Lightweight ozonizer for field and airborne use

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An efficient, lightweight apparatus for the production of ozone in flowing oxygen or air has been constructed and tested. The exciter is an automotive electronic ignition running from a 28-V dc power source. The discharge tube consists of coaxial conductive-coated flint glass tubing fitting into Teflon end pieces. A single such unit will produce 4% ozone in oxygen flowing at 0.2 l/min, or a maximum of 0.020 l of ozone per minute in a total flow of 1.0 l/min.

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INTRODUCTION

Ozone gas is in common use in atmospheric science as the reagent in chemiluminescent detectors of trace quantities of nitric oxide.[1-3] Because ozone is dangerous in high concentrations and difficult to store in any concentration under field conditions, one generally wishes to generate it close to the time and place of use. Thus there is a need for a convenient source of ozone in both the laboratory and the field.

One example of such a need in the authors' work is for a means of filling a reservoir of ozone in a rocket payload prior to launch. This source must be easily transported and produce a predictable, high (5%) concentration of ozone for several days at least.

Another example is the need for an on-line source of ozone in balloon and aircraft payloads. These sources must be as light, compact, and energy efficient as possible, and run from a dc power source. This application typically requires a source which maximizes the total production of ozone as well as its concentration.

Ozonizers with which we have had experience have had the disadvantages of large weight, high-energy consumption, relatively low yield, and yield degrading with time. The object of the work reported here has been to eliminate these disadvantages.

We describe below a simple design for an ozonizer discharge tube, with an exciting circuit based on an automotive ignition system. The system is lightweight, energy efficient, compact, and has a high stable ozone production rate.

I. CONSTRUCTION

A. Discharge tube

The ozonizer tube consists of two concentric pieces of flint glass tubing, centered and spaced by Teflon end plugs, and sealed with Viton O rings. A diagram of this arrangement is shown in Fig. 1. The innermost and outermost glass surfaces are coated with silver or with copper paint for electrical conductivity. Flowing dry oxygen or air passes between the two tubes.

The tubing is Kimble S-40140-V (20 mm outer diameter, 1.40 mm wall) and S-40140-AA (25 mm outer diameter, 1.45 mm wall), available from Sargent Welch. The air gap is thus about 1.0 mm. The length of the coated portion of the tube is 20 cm. The dimensions of the Teflon end plugs should be determined from the actual dimensions of the glass after it has been received, as there is some variation from batch to batch.

Previous experience with borosilicate (Pyrex) glass in this application was that the ozone yield decreased with time, often being reduced by a factor of four in a few hours. The tubes could be rejuvenated by careful cleaning. A white thin coating was often observed on "dirty" tubes. Apparently the difference in performance is due to the difference in composition of the glass.

B. Exciter

The high-voltage transformer for the exciter was a General Motors high-energy ignition spark coil (part no. DR-184) driven by the corresponding high-energy ignition "module" (part no. D1906). This module is a fast solid-state switch, controlled by a small (0–2 V) input signal. The module in turn controls the spark coil primary current, switching up to 32 V and self-limiting at 6 A. We drove the coil with a 28 V dc, 6 A supply to simulate the power available in a research aircraft. A simple square-wave generator for the control input was made from a pair of NE555 timing circuits, the first to control frequency and the second to control duty factor. A diagram of the exciting circuit is shown in Fig. 2.

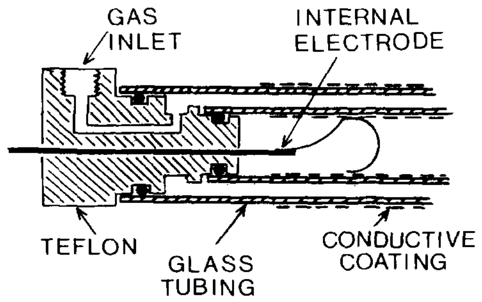

FIG. 1. Sectional view of one end of the ozonizer tube. The tubing outside diameters are 20 and 25 mm. The air gap is about 1 mm.

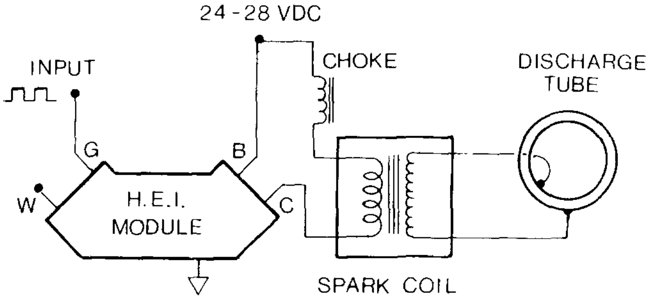

FIG. 2. Circuit diagram of the ozonizer exciter. The letters on the module connections refer to labeled terminals on the module.

