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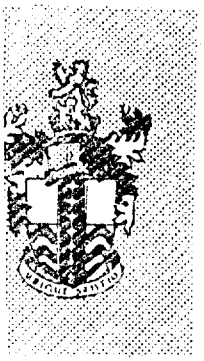

RSRE MEMORANDUM No. 4415

ROYAL SIGNALS & RADAR ESTABLISHMENT

LONG SELF-SUSTAINED DISCHARGE PULSES FOR CO_2 LASERS: FURTHER SKIRMISHES

Author: M R Harris

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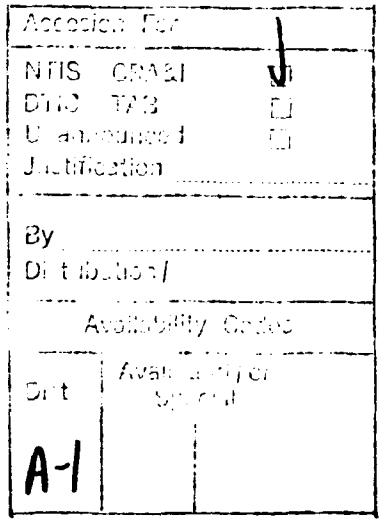
AUTHOR: M R Harris

DATE: August 1990

SUMMARY

Non-externally sustained glow discharges of 10.8μs and 26.25μs duration are operated in CO_2 laser gas mixtures over a pressure range 0.3 to 1 atm. The effects of gas mixture, pressure and pulselength are characterised and the influence of CO_2 dissociation products on the discharge are examined along with measurements of the rate of dissociation of CO_2.



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LONG SELF-SUSTAINED DISCHARGE PULSES FOR CO_2 LASERS: FURTHER SKIRMISHES

1 INTRODUCTION

RSRE Tech Memo No 4353 (Ref 1) described initial attempts at operating long self-sustained discharge pulses in typical CO_2 laser gas mixtures at total pressures up to about $\frac{1}{2}$ atmosphere. This work established broad requirements for the operation of such discharges showing promise for stable operation of pulses lasting tens of microseconds at pressures approaching 1 atmosphere. Presented here are the results of a more detailed characterisation involving studies of dependence on pressure, gas mixture and pulselength. The effect on the discharge of the CO_2 dissociation products CO and O_2 are examined, also measured is the rate at which CO_2 is dissociated.

2 DISCHARGE CONFIGURATION

2.1 Mechanical

Figure 1 depicts schematically the discharge chamber and electrical arrangement. The 100 x 30 x 30 mm^3 glow discharge is struck between a $\pi/2$ Rogowski profiled cathode and a perforated plane anode having approximately 30% optical transparency over the discharge area. The anode is formed from a 3 mm thick aluminium alloy plate drilled with an array of 4 mm dia holes giving staggered rows on a 6 mm x 4mm separation over an area slightly larger than the discharge. A radiussed cutter is followed into the holes to round out edges and give some improvement in optical transparency.

Positioned 25 mm below the anode is a flashboard which provides a burst of UV illumination to pre-ionise the discharge volume. The flashboard is formed from 0.6 mm thick alumina with a metallised pattern on both sides. On the back of the board a large area ground plane is formed whilst rows of 4 mm square pads are laid down on the front surface arranged so that 9 rows of 5 arcs each illuminate the discharge area.

2.2 Electrical

The flashboard was excited by a 10 nF capacitor in a rapid discharge circuit switched by spark gap 1 (SG1), charging voltages ranged from 30-45 KV. To ensure

that all rows of arcs were struck each row was ballasted with a 50Ω carbon compound resistor. Total peak currents were in the vicinity of 1500 Amps and pulse durations close to 400 ns.

SG1 also controlled two other rapid discharge circuits charged by the same high voltage supply as the flashboard circuit. One of these, the "spiker", rapidly discharges a 2nF capacitor through the main discharge volume. This highly overvolted discharge provides initial breakdown of the gas, dramatically increasing the electron density establishing conductivity in readiness for the application of the main discharge pulse.

The third circuit switched by SG1 comprises a nominal 1 nF capacitor which applies a trigger pulse to fire spark gap 2 (SG2) thus initiating the main discharge pulse. The main discharge pulse length was determined by a pulse forming network (PFN) the impedance of which was generally chosen to be close to or somewhat higher than match with the discharge. Charging voltages were typically less than 30 KV.

3 DISCHARGE CHARACTERISATION

3.1 Gas Mixture

The effect of variation of the ratio of constituent gases was assessed by setting the CO_2 concentration at 17% and altering the N_2 to Helium ratio. A CO_2 level of 17% was chosen as representative of a moderately rich laser gas mixture, earlier results have demonstrated that reducing the CO_2 concentration leads to improved discharge stability (ref 1). Fig 2 is a graphical representation of the results of this series of experiments. The total pressure was varied over a range from 0.3 to 1 atmosphere but assessment over the full range of mixtures was only possible at 0.65 atm and below. Above 0.65 atm with the more N_2 rich mixtures an insufficient voltage was available from the HT unit charging the "spiker" to satisfactorily breakdown the discharge gap. Indeed, at 1 atmosphere only the the most Helium rich mixture was operable. Fig 3 shows the variation of the discharge electric field strength with N_2 concentration. As the Helium is reduced the field strength increases, and over the range examined is independent of the total gas pressure.

At all pressures there is a marked trend to higher discharge energy loadings being achievable as the N_2 content increases. Although higher specific energy densities are possible at lower pressures Fig 4 shows that the fall off with increasing

pressure is not sufficient to prevent volumetric energy deposition maximising for any particular gas mixture with increased pressure. The criteria used to judge the limit of discharge energy loading was the appearance of an arc. As the discharge voltage and current increase arcs begin to set in late in the pulse, and as V and I are increased further the arc appears earlier. The values reported for field strength and energy deposition are those relating to an operating point just below onset of arcing giving reliable and reproducible operation from shot to shot.

3.2 Pulse Length

The series of experiments described above were carried out using a 10.8 μs PFN, to investigate the effect of further increasing the pulse-length a 26.25 μs PFN was utilised. Fig 5 compares the performance at the two pulse durations. The overall trend to improved specific energy deposition at higher N_2 concentrations is repeated at the longer pulse-length but the effect is more marked, whilst the curve for the shorter pulse is flattening out above a $N_2/(N_2 + He)$ ratio of about 0.7 the longer duration pulse is still rising steeply.

