Compact surface DBD reactor with stacked electrodes for efficient and controlled generation of ozone

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Abstract: Multiple SDBD electrode system consisting of several identical elements in the stacked configuration was designed to increase the production of ozone maintaining high O_3 production yield. Electrical characteristics and ozone production were investigated to evaluate the efficiency of ozone generation using an amplitude-modulated AC power in dry synthetic air and pure oxygen at atmospheric pressure.

Keywords: ozone, surface DBD, synthetic air, oxygen, production efficiency.

1. Introduction

Using power modulated surface dielectric barrier discharge (SDBD), we recently proved that duty cycle strongly influences ozone concentration both in synthetic air and pure oxygen, and that ozone yield is almost independent of specific energy density at a low energy density [1,2].

Most recently, we investigated the influence of duty cycle on ozone generation and discharge over a relatively wide range, in volume dielectric barrier discharge (VDBD) [3,4]. We confirmed that duty cycle variation provides a simple tool for developing an ozone generator that simultaneously delivers adjustable ozone concentration over a wide range and at nearly constant ozone yield.

However, the single SDBD electrode arrangement limits total ozone production (given by the surface covered by micro-discharges and delivered energy density), which is not of practical interest for 'medium-scale' laboratory or industrial ozone generation. In order to boost the ozone production by a factor of 10 maintaining at the same time the production yield (energy efficiency), we designed a compact reactor with multiple SDBD electrodes in stacked configuration [5].

2. Compact SDBD reactor design

A traditional SDBD (symmetric or asymmetric) electrode plates powered using amplitude-modulated AC high-voltage waveforms are employed here to develop a unique, practical ozone generator with a widely adjustable ozone concentration that simultaneously delivers ozone at nearly constant ozone yield.

The discharge exposed nickel-based electrodes were deposited either on both sides (symmetric configuration) or on one side (asymmetric configuration) of a thin alumina substrate (100 mm x 100 mm x 0.635 mm, Al_2O_3 purity of 96%, dielectric constant $\varepsilon_r = 9.6$ at 1 MHz) using the screen printing technique. The exposed nickel electrode consists of 17 interconnected parallel strips (1 mm wide, 75 mm long and separated by 3 mm) [1, 2].

In the case of asymmetric configuration, a silver-based induction electrode (74 mm x 74 mm) completely covers one surface of the alumina plate.

The reactor contains slots for positioning and powering of up 10 SDBD plate electrodes, gas-feeding distribution system assuring constant mass-flow of working gas within each section is illustrated in Figure 1. The discharge gap was fed with pure oxygen or synthetic air (99.999%; containing H_2O<2 ppm, $CO+CO_2$<0.4 ppm). The flow rate of 10 slm was fixed using a Bronkhorst HI-TEC mass-flow controller.

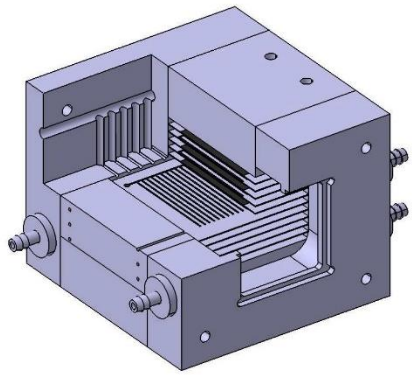

Fig. 1. Sketch of the reactor with 10 stacked SDBD plate electrodes.

Fig. 2. Photograph of the reactor with 5 stacked symmetric SDBD electrodes.

The discharge was powered by an AC, high-voltage power supply composed of a TG1010A function generator (TTi), a Powertron model 250A RF amplifier and a high-voltage step-up transformer. The applied AC, high-voltage waveforms (f_{AC}=5 kHz) were modulated by a square-wave waveform producing a T_{ON} (four AC cycles) and T_{OFF} period with a variable duty cycle $D=T_{ON}/(T_{ON}+T_{OFF})$. Figure 3 illustrates system with 5 powered symmetric SDBD electrodes producing micro-discharges on both sides of each plate

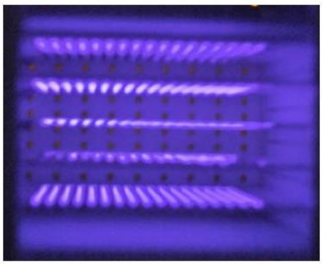

Fig. 3. Photograph of the powered reactor with 5 stacked symmetric SDBD electrodes. Micro-discharges in synthetic air (10 slm) cover both sides of each plate.

A Tektronix oscilloscope (DPD4043, 350 MHz, 2.5 GS/s) was used to record the electrical characteristics of the discharge. The discharge high-voltage waveforms were sampled using a Tektronix P6015 high-voltage probe. A Tektronix P6139A high-voltage probe was employed to monitor the voltage drop on a transferred-charge-measuring non-inductive capacitor inserted between the grounded electrode and grounding lead.

