AN EXPERIMENTAL ASSESSMENT OF GLASS-BEAD DISCHARGE OZONISERS

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Abstract

The use of a novel dielectric barrier discharge configuration for the production of ozone, in which the discharge space is packed with glass spheres, has been assessed. The dependence of ozone production, ozone concentration and energy efficiency on parameters such as discharge gap width, glass sphere size and gas flow rate and composition has been measured. It was found that energy-efficient ozone production is possible using the glass-bead ozoniser. However, owing to the fact that the glass spheres occupy a significant fraction of the discharge volume, the residence time of the gas for a given air flow rate was much smaller than for a conventional ozoniser. This meant that the ozone production was somewhat smaller for the glass-bead ozoniser than for a conventional ozoniser, particularly at higher voltages.

1. Introduction

Ozone is a potent germicide, and a very strong oxidising agent. It is widely used for the disinfection and purification of drinking water. Other major applications include the treatment of waste water, swimming pools, cooling water circuits and industrial wastes, and as a bleaching agent in the pulp and paper industry.

Ozonisers based on the dielectric-barrier discharge have been used industrially to produce ozone for almost a century. In general, such ozonisers are constructed of two concentric metal tubes, with an intervening dielectric tube and air gap. An ac voltage is applied across the metal tubes. Air or oxygen is passed through the air gap, where some of the oxygen molecules are transformed into ozone by the reactions $O_2 + e^- \rightarrow O + O + e^-$ and $O_2 + O + M \rightarrow O_3 + M$.

We have altered the geometry of the conventional discharge ozoniser by filling the air gap with glass spheres. Similar geometries, with ferroelectric rather than glass spheres being used, have been tested elsewhere for other applications, such as the removal of volatile organic compounds \cite{1, 2}. In the ozoniser, the glass spheres are expected to lower the breakdown voltage by increasing the electric field strength, and to provide a path for the conduction of heat away from the discharge. The latter factor in particular is advantageous for ozone production, which is favoured by low temperatures.
A previous study [3] examined the properties of dc discharges in discs formed by the fusing of glass spheres. In this paper, we consider ac discharges, and concentrate on apparatus containing loose rather than fused spheres.

2. Technical details

The ozoniser is similar in design to the discharge apparatus used by Ogata et al. [2]. A schematic diagram of the ozoniser is given in Figure 1. The high-voltage central electrode is a stainless steel rod. The dielectric spheres, which are composed of soda lime glass, are confined between this central rod electrode and a glass tube of inner radius 50 mm and thickness 2.2 mm. An earthed copper mesh, which is wrapped around the glass tube, is used as the second electrode. A teflon disc is used to confine the glass spheres at each end of the ozoniser. The disc is perforated by 1 mm diameter holes to allow gas flow into the discharge space. The gas flows through a cavity in the end of the central electrode, then into an air space defined by the electrode, the teflon disc, and a teflon end cap, and finally through the disc into the glass-sphere filled discharge space.

Unless otherwise mentioned, the length of the discharge region, defined by the length of the outer mesh electrode, was 500 mm. To avoid arcing along the external surface of the ozoniser, approximately 50 mm clearance was left between the ends of the mesh electrode and the teflon end caps.

![Schematic diagram of the glass-bead ozoniser.](image)

**Figure 1.** Schematic diagram of the glass-bead ozoniser.

The ozoniser was excited by a 50 Hz sine wave supplied by an oil-filled transformer driven by the output from an autotransformer. All voltages quoted are rms values. The gas used was bottled air or oxygen, with a dew point below -40°C. The ozone concentration in the gas leaving the ozoniser was measured by a PC Wedeco Ozone Monitor, which uses the ultraviolet absorption technique. Power consumption in the ozoniser was measured by determining the area of the charge–voltage Lissajous figure, as described by Kogelschatz [4].
3. Results and discussion

Three parameters are generally used to describe the performance of an ozoniser. The first two, ozone concentration and ozone production rate, are important in all applications. The ozone concentration has to be above a threshold level, typically of the order of 1% by volume in water purification applications, to ensure adequate performance. The requirements for ozone production rate, which is proportional to the product of the ozone concentration and the gas flow rate, are also determined by the application. For water purification applications, an ozone production rate of the order of 1 g h\(^{-1}\) is required for small-scale applications, increasing to kgh\(^{-1}\) for larger scale applications. For a given ozoniser design, ozone concentration and production rate can be increased by increasing the length of the active region, and production rate may be further increased by connecting ozonisers in parallel.

The third parameter, the energy efficiency of production, is only of major significance in large installations, since the power requirements of small (< 10 g h\(^{-1}\)) ozonisers are of the order of an electric light bulb. Typical energy efficiencies are around 50 g(kWh)\(^{-1}\).

The ozone concentration, ozone production rate and energy efficiency of glass-bead ozonisers were measured for a range of parameters. Two distinct types of discharge were observed, depending on the relative size of the interelectrode gap and the glass spheres. When the interelectrode gap was more than about twice the sphere diameter, discharges of filamentary character were visible in the active region. These filaments had the appearance of small-scale lightning discharges, and were visible both amongst the spheres, and between the spheres and the glass tube. The individual filaments had lengths of several centimetres, and were crooked, presumably because the filaments deviated around the glass spheres. When, in contrast, the interelectrode gap was less than twice the sphere diameter, the discharge had the appearance of an even glow, with no filaments visible.