3.3 Discharge Gap

An attempt was made to extend the discharge operational range at atmospheric pressure to N_2 rich gas mixtures by reducing the discharge gap from 3 cm to 2 cm and thus overcome the charging voltage limitation on the spiker capacitor. It rapidly became apparent that operation at the reduced gap was markedly inferior. A comparison of performance at the reduced and normal gaps is shown in Figure 6. No attempt was made to ascertain why the performance was degraded, but the implication is that this discharge technique is better suited to large cross-section, hence high energy, devices.

4 CO_2 DISSOCIATION PRODUCTS

4.1 Tolerance to Dissociation Products

Since it is desirable to operate CO_2 lasers sealed off it is useful to know how the dissociation products affect the discharge. The dissociation products O_2 and CO were added to the flowing gas stream separately and together. Where both were added a ratio of 2.5 $CO:O_2$ was used, this non-stoichimetric ratio was chosen as typical of both short pulse TEA lasers and e-beam sustained devices (refs 2 & 3).

Fig 7 shows the effect on maximum energy loading for the addition of O_2, CO and CO + O_2. The discharge was operated at a total pressure of 0.65 atm in a gas mixture with $N_2/(N_2 + He) = 0.7$, the pulse length was 10.8 μs. Where CO + O_2 was added the horizontal axis of the graph refers to the O_2 component. Although arc free discharges are operable to O_2 levels beyond 1% the specific energy deposition is greatly reduced and in practice O_2 levels beyond about 0.25% would be undesirable.

Fig 8 shows the effect of dissociation products on electric field strength. O_2, CO, and CO + O_2 all increase the value of E/P at which the discharge operates. The effect of CO is not quite as marked as that of O_2, but the similarity suggests that CO has a strong electron affinity! Fig 9 compares the discharge I-V characteristics with and without the addition of 1% CO. The added CO leads to a large increase in discharge impedance, again, characteristic of an electron attacher. This is not understood, but might be attributable to the extremely high attachment coefficients of the metal carbonyls (ref 4) which are inevitably present in CO which is stored in steel cylinders.

4.2 CO_2 Dissociation Rate

To determine catalyst requirements for sealed operation a knowledge of the rate at which CO_2 is dissociated in the discharge is required. The apparatus used for this measurement is shown schematically in Fig 10. The discharge cell was operated sealed at 0.65 atm for a number of shots, the pressure was brought to atmospheric by the addition of N_2. The gas at atmospheric pressure was circulated around a loop containing a bellows pump and an infrared absorption CO analyser. To quantify the contributions to dissociation by the various discharge elements measurements were carried out operating the flashboard alone and the flashboard plus spiker, as well as the full discharge.

A solid CO_2 cold trap was introduced to the system to trap out condensible species which were strong electron attachers, probably mostly water vapour liberated by the large amount of plastic used in the cell construction. Without the cold trap once the discharge cell was sealed off the discharge impedance would rise dramatically, even with the cold trap some impedance rise and consequent loss of performance was suffered. This impedance increase could not be attributed to the small levels of O_2 and CO produced by the discharge and appeared in the absence of discharging. The species producing this impedance rise have not been determined.

A 10.8 μs discharge operating at 0.65 atm in $4N_2:1CO_2:1He$ gas mixture at approximately 15KV and 33 Amps for 52 shots produced 0.012% CO. Since the system volume is about 5 litres this equates to a CO generation rate of 1.15ℓPa/shot for the 90 cc discharge. For comparison, a mini-TEA laser with an 11cc discharge volume generated CO at a rate of 1.67ℓPa/shot (ref 5).

Similar measurements were carried out for the flashboard alone over 200 shots and the flashboard and spiker for 150 shots. The contribution due to the various elements making up the total discharge were:-

Flashboard	< 10%
"Spiker"	> 60%
"Sustained" discharge	~ 30%

Under the conditions that the device was operating about 10% of the total energy dissipated was going into the spiker which provided over 60% of the dissociation. This is almost certainly due to the extremely high value of E/P imposed during this step where a high degree of electron multiplication is sought.

5 CONCLUDING REMARKS

Although this memorandum is entitled 'Long Self-Sustained Discharge Pulses....' the mode of operation is more akin to that of the 'pulser sustainer' device. If the interpretation of self-sustained operation is taken as the discharge being operated such that ionisation processes are generating electrons at a rate exactly matching the loss due to electron removal processes, then, apart from the spiker, this scheme does not qualify. The I-V plot in Fig 9 shows a nearly ohmic character whereas in the self-sustained mode discharges show large increases in current for virtually no voltage rise. Therefore the discharges described here are not operating at sufficiently high field strengths for electron generation to match loss. Further evidence of this can be gained from the voltage and current waveforms which tend to show some increase in voltage and fall in current with time during the pulse, i.e. the impedance rises during the pulse as the electron density decays. The onset of instability no doubt reflects a crossing of the threshold into true self-sustained operation. The term self-sustained is correct in so far as the discharges are not externally sustained, and it is this feature which is the virtue of this technique.

ACKNOWLEDGEMENT

I would like to express thanks to Dr D V Willetts for encouraging discussion on this topic.

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2 D S Stark, A Crocker and G J Steward. J. Phys E Sci. Instrum, Vol 16, pp158-161.

3 M R Harris and D V Willetts. Proc. 5th Conf on Coherent Laser Radar, Munich, 5-9 June 1989, pp105-108.

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5 D S Stark, P H Cross and M R Harris. J. Phys E Sci. Instrum. Vol 11, pp 311-315, 1978.

