THE PRODUCTION OF A LARGE VOLUME ELECTRIC DISCHARGE

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ABSTRACT

The purpose of this work was to investigate the production of a large volume electric discharge with particular reference to the superposition of d.c. and induction coupled discharges. The principle objective was to enable a reduction in the operating frequency of the high frequency power source to a value more amenable to industrial application. This was achieved.

1. INTRODUCTION

In the present economic climate abrupt changes in the price of fuels such as oil and gas are commonplace and a continuous check on the commercial feasibility of plasma processes should be made. Far greater use of plasma and other electrically based industrial processes is envisaged for the future as the awareness of the eventual exhaustion of alternative energy supplies increases and the availability, even in the short term, of alternative fuels becomes even more subject to political pressures and severe economic instabilities.

The application of arc discharge devices to chemical synthesis has encountered many problems including non uniform treatment of material throughput and lack of control over the residence time within the discharge region. These problems occur because of the high temperature gradients that exist within the discharge in many arc heater designs and because the discharge itself does not normally completely fill the reaction zone.

Various methods have been proposed to improve the uniformity of the discharge within the reaction zone.

Materials with low ionization potential, such as alkali salts, may be used to enhance the electrical conductivity in the lower temperature regions of a discharge by seeding(1), thereby increasing the discharge diameter. Seeding is only partly effective and the seeding products are often unacceptable.

Rotation of the surrounding enclosure around an arc reduces convection effects, and the arc expands(2). An expansion of up to 10 times the diameter of the equivalent free-burning arc has been achieved. The effect of increasing the arc current or introducing particulate or gaseous flows into the arc column is to reduce this.

The induction coupled discharge can be used to provide a large volume of plasma(3). Although the discharge is diffuse, large temperature variations occur across the diameter of the discharge, especially at low frequencies, and the discharge can be unstable at relatively low product feed rates. A possible way of obtaining a more uniform temperature distribution, and to aid stability, is to combine the r.f. discharge with a d.c. arc. It would also be advantageous to reduce the operating frequency of the induction coupled discharge to less than 10 kHz which is within the range of motor alternator sets or static invertors. Conversion efficiencies would then be over 95% compared with the typical conversion efficiencies of 60% for industrial vacuum tube oscillators working in the class C mode.

To achieve efficient coupling of the energy from a medium frequency source, a d.c. arc of large diameter and high overall electrical conductivity is required[4]. One possible method of obtaining a large volume of ionized gas is to use a multiple arc system [5]. Although various multiple arc systems have been developed and are used in 3 phase arc furnaces, mercury arc rectifiers and plasma torch furnaces with 2 or more torches supplied from separate power supplies [6] all use separate arcs with only one common electrode. To produce a large volume of ionized gas it is necessary that the arcs should mix but interaction between the arc supply circuits occurs causing instability and, due to the negative gradient of the arc dynamic resistance, all the current will eventually be carried by one arc. Interaction between the arc supply circuits can be avoided if the power supplies are totally isolated from each other. This is relatively difficult and cumbersome with batteries but can be more easily achieved using a transformer with several secondary windings. In this case the isolation is not infinite but the mutual coupling between the secondary windings of the transformer will normally be very small.

2. MULTIPLE ARC SYSTEM

An analysis of the conditions for the stable operation of a multiple arc system has been given elsewhere [7].

Experimental results [5] showed that a large volume of ionised gas could be obtained using a horizontal multiple arc system in which six power supplies were used electrically isolated from each other. Attempts to couple r.f. energy at 450 kHz i.e. an order of magnitude below operating frequencies usually associated with induction coupled discharges into the horizontal multiple arc discharge proved unsuccessful. Analysis of the overall efficiency of coupling showed that a multiple arc discharge greater than 40 mm diameter would be required for efficient coupling [8]. The horizontal multiple arc system used was unable to sustain a stable discharge of diameter greater than 30 mm with subsequent coupling efficiencies below 20%. Because of this and the severe practical limitations associated with this horizontal configuration the use of this form of multiple arc to initiate the coupling of r.f. energy was abandoned and other multiple arc discharge configurations had to be investigated.

A theoretical analysis proposed by Hobson[8] was used to estimate the overall coupling efficiencies between the possible vertical multiple arc discharge configurations and a high frequency power source at 450 kHz. A hollow cylindrical vertical multiple arc discharge system was subsequently designed and constructed and the characteristics of the multiple arc discharge formed by it were established.