Averaged voltage–charge characteristics were analysed to determine the mean energy dissipated during the T_{ON}. Two ozone monitors, i.e. API 450 and API 450M (both Teledyne Instruments), were used in parallel to measure the ozone concentration at the reactor outlet.

3. Results

Systematic measurements of electrical characteristics of the discharge and concentrations of produced ozone were performed to evaluate the efficiency of ozone production in the reactor with 5 SBDB electrodes mounted and powered in both pure oxygen and dry synthetic air.

Figures 4 and 5 illustrate the variation in ozone concentration and ozone yield at a fixed flow rate of 10 slm as a function of the energy density in pure oxygen and synthetic air, respectively. One can see that, at given energy density, O_3 concentration/yield in oxygen is roughly two times bigger with respect to synthetic air. When the energy density increases to 10^4 Wh/l, the ozone yield reaches minimum of 50 g/kWh in air and 120 g/kWh and in oxygen. Ozone production as a function of the energy density in synthetic air and pure oxygen at a fixed flow rate of 10 slm is shown in figure 6. For a given configuration (5 stacked SDBD electrodes and 10 slm), ozone production reaches as much as 0.8 g/h and 2 g/h in air and oxygen, respectively.

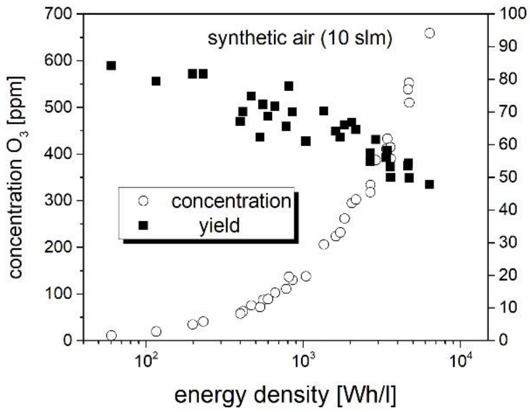

Fig. 4. Ozone concentration and yield as a function of the energy density in synthetic air at a fixed flow rate of 10 slm.

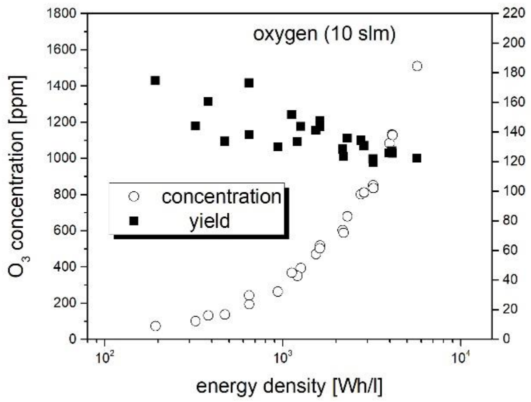

Fig. 5. Ozone concentration and yield as a function of the energy density in pure oxygen at a fixed flow rate of 10 slm.

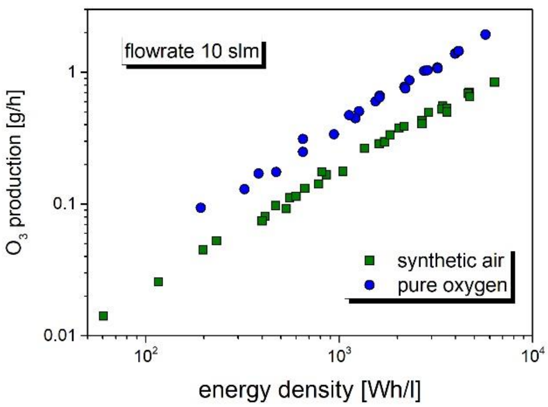

Fig. 6. Ozone production as a function of the energy density in synthetic air and pure oxygen at a fixed flow rate of 10 slm.

4. Conclusion

We extended our previous study of ozone production efficiency by the air/oxygen-fed SDBD to the production efficiency of ozone using compact reactor containing 5 SBDB electrodes in the stacked configuration. Energy efficiency of such a modular arrangement powered by the amplitude-modulated AC is fully compatible with that of the single SDBD electrode.

Considering a full potential of this design (i.e. up to 10 stacked symmetric/asymmetric SDBD electrodes and a maximum flow rate of 50 slm), this compact solution provides a very robust and stable source of ozone 'on-demand' with production rate of up 5 g/h in oxygen and 2 g/h in dry air. The O_3 production yield between 120-180 g/kWh and 50-80 g/kWh in dry air is achieved with no external cooling. An alternative use of this concept might be in the area of decomposition/conversion/reduction of low-level harmful air pollutants, such as emissions of volatile organic compounds from small industrial facilities.

Acknowledgement

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5. References

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