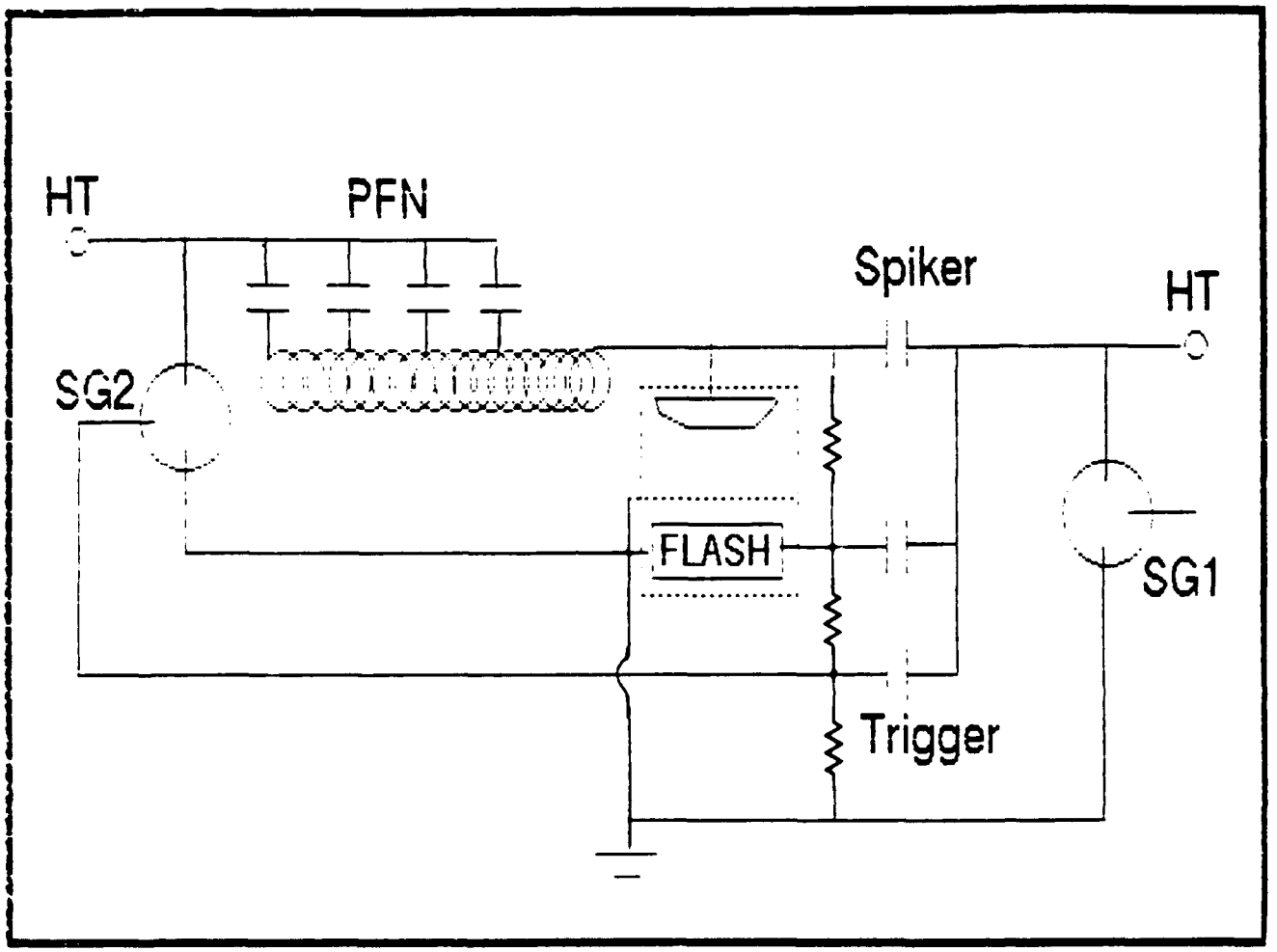


Figure 1. Electrical arrangement for long pulse self-sustained operation.

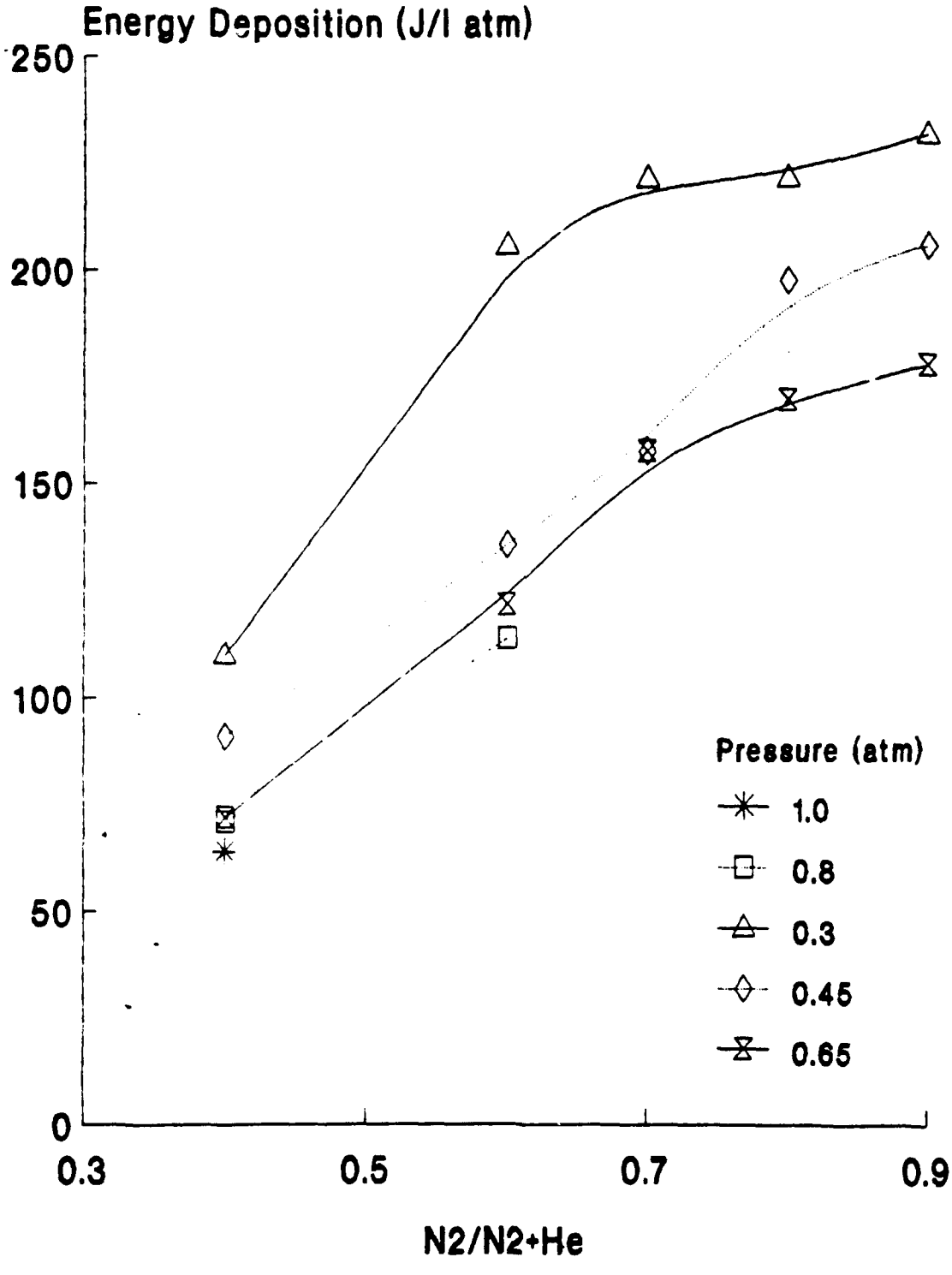


Figure 2. Effect of gas mixture on specific energy deposition. CO_2 = 17%; pulselength = 10.8 μS.

