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Development of ozone concentration meter based on corona discharge

Presented by Academician of the NAS of Ukraine I.E. Garkusha

An ozone concentration measuring device based on the Paschen curve shift in a corona discharge gap has been developed. The device enables measurement of ozone concentrations in the range of 1 to 40 mg/l. The cyclic measurement time ranges from 1 to 10 minutes. Current-voltage characteristics of a coaxial discharge tube with a thin anode (platinum wire) were measured at atmospheric pressure. A PIC18F2550 microcontroller-based controller manufactured by Microchip Technology Inc. controls the ozone meter. This novel device can be used to measure the concentration of any gas in air, provided it is properly calibrated.

Keywords: *ozone concentration meter, Paschen curve, microprocessor, corona discharge.*

Introduction. Ozone meters and monitoring systems are widely used in various fileds, ranging from industrial hygiene to virus disinfection and sterilization [1, 2]. As the scope of ozone applications expands, there is growing demand for accurate, low-cost ozone monitoring systems. Ozone meters operate based on chemical, physicochemical, and physical principles [3—5].

Among physical methods, the most widely used is optical absorption analysis, based on the absorption of radiation by ozone in specific regions of the electromagnetic spectrum (UV, visible, and infrared regions) [5]. The instrument measures the difference in the intensity of ultraviolet radiation passing through the analyzed and reference gas mixtures.

Many companies manufacture devices for measuring and monitoring ozone concentrations that approach or exceed the maximum permissible concentration (MPC) level. Portable ozone meters based on ultraviolet absorption at a wavelength of 254 nm and semiconductor ozone sensors have been developed at the Institute of Plasma Physics, KIPT [6]. The device utilizes an MQ-131 semiconductor ozone sensor.

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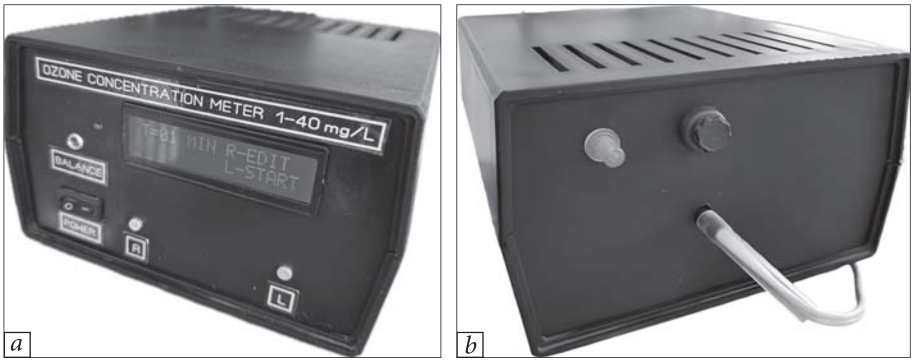


Fig. 1. General view of ozone concentration meter: *a* — front panel; *b* — rear panel

Acoustic meters determine gas concentration based on its specific weight and can be used to monitor ozone concentration. An acoustic ozone meter has also been developed to measure ozone concentration at the outlet of compressor-type ozonators [7]. Ozone concentration is measured based on the dependence of sound propagation speed on the density of the gas medium [8].

The most common portable measuring devices available on the market still operate on the principle of ozone absorption of ultraviolet radiation. Given the high cost of these devices (up to $4,000), there is a need to develop low-cost measuring devices and ozone concentration meters. The determination of ozone gas remains a challenge for modern analytical chemistry due to its wide concentration range (low ppb to low ppm), short-term fluctuations, and high reactivity.

Research objective. This paper presents the results of the development and investigation of an ozone concentration meter that utilizes the Paschen curve shift effect in the discharge gap as a function of gas composition.

Experimental Setup. The developed meter (Fig. 1) operates in the 1—40 mg/l measurement range with an accuracy of no more than 4 %. The device uses a two-channel differential measurement circuit with a cyclic measurement mode of 1 to 10 min. Control is performed in dialog mode using (L) and (R) buttons.