A vertical multiple arc system was constructed based on the analysis developed by Hobson [8]. The assembly and its associated electrical supply circuit are shown in Fig.1 and Fig. 2 respectively. The electrode holder enabled 6 pairs of electrodes of 6 mm diameter to be used and a laminar gas flow of argon was fed to the discharge region through a brass plenum chamber mounted above the torch. The gas flow rate was measured with a variable area flowmeter over the range 10^{-4} m^3/s to 13.10^{-4} m^3/s.

The insulated electrode holder contained six 10 mm diameter brass clamps, to hold the carbon electrodes which were situated equally spaced on a pitch circle of 30 mm diameter. A 25 mm thick Syndanyo sheet was placed between the electrode holders and the discharge region to prevent deterioration of the insulated electrode holder.

A silica tube of 190 mm length and 70 mm internal diameter surrounded the discharge region and electrically isolated the d.c. arcs from the work coil of the high frequency power source. The work coil had 7 turns of 80 mm diameter and a total length of 63 mm. It was constructed of 6 mm external diameter water-cooled copper tubing. This relatively small diameter was chosen to increase the work coil turns per metre or power density available from the high frequency power source.

The separation of each pair of electrodes could be adjusted simultaneously to a maximum of 100 mm. The arcs were initiated by short circuiting the electrodes and then slowly drawing them apart to form the arcs.

3. DISCHARGE CHARACTERISTICS

The electrodes were initially connected with the anode vertically above its corresponding cathode. Filamentary arcs were formed when the electrodes were withdrawn from the short circuited position. As the arc length was increased the electromagnetic forces of attraction between the individual arcs caused the formation of a narrow conducting region along the central axis of the discharge vessel, although conducting paths to each electrode root still existed. This formation of a narrow conducting region was predominantly dependent on the arc length, although the tendency to form did increase slightly with arc current. Beyond an arc length of approximately 20 mm a reduction of arc current to less than 5 A did not stop the formation of a central conducting zone. Increasing the argon flow rate up to 13.10^{-4} m^3/s increased the instability of the system and slightly increased the tendency to form a central conducting zone.

Reversing the connections to each alternate electrode pair, such that each arc was then adjacent and diametrically opposite arcs with an opposite direction of current flow, reduced the effect of the electro-magnetic forces to form a narrow conducting zone. Adjacent arcs were now repelled and the whole discharge configuration tended to spread apart. The filamentary arcs formed with this second electrical connection to the electrodes showed no tendency to constrict on the axis but moved slightly radially outwards. The voltage-current characteristics were derived from oscilloscope traces of the arc voltage and current waveforms for both the vertical multiple arc discharge and for a single arc. Electrode spacings of 7 mm, 20 mm and 40 mm were used with argon flow rates up to 7.10^{-4} m^3/s. The results are shown in Fig. 3.

Increasing the argon flow rates cooled the outer zones of the multiple arc discharge and hence the arc voltage required for a particular arc current was increased. The arc voltage was also increased with electrode spacing.

Comparison of the voltage-current characteristic of the vertical multiple arc discharge and a single arc at a constant gas flow showed that at an electrode spacing of 7 mm the two discharges were similar as no coalescing took place within the multiple arc system and the electrode phenomena dominated. Increasing the electrode spacing to 20 mm allowed interaction between the arc columns of the multiple arc system. The conductance of the multiple arc discharge was always greater than that of the single arc, as in the case of the horizontal multiple arc system.(5) The difference in conductance was less for the vertical system, however, as the distance between the individual arcs was greater and hence their interaction less.

4. SUPERPOSITION OF R.F. POWER

In the production of a large volume discharge by means of the superposition of a d.c. and an induction coupled discharge the principal obstacle encountered was the inability to inductively couple energy in a manner which would enable a reduction in operating frequencies to values more amenable to industrial application. However, when r.f. energy at 450 kHz was applied to a vertical multiple arc discharge consisting of 6 d.c. arcs of approximately 10A each and length 40mm interaction could be visually detected by the formation of a large diameter and more intense discharge. The values of anode current, grid current and tank current were also observed to change appreciably when the d.c. current was raised between 8A and 20A for an argon flow rate of 3.10^{-4} m^3/s. Typical values of the operating parameters of both the d.c. and r.f. power sources are as follows:-

D.C. arc current (each supply)	= 20A
D.C. arc voltage	= 20V
Total d.c. power input	= 2.4kW
Anode voltage	= 7.4kV
Anode current	= 1.6A
Estimated overall efficiency of coupling [8]	= 60%
Estimated Total r.f. power input	= 6.7kW

The r.f. power input varied insignificantly with d.c. arc current or electrode spacing once the large volume discharge had formed. Investigations were therefore concentrated on the parameters of the multiple arc system i.e. arc length, arc current and gas flow rate to achieve the formation of a large volume discharge.

