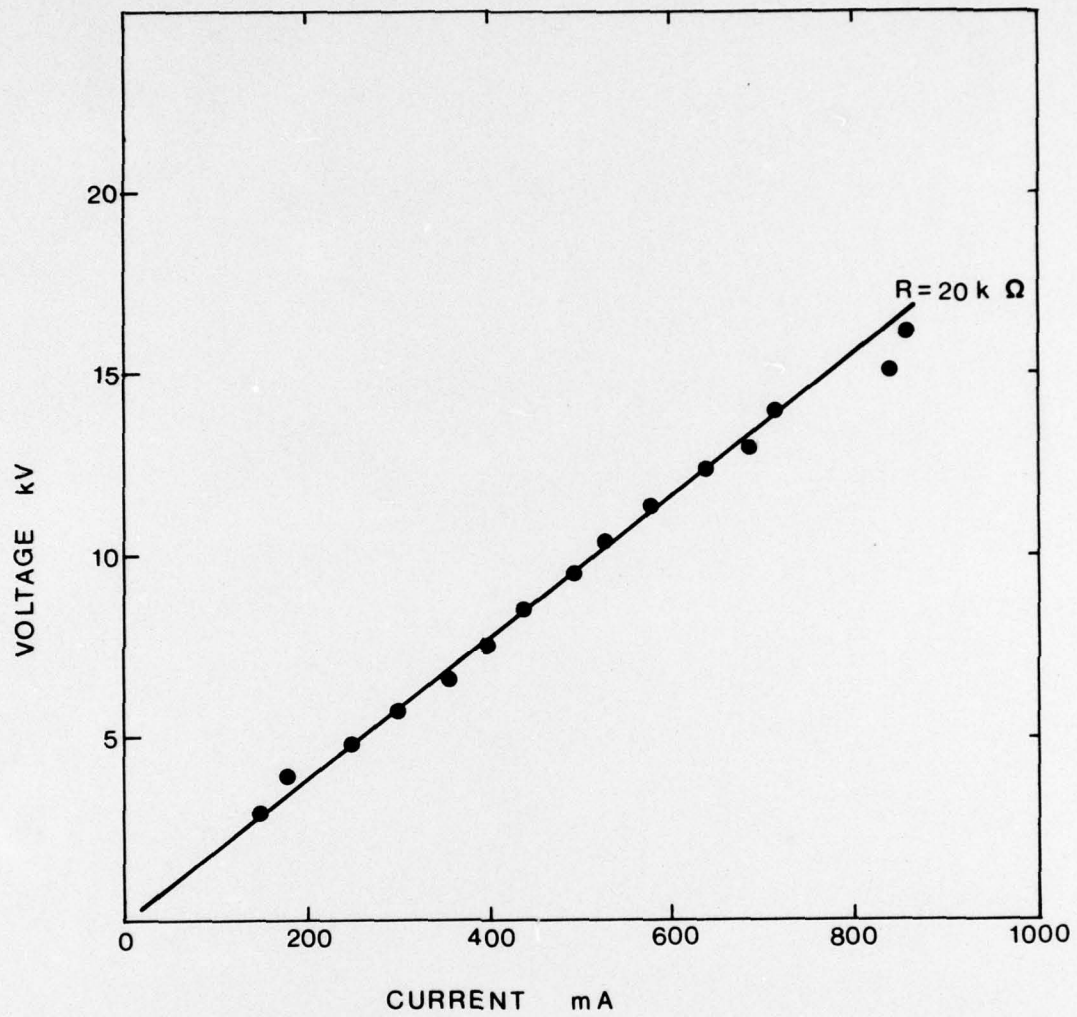


FIG. 3 - Current-voltage characteristics of the discharge in N_2 for a discharge length (L) = 60 mm, a total pin current (I_p) = 2.5 A, a flow rate (\dot{m}) = 34 gs^{-1} , and a pressure (P) = 96 kPa.