Main technical characteristics of the ozone concentration meter:

Measurement range	1—40 mg/l
Accuracy	No more than 4 %
Power supply	AC 220 V ±15 %, consumption < 7 W
Warm-up time	5 min
Dimensions	170 × 140 × 95 mm
Weight	1.2 kg
Measurement mode	Single and cyclic (1—10 min intervals)
Controller	PIC18F2550, Microchip Technology Inc.
Anode material	Platinum wire, Ø 0.1 mm
CMRR	~80 dB

Results and discussion. The meter operates according to the following algorithm. Measurement occurs in two 2-second cycles.

Operating principle. The block diagram of the meter is illustrated in Fig. 2.

Step 1. Valve *7* opens, and pump *4* sequentially passes the ozone-air mixture through chamber *1*, then chamber *2*, through the pump, and to the outlet. After 2 s, the pump shuts off and the high-voltage power supply turns on.

When the threshold voltage is reached, the comparator triggers, and the currents from the measuring tubes pass through the differential current amplifier, generating an equivalent voltage at the microprocessor's input, which is then recorded.

Step 2. Valve *7* closes, and valve *6* opens. The process proceeds similarly to Step 1. However, the microprocessor now records two measurements: one with ozone and one without. The difference between these readings, multiplied by a calibration coefficient, determines the ozone concentration value.

The entire process takes 5 s. The use of a differential current amplifier maximally suppresses all interference parameters as common-mode noise, isolating and amplifying only the difference (differential potential). Common-mode signal is suppressed by approximately 80 dB (Fig. 3).

Discharge tube geometry and materials. The geometry of the discharge tube, as well as the materials used to construct the anode and cathode, influence the concentration monitoring process in highly aggressive ozone environments. To maximize electric field strength, the anode thickness and oxidation must be minimized. For this purpose, a thin platinum wire with a diameter of 0.076 mm was used as the anode material.

Current-voltage characteristics. Current-voltage (I-V) characteristics were measured for a coaxial discharge tube with a thin anode at atmospheric pressure. The discharge I-V characteristics exhibit distinct regions with different properties (Fig. 4, 5). These processes can be described using Paschen's law.

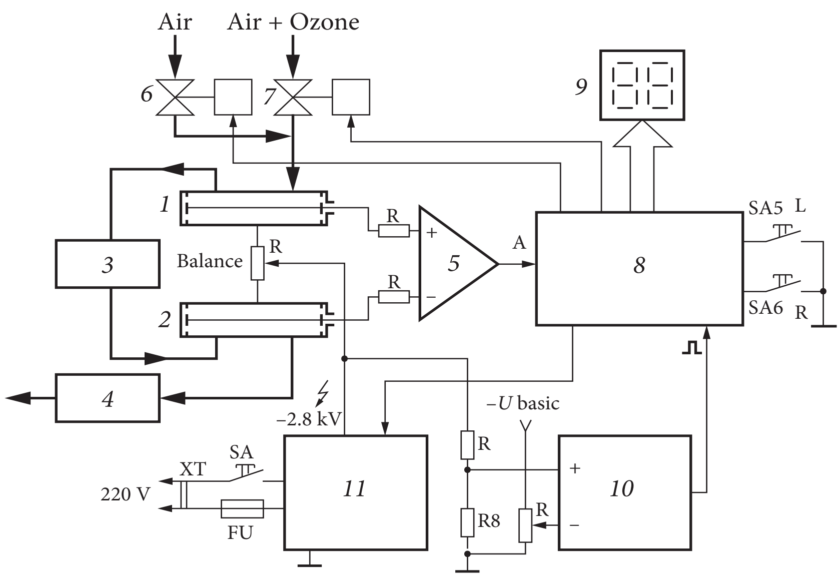


Fig. 2. Block diagram of an ozone concentration meter with a corona discharge sensor: *1*, *2* — coaxial gas discharge tubes; *3* — destructor; *4* — pump; *5* — differential current amplifier; *6* — air valve; *7* — valve for ozone-air mixture; *8* — microprocessor unit; *9* — LED indicator; *10* — comparator; *11* — power supply