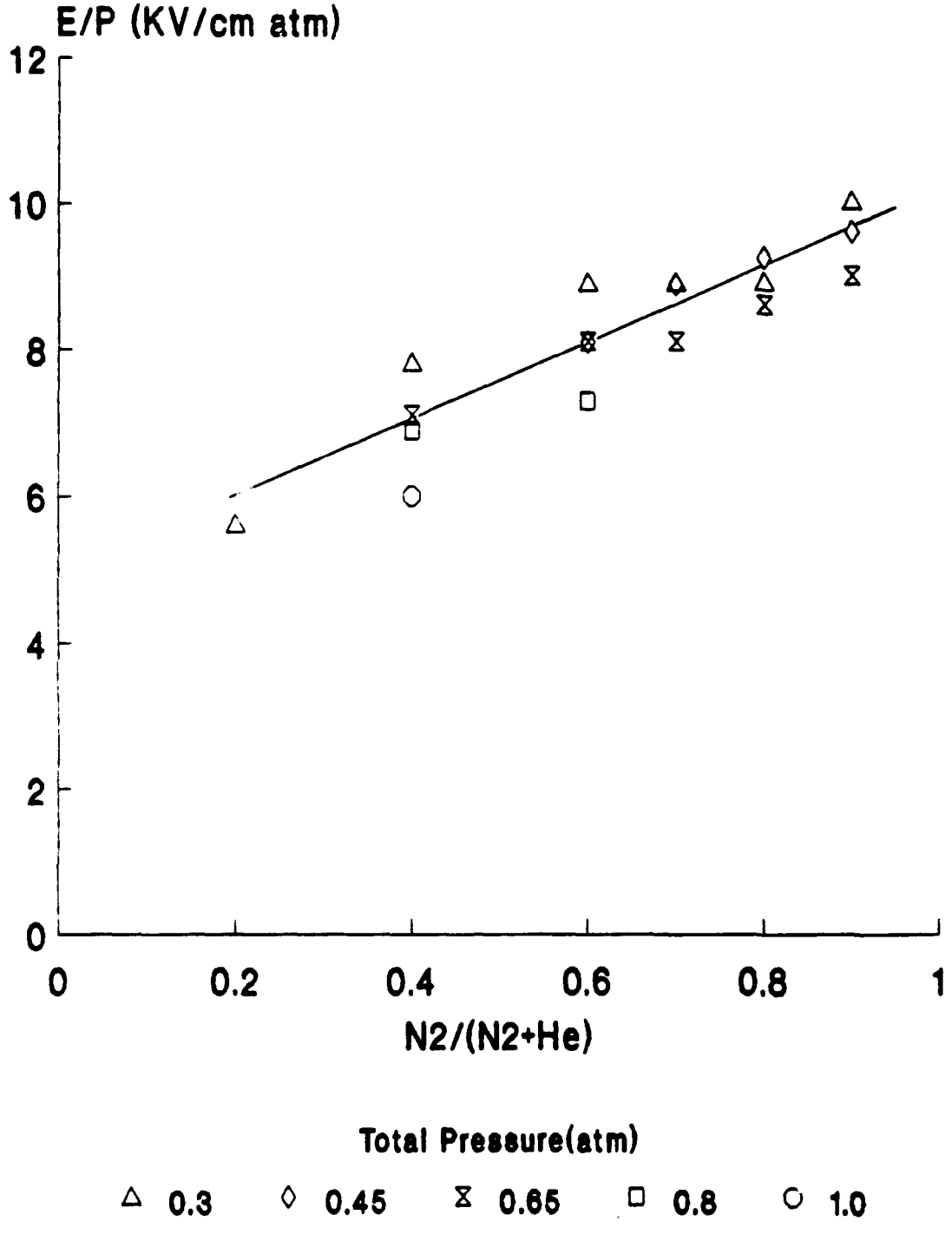


Figure 3. Variation of electric field strength with gas mixture and pressure. CO2 = 17%; pulselength = 10.8 μS.