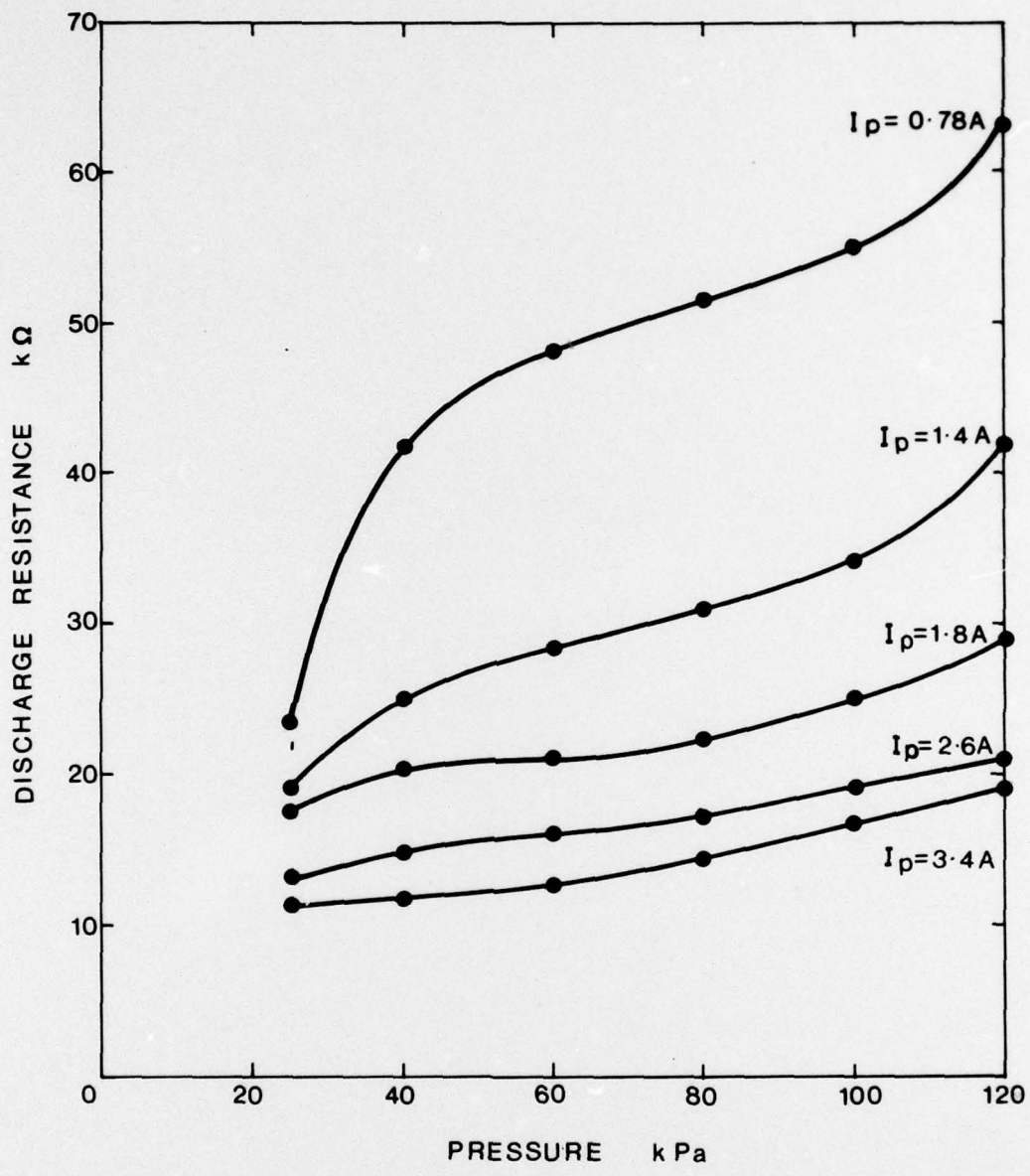


FIG. 4 - Discharge slope-resistance, in N_2 , as a function of pressure, for $L = 60\text{ mm}$ and $\dot{m} = 34\text{ gs}^{-1}$.