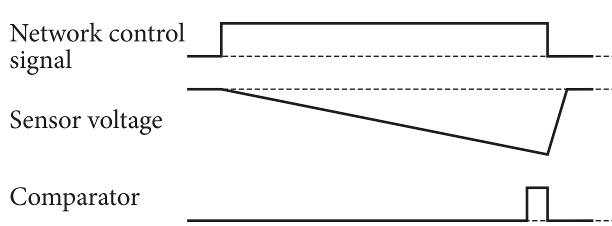


Fig. 3. Plots of voltage signals

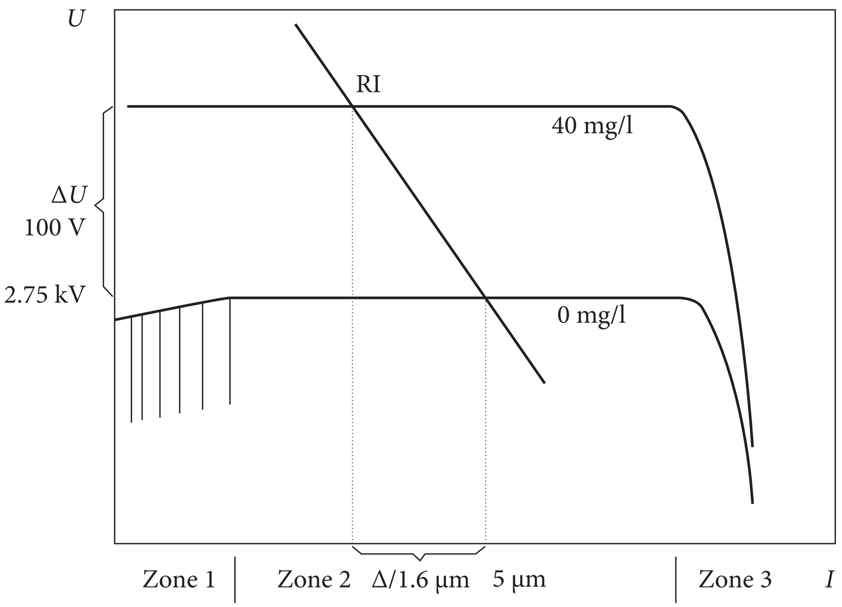


Fig. 4. Current-voltage characteristics of the glow discharge on ozone concentration in the air (the straight line represents a direct load)