Below 8A, no interaction could be detected either from the intensity of the discharge or from the values of the induction heater tank circuit current and voltage.

For electrode spacings below 20 mm no change could be detected in the discharge on the application of the r.f. power. Increasing the electrode spacing to in excess of 30 mm, the formation of a more intense and diffuse discharge was seen which occupied a diameter of approximately 30 mm centred on the axis of the torch and a length equal to the electrode spacing. The 12 arc roots could still however be clearly observed. The coupling of r.f. energy increased the conductance of the multiple arc discharge and the voltage/current characteristics for various argon flow rates and electrode spacings are noted in Fig. 4.

Fig. 4a shows the variation of the voltage/current characteristic with argon flow rate between approximately 3.10^{-4} m^3/s and 7.10^{-4} m^3/s for an electrode spacing of 40 mm. The measurements of the voltage and current were taken directly from photographs of the oscilloscope wave forms and the conductance of the discharge increased by approximately 1.5 times on the application of the r.f. power and the subsequent formation of the diffuse discharge.

The variation of the voltage-current characteristic with electrode spacing in the presence of r.f. power is shown in Fig. 4b. Below an electrode spacing of 20 mm the application of r.f. power had no effect on the discharge whilst above 50 mm the power input caused excessive overheating of the discharge vessel and the multiple arc discharge, without the superposition of r.f. power was not stable.

To summarise for electrode spacings in excess of 20 mm arc currents in each supply greater than 8A, and argon flow rates between approximately 3.10^{-4} m^3/s and 7.10^{-4} m^3/s, it was possible to inductively couple approximately 7kW of energy at 450 kHz into a vertical multiple arc system. The principal objective of inventing a method by which energy can be inductively coupled into a combined discharge in a manner ideally suited to application at relatively low operating frequencies had therefore been achieved.

4. CONCLUSIONS

The major achievement of the present work is the discovery of a method of efficiency coupling electrical energy into a d.c. arc configuration which, it is envisaged, can be adapted to operating frequencies within the range of static inverter power supplies with the subsequent reduction in capital and running costs of the process. Estimates have been made of the number of 100 A power supplies needed and the total d.c. power requirements to initiate a combined d.c. and induction coupled discharge for various operating frequencies.[(8)] For an operating frequency of 10 kHz, which is within the range of modern static inverters, approximately twenty 100 A d.c. power supplies would be required and a total d.c. power input of approximately 100 kW, giving a discharge diameter in excess of 150 mm. Further progress in the reduction in the operating frequency of a combined d.c. and induction coupled discharge would therefore seem feasible and further research in this area is to be undertaken.

5. REFERENCES

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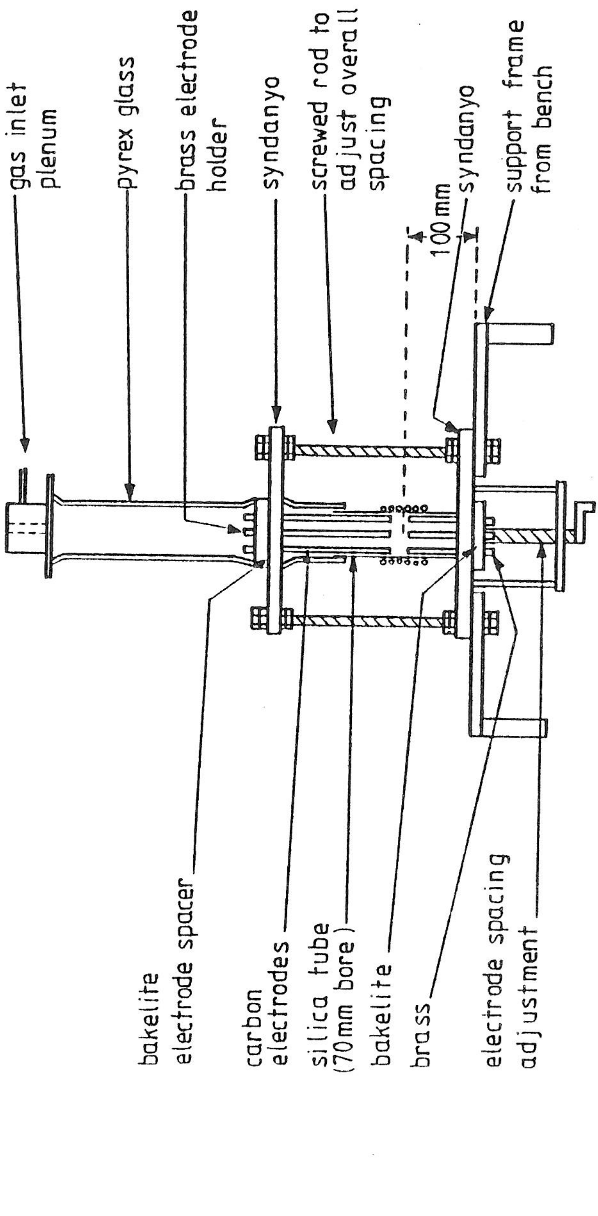