C. Engineering parameters

Three ozonizer units based on the automotive exciter have been built in our lab. The first of these is the prototype, with components simply mounted on a plywood board. The second is a small, efficient dc-driven unit intended for incorporation into airborne apparatus. It requires a supply of 6 A at 24–28 V dc, and has an average power consumption of about 80 W. Its outside dimensions are 5.5 × 7 × 11 in., and it weighs 11 lbs.

The third unit is a rack-mounting version which contains its own dc power supply and operates from the commercial 120 V ac supply, requiring less than 200 W. It is 19 × 7 × 12 in., and weighs 30 lbs.

II. RESULTS

The data given in this section were obtained with the prototype ozonizer, but the performance of the other two units is similar. The production of ozone as a function of flow rate of the oxygen supply is shown in Fig. 3. The ozone production is 3.8% at a total gas flow rate of 250 standard cubic centimeters per minute (sccm) or about 9 sccm of ozone.

Ozone production as a function of time (at a total gas flow of 250 sccm) is shown in Fig. 4. Except for an initial decrease following turn on, production remained constant at 3.8% during a test period of 4 days.

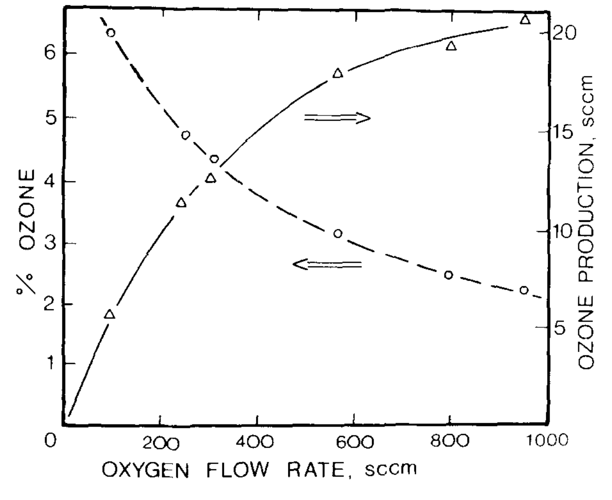

FIG. 3. Ozone yield as a function of the delivery rate of dry oxygen, at atmospheric pressure.

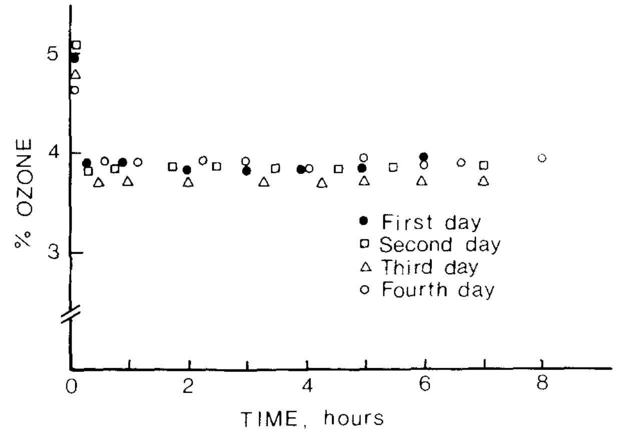

FIG. 4. Ozone yield over a 4-day test period, showing no loss in efficiency.

The relation between ozone yield and voltage applied the coil primary is shown in Fig. 5. The relationship appears to be linear, with an intercept on the voltage axis. We also used this discharge tube with a commercial neon sign high-voltage transformer, operating from a 60-Hz sinusoidal voltage, and found that a similar linear relationship applies (Fig. 6).

We found no increase in ozone yield with increase in tube length, using the automotive exciter. We also found only a slight improvement in ozone production from operating two ozonizer tubes in parallel from a single exciter. It appears from these results that energy from the exciter is coupled into the gas quite efficiently, and that the limitation is in available energy.