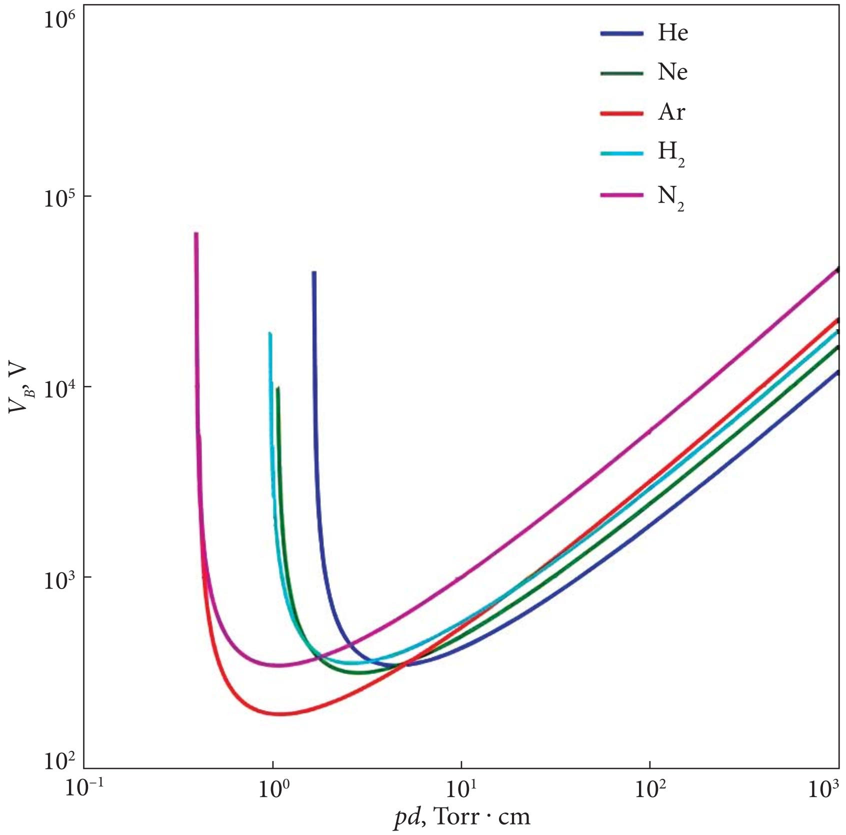
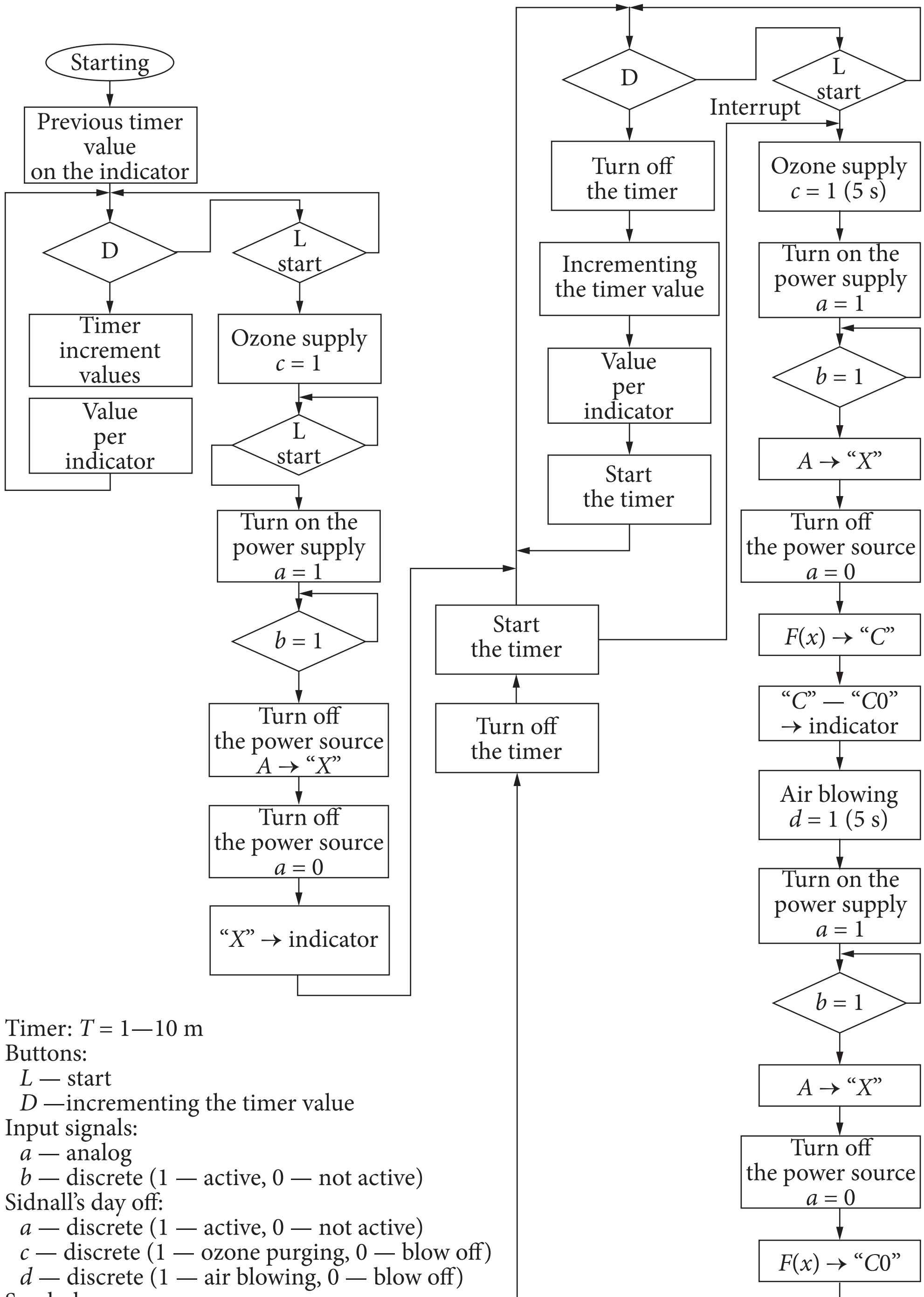