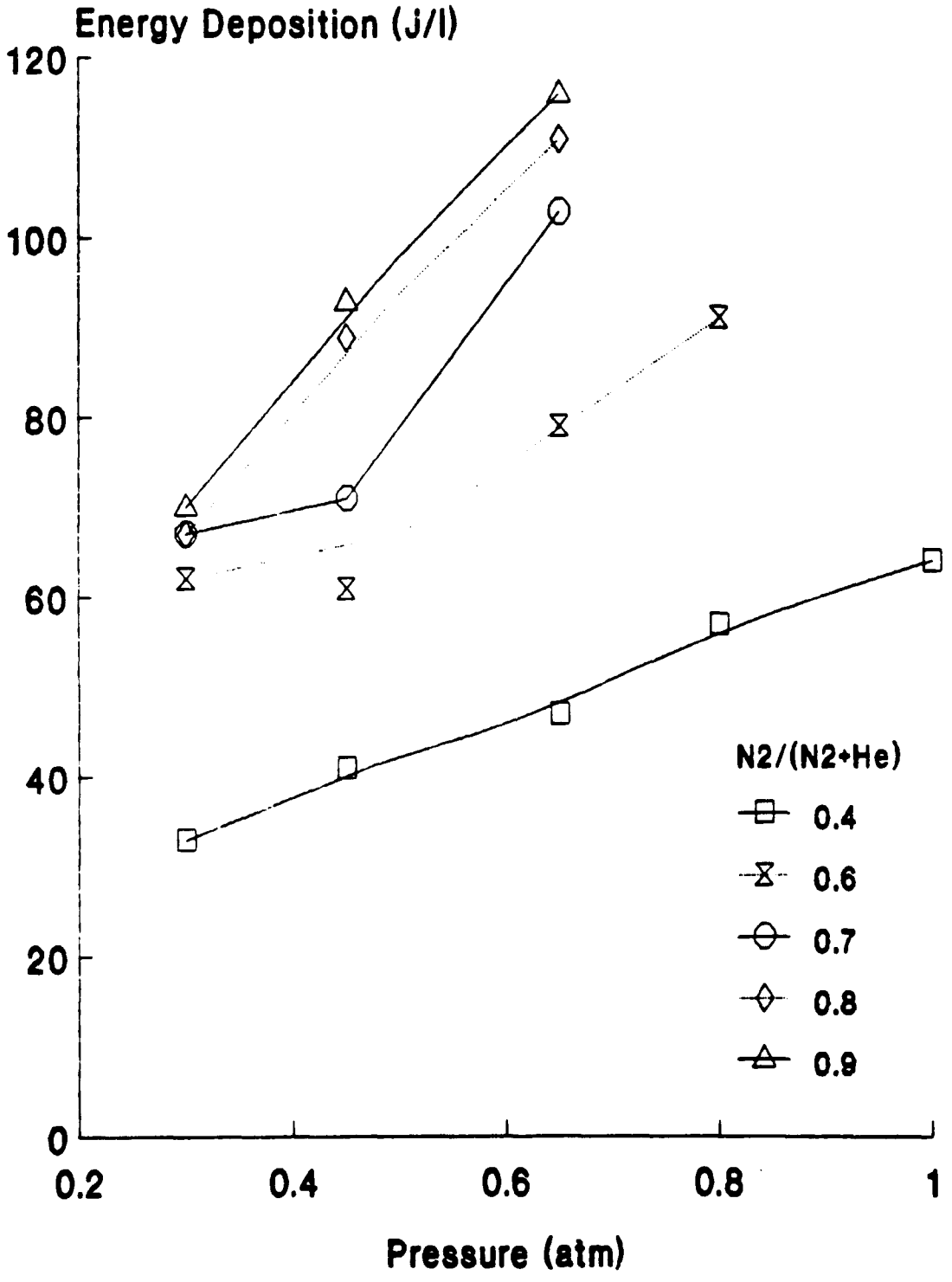


Figure 4. Volumetric energy loading vs total pressure for various gas mixtures. CO_2 = 17%; pulselength = 10.8 μS.

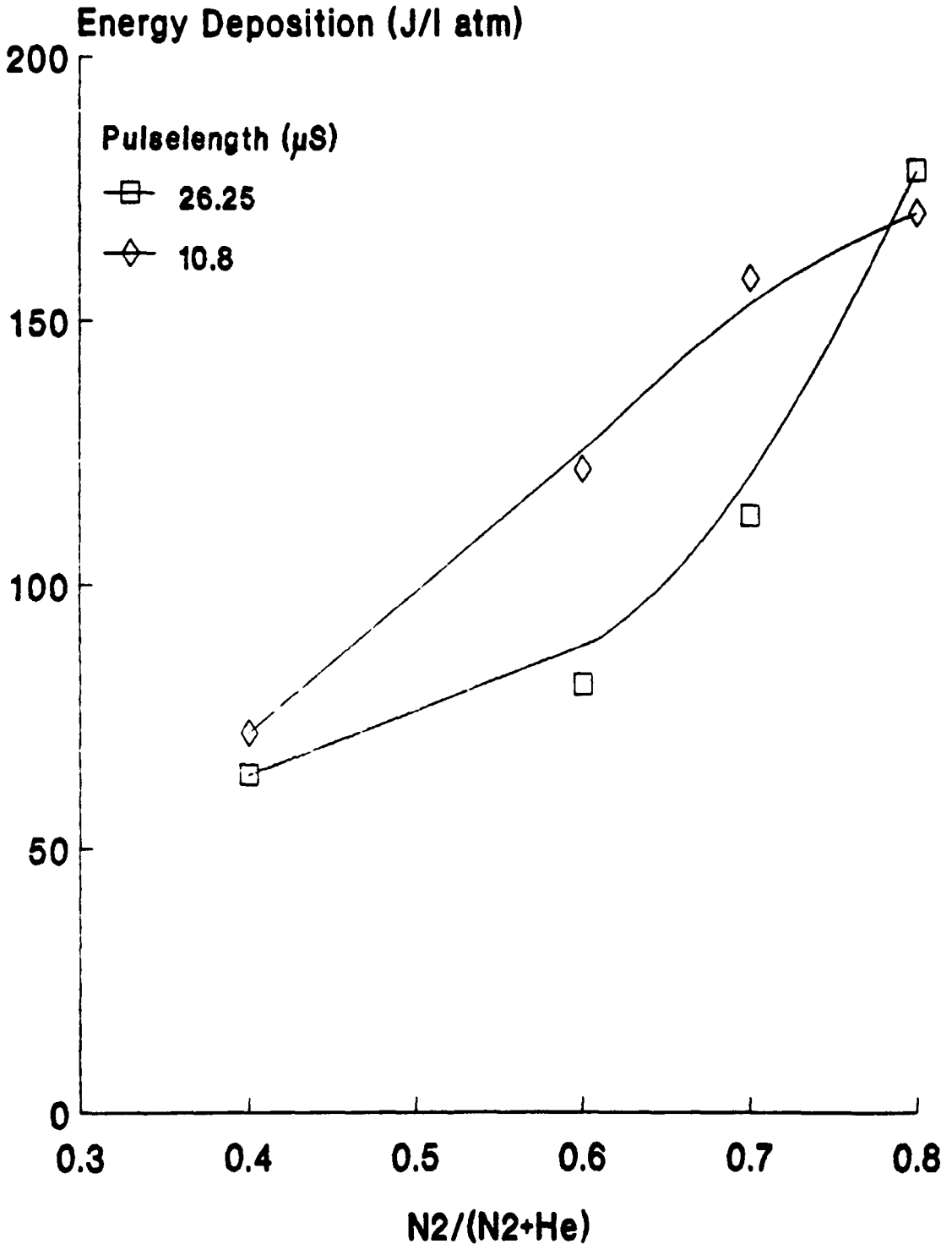


Figure 5. Specific energy deposition with gas mixture at two pulselengths. CO2 = 17% ; pressure = 0.65 atm.