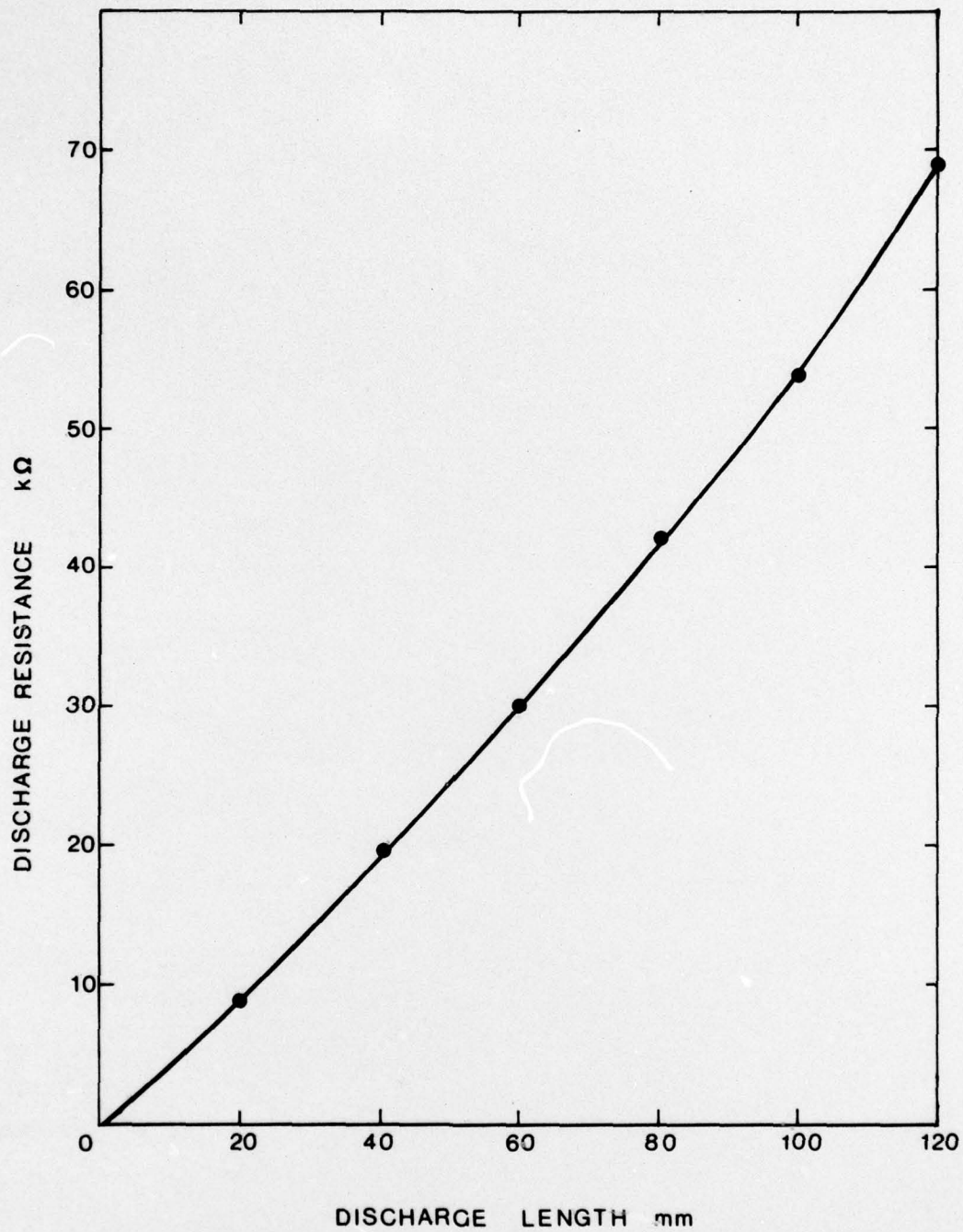


FIG. 5 - Discharge slope-resistance, in N_2 , as a function of length, for $I_p = 1.3$ A, $\dot{m} = 34$ gs^{-1} and $P = 100$ kPa.