Fig. 5. Paschen curves for different gases in the discharge chamber



Timer: T = 1—10 m
Buttons:
L — start
D —incrementing the timer value
Input signals:
a — analog
b — discrete (1 — active, 0 — not active)
Sidnall’s day off:
a — discrete (1 — active, 0 — not active)
c — discrete (1 — ozone purging, 0 — blow off)
d — discrete (1 — air blowing, 0 — blow off)
Symbols:
“*X*” — argument
“*C*” — ozone concentration value (mg/l)

Fig. 6. Program algorithm of microprocessor operation

The Paschen curve graphically represents the dependence of breakdown voltage on the product of gas pressure and electrode spacing. The breakdown voltage is described by the equation:

$$V_B = \frac{Bpd}{\ln(Apd) - \ln\left[\ln\left(1 + \frac{1}{\gamma_{SE}}\right)\right]},$$

where V_B is the breakdown voltage (V); p is the pressure (Pa); d is the gap distance (m); γ_{SE} is the secondary-electron-emission coefficient. Constants A and B are determined experimentally and are roughly constant over a restricted range of E/p for any given gas.

Discharge Zones. The discharge at atmospheric pressure was investigated. Each zone within the given gas volume in the coaxial tube exhibits its own characteristics. According to the I-V characteristics, the discharge in the chamber has three characteristic zones (see Fig. 4).

Zone 1 — auto-relaxation region. Short breakdown pulses occur at low current. For different gases, these pulses exhibit distinct breakdown voltages at atmospheric pressure.

Zone 2 — stabilization regime (plateau). A low-current glow discharge occurs, and the cathode spot ignites. The stabilizing voltage U_{st} depends on electrode geometry (anode and cathode diameters, as well as the length of the cathode area). This region is of particular interest because U_{st} exhibits sufficient sensitivity to the gas composition in the tube. When the ozone concentration changes from 0 to 0.8 %, U_{st} changes by up to 5 %, which is satisfactory performance for a gas analyzer.

Zone 3 — breakdown zone. Once the cathode spot glow spreads over the entire cathode area, the discharge transitions to high-current breakdown pulses.

User interface and operation. After powering on the device, a measurement without ozone can be performed first by pressing the L button. Then, if necessary, pressing the R button sets the measurement cycle interval. After that, the ozone-air mixture under test is circulated, and pressing the L button initiates the measurement cycle.

The display shows the current ozone concentration (0 to 40 mg/l), the cycle timer (1 to 10 min), and dialog information. For continuous ozone concentration monitoring, a cyclic measurement mode is provided with intervals ranging from 1 to 10 minutes. All processes are fully automated by a PIC18F2550 microcontroller-based controller (Microchip Technology Inc., USA) (Fig. 6).

Conclusion. An ozone concentration meter based on a corona discharge sensor has been developed. The meter utilizes the Paschen curve shift effect in the discharge gap as a function of gas composition. To stabilize the measurement mode against various varying parameters (temperature, humidity, pressure, etc.), a differential measurement circuit was employed using two identical coaxial tubes sequentially flushed with gas through the destructor. The coaxial discharge tube was found to be suitable for use as a gas analyzer sensor. This method can be used to measure the concentration of any gas in air, provided that proper calibration is performed.

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РОЗРОБЛЕННЯ ВИМІРЮВАЧА КОНЦЕНТРАЦІЇ ОЗОНУ НА ОСНОВІ КОРОННОГО РОЗРЯДУ

Розроблено новий пристрій для вимірювання концентрації озону, що ґрунтується на зсуві кривої Пашена в коронному розрядному проміжку. Такий пристрій дає змогу вимірювати концентрацію озону в діапазоні від 1 до 40 мг/л. Час циклічного виміру становить від 1 до 10 хв. Вольтамперні характеристики визначено для коаксіальної розрядної трубки з тонким анодом (платиновий дріт) за атмосферного тиску. Контролер на базі мікропроцесора PIC18F2550 виробництва Microchip Technology Inc. керує озонометром. Цей пристрій можна використовувати для вимірювання концентрації будь-якого газу в повітрі за умови правильного калібрування.

Ключові слова: *вимірювач концентрації озону, крива Пашена, мікропроцесор, коронний розряд.*