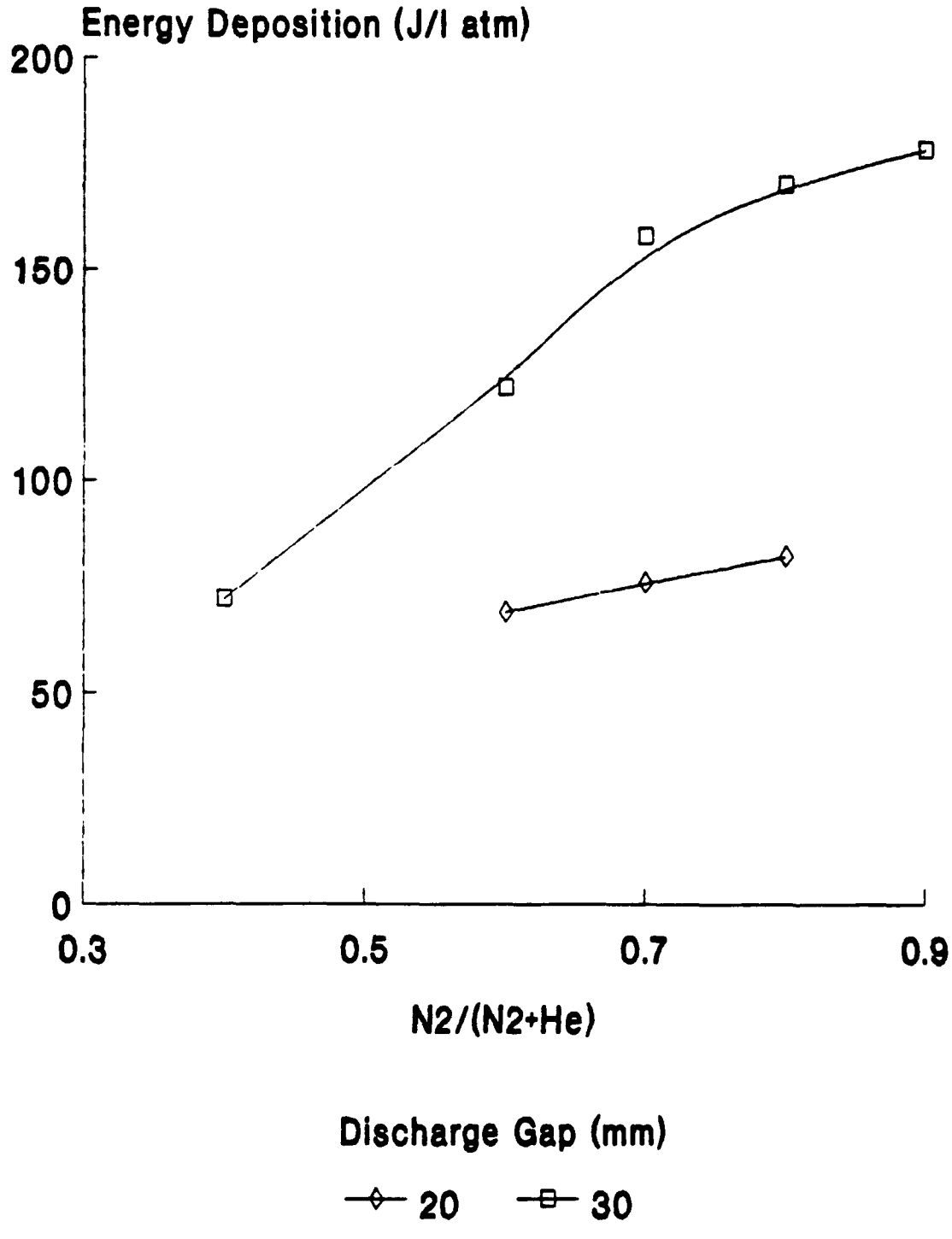


Figure 6. Influence of discharge gap on maximum energy loading. CO2=17%; pulselength=10.8μS; P=0.65atm.