Fig. 1. Vertical Multiple Arc.

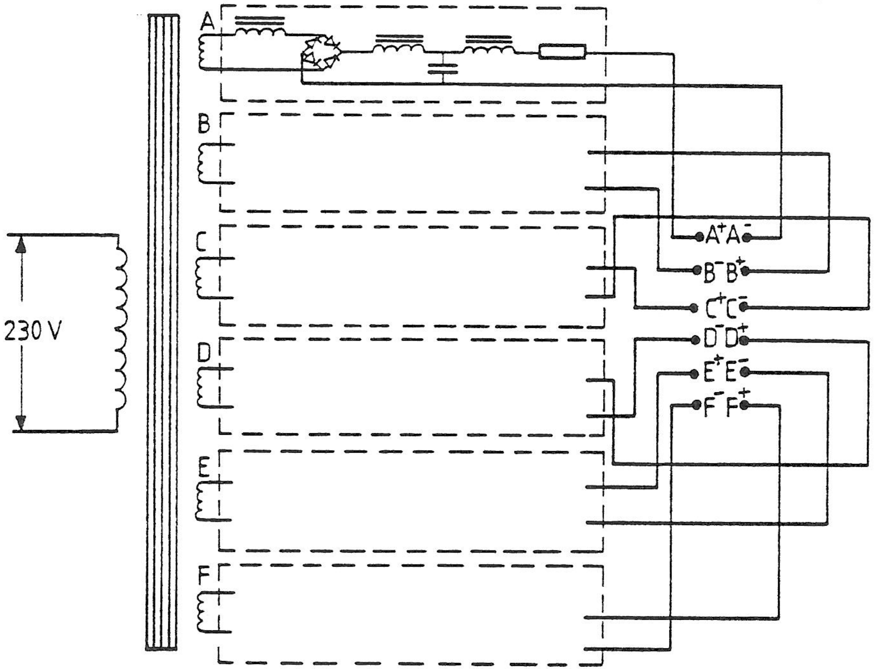
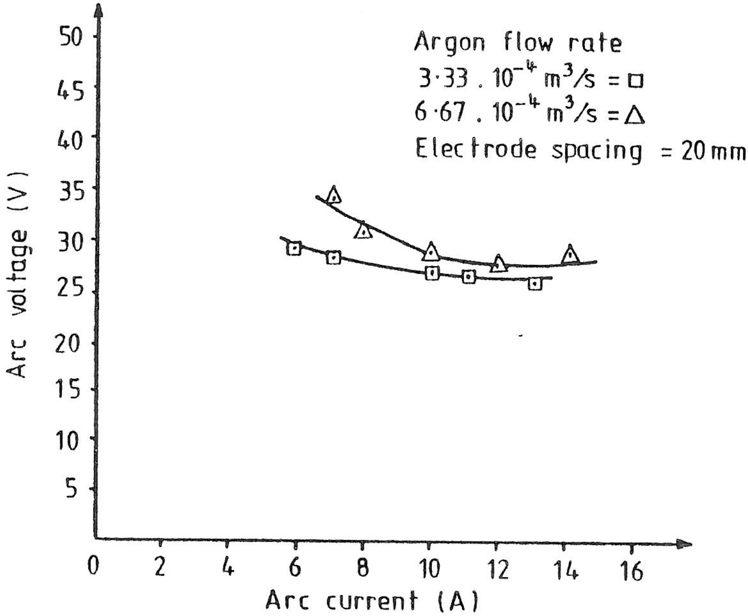
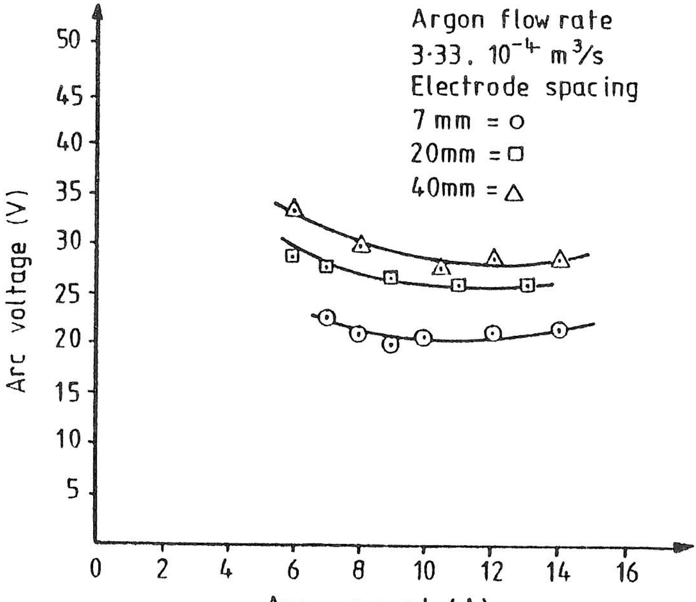