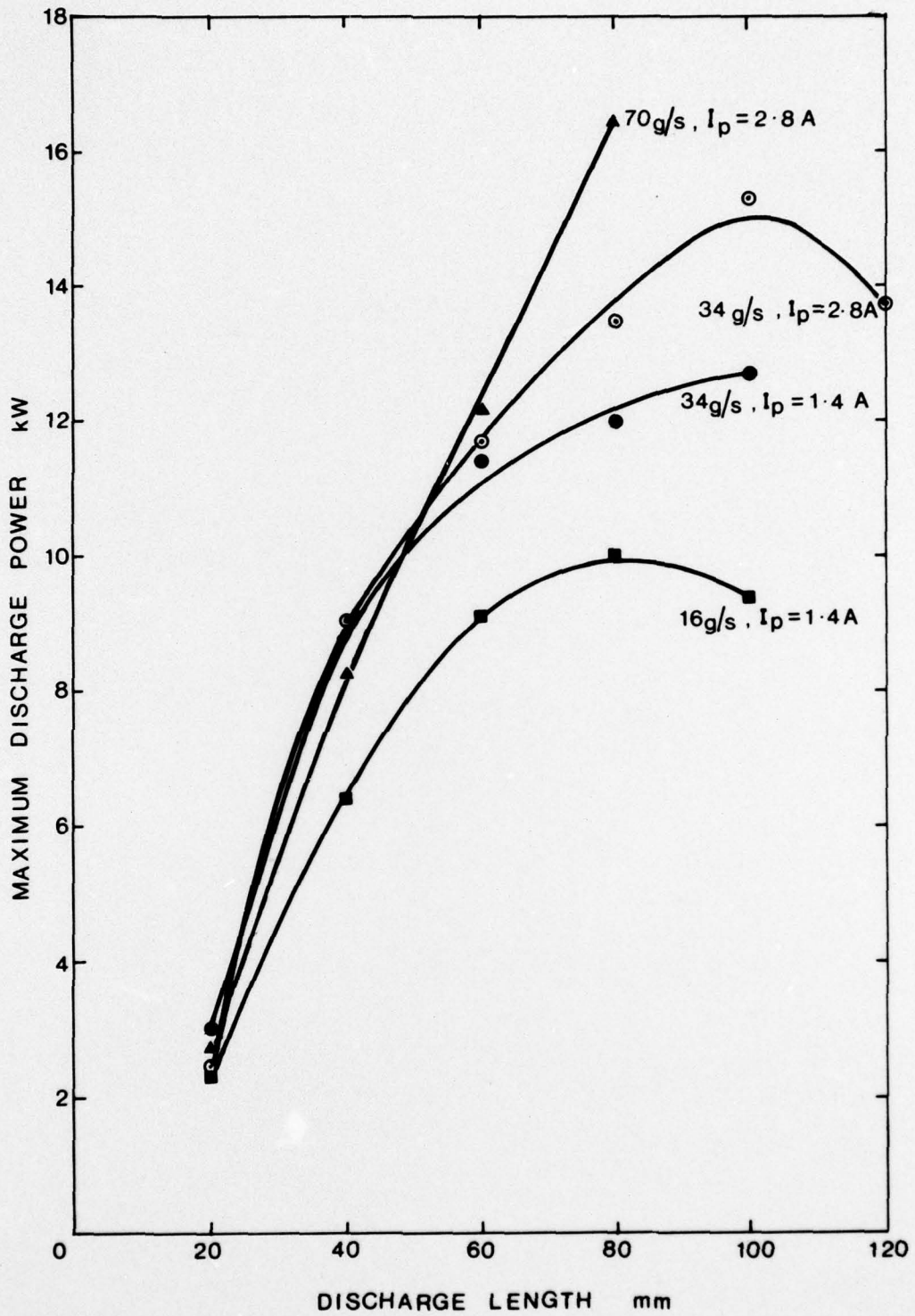


FIG. 6 - Maximum stable discharge power as a function of length, in N_2 , at 100 kPa.