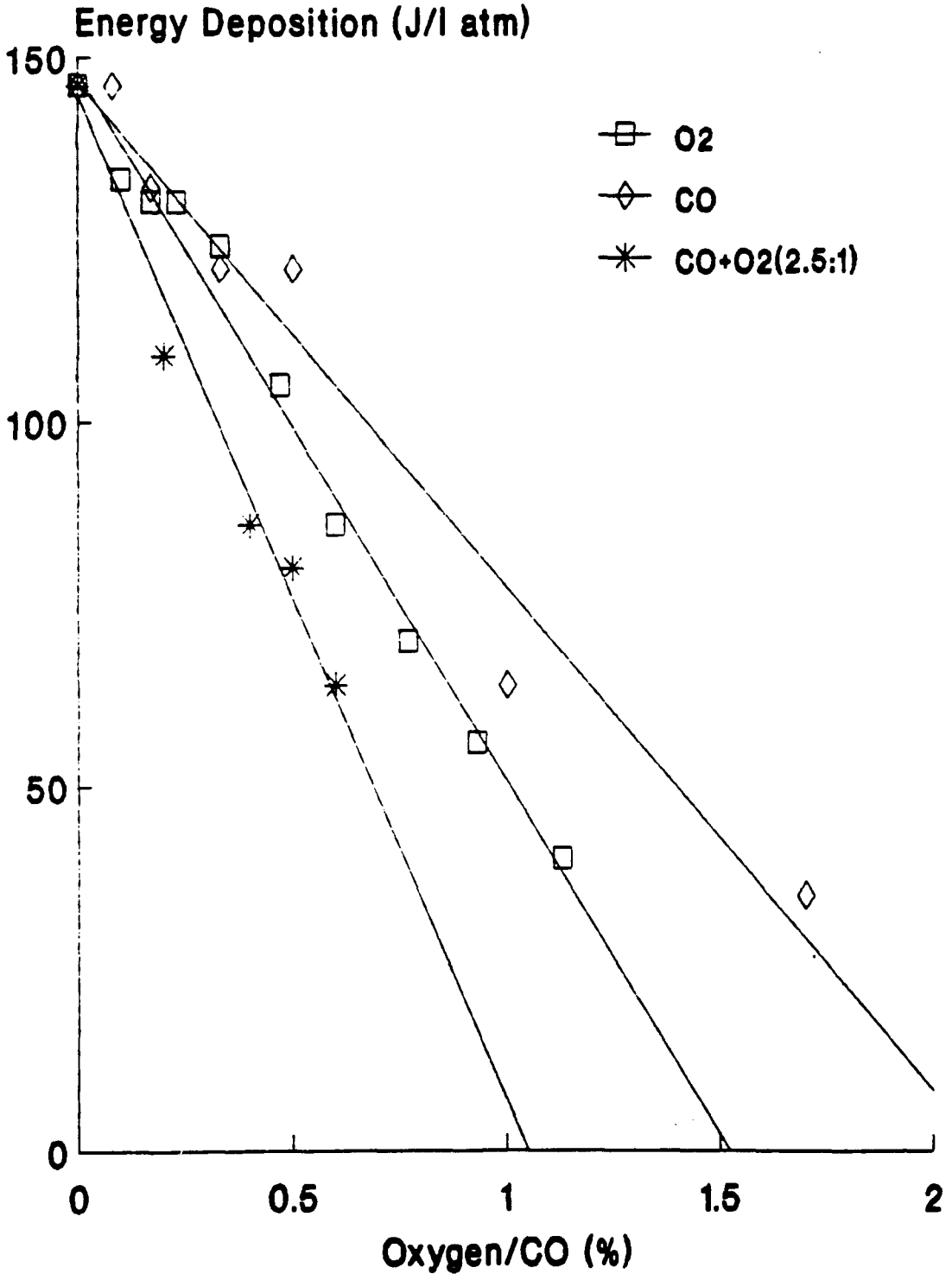
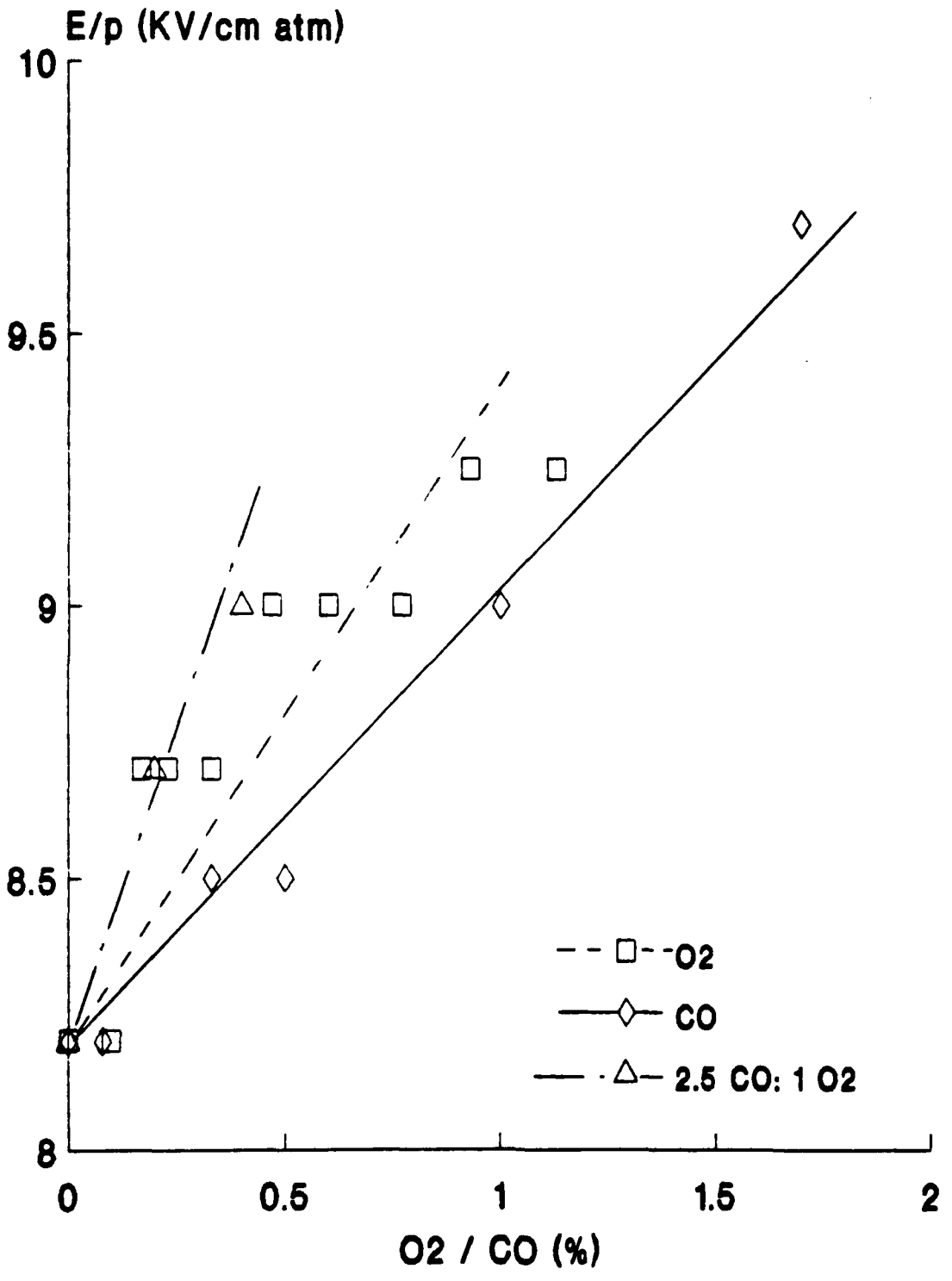


Figure 7. Effect of CO and O2 on maximum discharge energy loading. CO2 = 17%; N2/(N2+He)= 0.7; P= 0.65 atm.