Fig. 2. Electrical Circuit used with Vertical Multiple Arc System

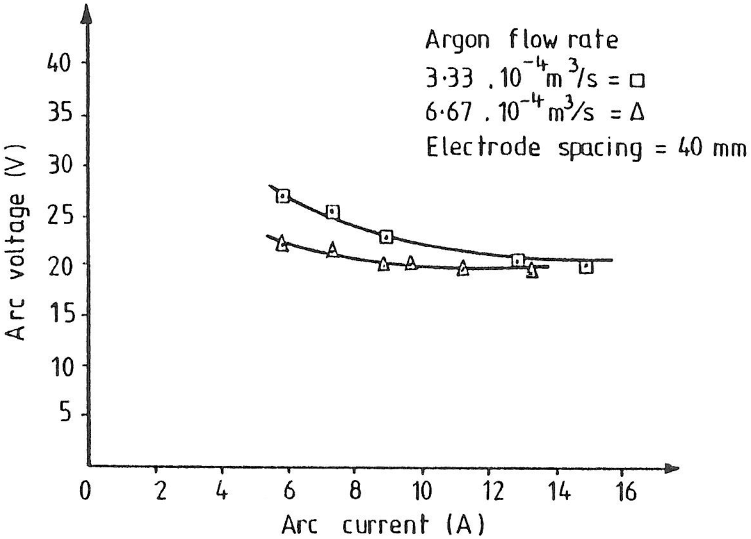


(a)

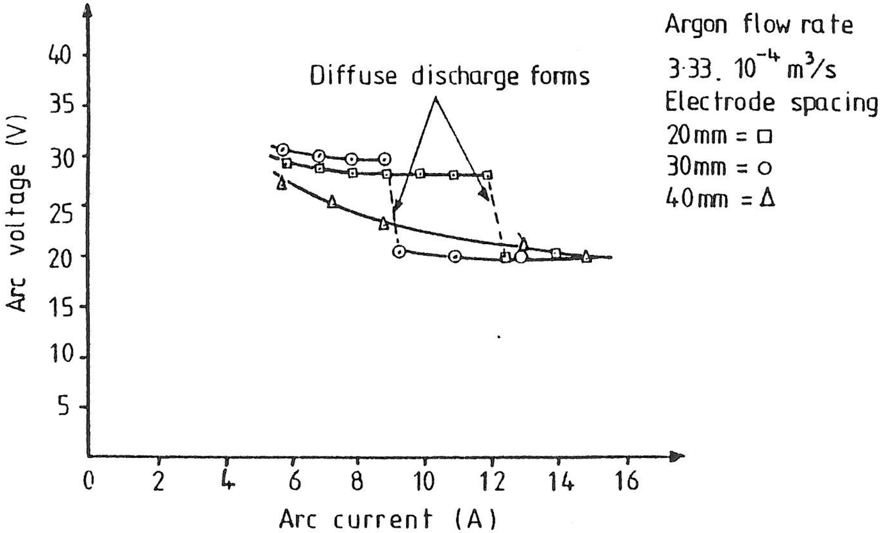


(b)

Fig. 3. Variation of the voltage & current characteristic of the vertical multiple arc discharge with
(a) Argon flow rate. (b) Electrode spacing.



(a)



(b)

Fig. 4. Variation of characteristic of vertical multiple arc system in the presence of r.f. power
(a) Argon flow rate. (b) Electrode spacing.