Figure 2 shows the ozone concentration and production rate for a discharge with 5 mm glass spheres and interelectrode gaps of 7 and 10 mm. In the 7 mm gap case, the discharge had the appearance of a glow, and in the 10 mm gap case, strong filamentary activity was apparent. The ozone production was significantly greater in the case of the smaller gap, despite the significantly lower residence time for a given gas flow rate. The ozone concentration was larger for lower gas flow rates, but the production was greater for intermediate gas flow rates. The energy efficiency of the ozonisers was between 50 and 60 g(kWh)\(^{-1}\) for the 7 mm gap, and between 40 and 50 g(kWh)\(^{-1}\) for the 10 mm gap.

Using oxygen rather than air as the discharge gas increased ozone concentration and production rate by a factor of 3.5 to 4.0 for the range of conditions of Figure 2. The energy efficiency was increased by a factor of about 3. These increases are somewhat larger than those found in conventional ozoniser designs [4].

Figure 3 shows results for an ozoniser in which the interelectrode gap was narrowed to 4 mm. The glass sphere diameter was reduced to 3 mm at the same time. The ozone production was improved at voltages below 15 kV, with the improvement being larger at lower voltages. This is consistent with the lower breakdown voltage, corresponding to the narrower gap. The energy efficiency was between 60 and 70 g(kWh)\(^{-1}\), that is, about 10 g(kWh)\(^{-1}\) larger than for the 7 mm interelectrode gap.
Figure 2. Ozone concentration and production for ozoniser of active length 500 mm filled with 5 mm diameter glass spheres, for different interelectrode gaps and air flow rates.

Figure 3 also illustrates the effect of replacing the glass spheres with conducting spheres. For this purpose, 3 mm lead spheres were used, with the interelectrode gap maintained at 4 mm. It can be seen that the breakdown voltage is greatly reduced, and that the metal spheres give greater ozone production than glass spheres for voltages below 10 kV. For higher voltages, the glass spheres give superior results.

The metal spheres act as an extension to the inner electrode, and hence the effective gap between the inner electrode and the glass tube varies between zero and the radius of the spheres. The lower breakdown voltage is a consequence of this smaller gap. However, the discharge activity is confined to the relatively small region between the edge of the spheres and the glass tube, and the ozone produced in this region is diluted by the air flowing between the spheres.

The performance of the glass-bead ozonisers was also compared to that of a conventional ozoniser, which was obtained simply by removing all spheres from the interelectrode gap. As shown in Figure 3, the conventional ozoniser outperforms the glass-bead ozonisers for voltages above 11 kV. It appears that, while the presence of glass spheres leads to a decrease in the breakdown voltage, and hence to the production of more ozone at low voltages, the decrease in gas residence time associated with the presence of the spheres leads to a reduction in performance at higher voltages. The energy efficiency for the conventional ozoniser was between 60 and 70 g(kWh)^{-1}, similar to that measured for the glass sphere ozoniser with the same interelectrode gap.
Figure 3. Ozone production for an ozoniser with active region of length 500 mm for different interelectrode gaps and sphere sizes and compositions, for an air flow rate of 7.5 l. min⁻¹.

As noted in Section 1, discharges in discs of fused glass spheres were investigated by Ohsawa et al. [3]. To compare the production of ozone by loose and fused glass spheres, an annulus of fused spheres was prepared by heating 2 mm glass spheres in a specially constructed mould to a temperature close to their melting point. The annulus was inserted into an ozoniser with an interelectrode gap of 10 mm and active region of length 150 mm. Measurements were also performed for the same ozoniser filled with loose spheres of the same size. The results are compared in Figure 4.

The use of fused spheres is found to significantly decrease the ozone production. The discharge appears to be confined to the region between the edge of the fused sphere annulus and the glass tube; presumably, there is a similar discharge region between the inside of the annulus and the inner electrode. This is in accord with observations of dc excitation of fused sphere discs [3]. For loose spheres, in contrast, the discharge was observed to occupy the regions between the spheres, as well as between the spheres and the glass tube.

It was noted above that the decrease in gas residence time caused by the presence of the glass spheres negatively affected the performance of the ozoniser. One means of decreasing the volume occupied by the dielectric inserted in the interelectrode space, and thus to increase the gas residence time, is to replace the glass spheres by irregularly shaped glass pieces. This was tested by filling the shorter ozoniser, with active region of length 150 mm, with glass Raschig rings (short glass tubes) of length 6 mm and outer diameter 6 mm. For this configuration, measurements showed that the ozone concentration, for an air flow rate of 1.5 l. min⁻¹ and voltage of 14 kV, was 0.047% by volume, compared to 0.065% for loose glass spheres of diameter 2 mm under the same conditions. Further, the discharge was strongly filamentary in appearance. This is associated with the higher electric fields caused by the sharper edges of the Raschig rings.
Figure 4. Ozone concentration produced by ozoniser with active region of length 150 mm with a 10 mm interelectrode gap filled with fused or loose 2 mm glass spheres, for different air flow rates.

4. Conclusions

We have investigated the performance of ozonisers in which the interelectrode space is packed with glass spheres. It was found that energy-efficient ozone production was possible in such configurations. In general, ozone production and energy efficiency were improved by reducing the interelectrode gap, and increasing the diameter of the spheres relative to the gap. The presence of glass spheres reduced the breakdown voltage, and led to improved performance at lower voltages. However, at higher voltages, the ozone production was increased by removing the glass spheres. This was at least partly due to the increased gas residence time.

References