The ozone yield as a function of excitation frequency shows two nearly equal maxima, one near 330 Hz, and one near 3500 Hz. At 300 Hz the module behaves as

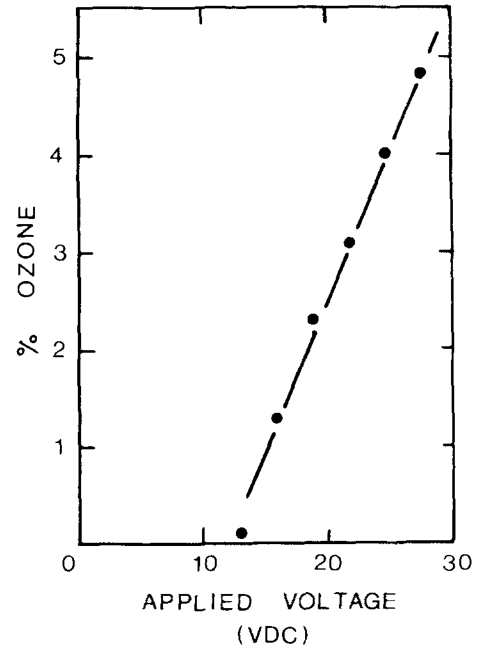

FIG. 5. Ozone yield as a function of the dc supply voltage to the coil, in dry oxygen, at a flow rate of 0.25 l/min, with excitation from the automotive module and coil.

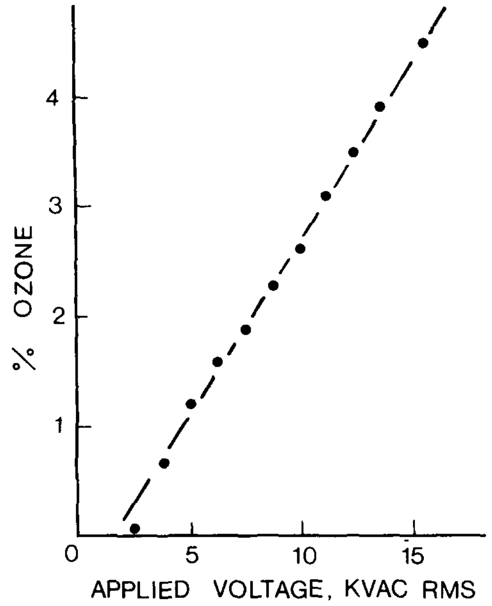

FIG. 6. Ozone yield as a function of applied ac voltage from a neon sign transformer, in dry oxygen at 0.25 l/min.

intended in the automotive ignition system. At the higher frequency it operates in quite a different mode, which we do not understand. Nonetheless, it works. Ozone production was highest for duty factors of the square-wave input of 50%–70% "high".

One disadvantage of the exciter is that the coil "sings" at these frequencies, making it desirable to enclose the instrument in a box with sound-absorbing material. The box has metal walls for rf shielding, and contains a fan to keep temperatures close to ambient, since ozone production degrades at elevated temperatures.

III. DISCUSSION

Our result, that ozone yield is linear in the peak applied voltage conflicts with that of Rosen,[4] who found that ozone yield varies as the square of the applied voltage. An analysis by Lowther[5,6] of the physical relationships in the discharge gives the following expression for the power expended (and hence ozone formed):

$$P = 4Afe_0(e/d)V_s(V_0 - V_s(eg + d)/eg), \qquad (1)$$

where P is the power expended, A is the surface area of the discharge, f is the frequency of the applied voltage, e_0 is the permittivity of vacuum, e and d are the dielectric constant and thickness of the dielectric, g is the thickness of the air gap, V_0 is the peak applied ac voltage, and V_s is the breakdown potential in the gap. That is, power is a linear function of peak applied voltage. However, if we differentiate Eq. (1) with respect to V_s, we find an optimal value of V_s at which P is a maximum, given by

$$V_s = 0.5V_0eg/(eg + d). \qquad (2)$$

Substituting this value into Eq. (1) gives

$$P = AFe_0(e/d)(eg/(eg + d))V_0^2,$$

which is apparently the relationship quoted by Rosen. It is important to note, however, that the quadratic relationship applies only when the air gap or gas pressure is continuously adjusted for the optimal value of V_s. In the more practical case, where V_0 alone is varied, the linear relationship (1) applies.

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[6] J. J. Carlins and R. Clark, "Ozone Generation by Corona Discharge," in *Ozone Technology and its Applications*, edited by R. Rice, Vol. 1, (Ann Arbor Science Publishers, Ann Arbor, Mich., 1982).