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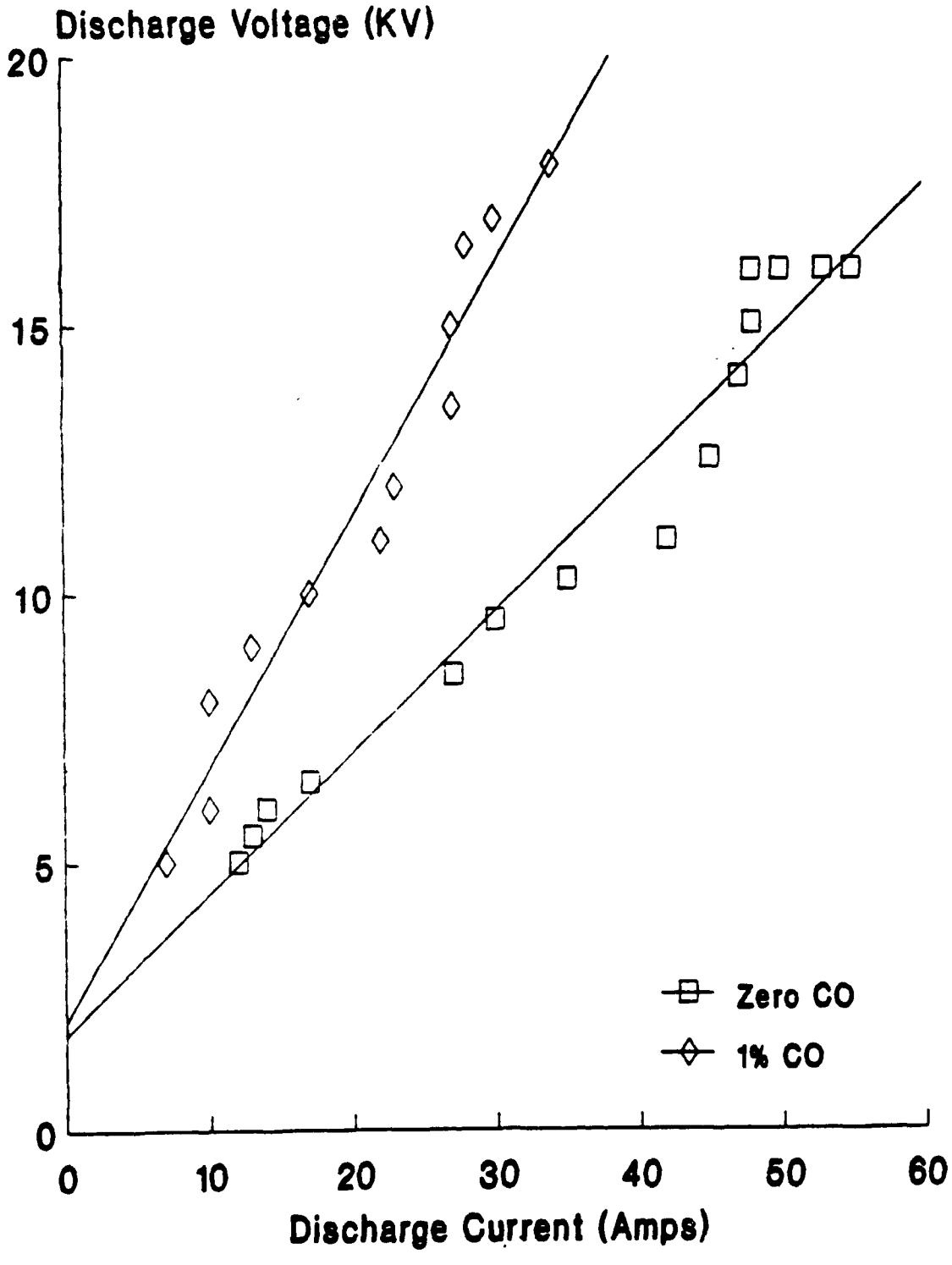

Figure 9. Discharge I-V characteristics with and without addition of 1% CO. CO2=17%;N2/(N2+He)=0.7;pressure=0.65atm.

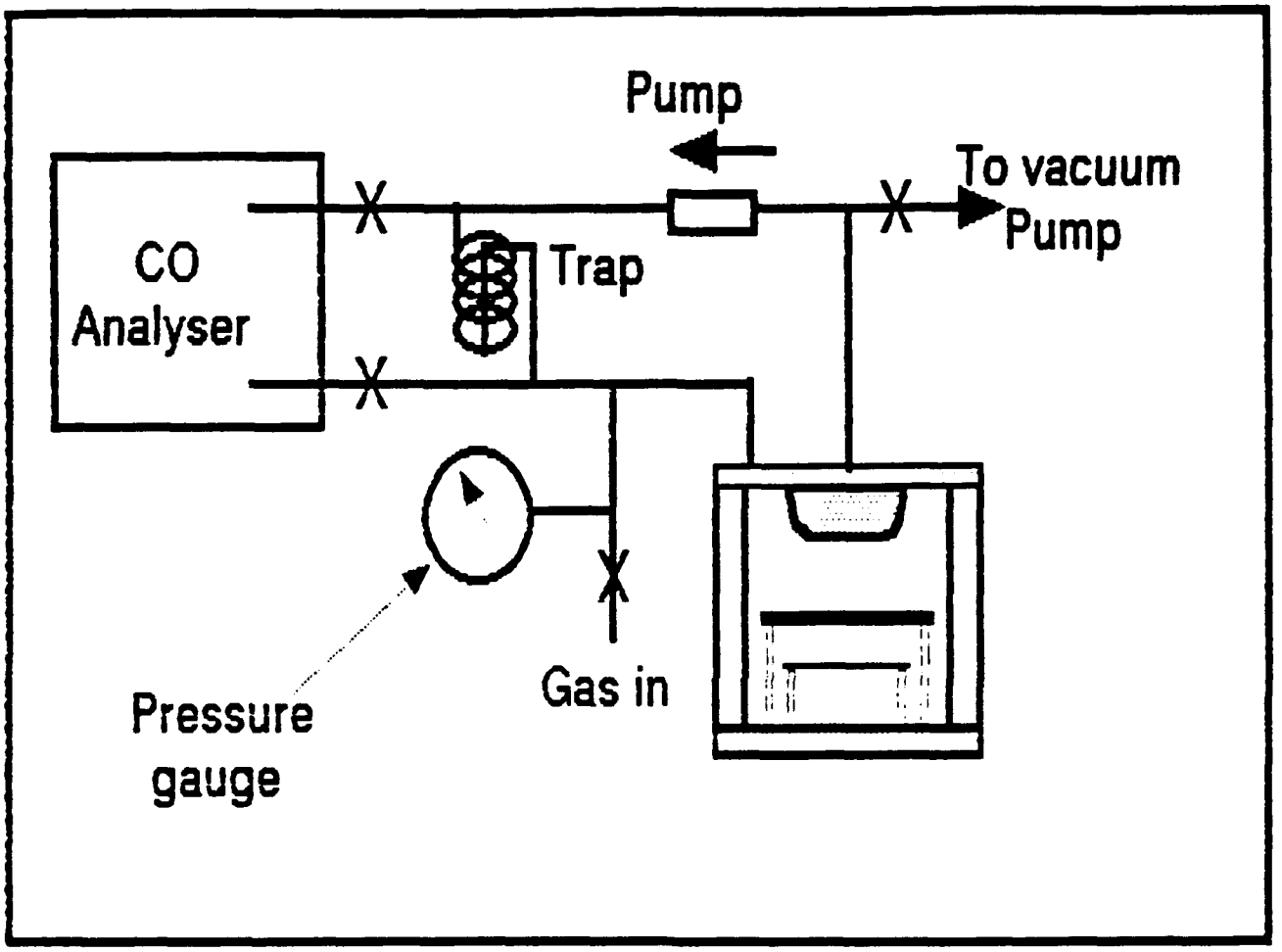

Figure 10. Arrangement for measurement of CO2 dissociation rate

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Abstract

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