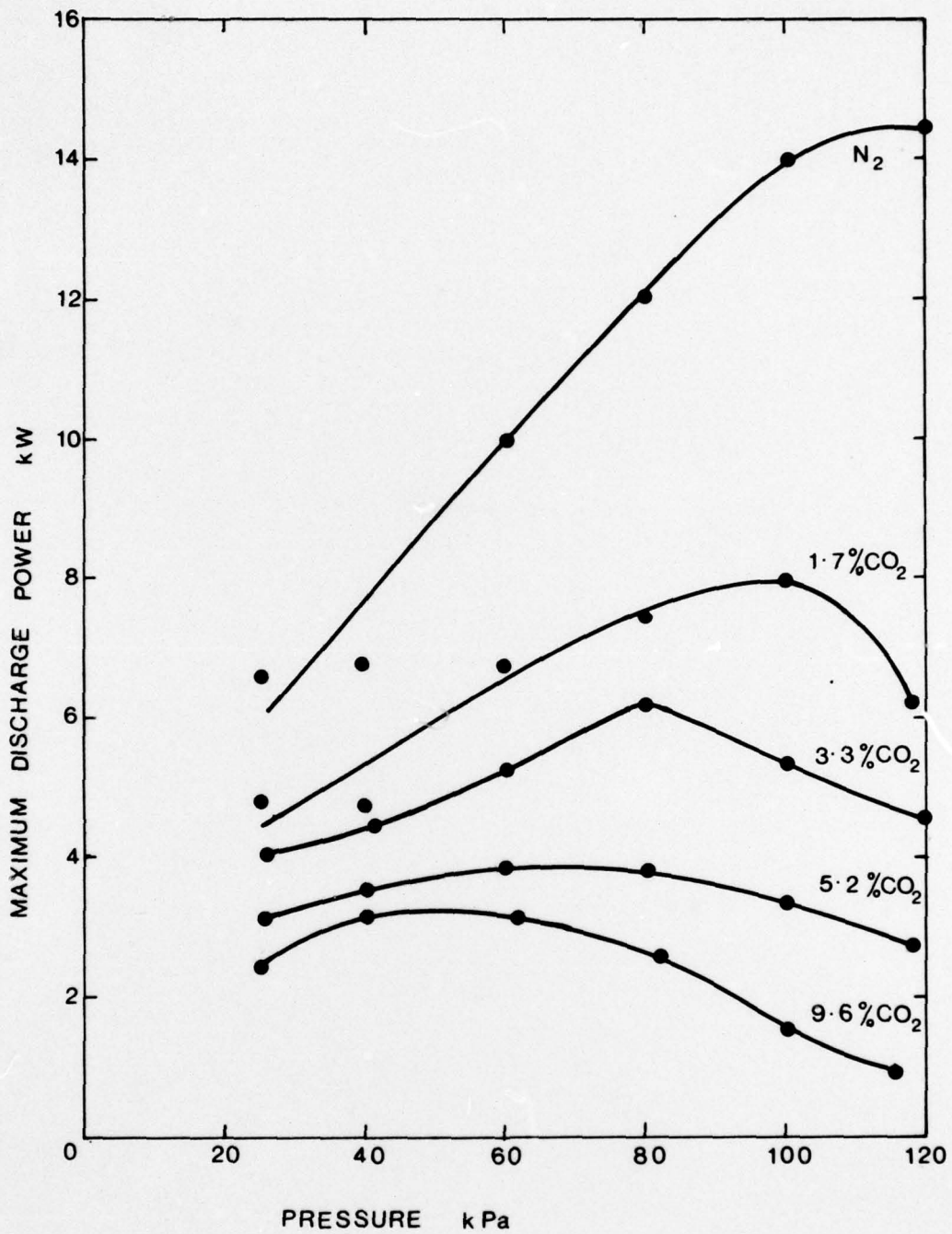


FIG. 7 - Maximum stable discharge power in different CO₂/N₂ gas mixtures as a function of pressure, for L = 60 mm, I_p = 1.3 A and $\dot{m} = 34 \text{ gs}^{-1}$.

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