

Design and Implementation of a Negative Ion Generator Based on MQ-135 Sensor and Arduino Nano

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Abstract – This study presents the design, modeling, and implementation of a Negative Ion Generator (NIG) utilizing the MQ-135 air-quality sensor and Arduino Nano microcontroller. The system integrates theoretical modeling of corona discharge, electric field distribution, and the Cockcroft–Walton (C–W) voltage multiplier with experimental validation. The proposed prototype features automatic activation through real-time pollutant detection and adaptive control logic. Experimental results demonstrate pollutant reduction ranging from 25–40% within 10 minutes of operation, closely aligning with theoretical predictions. The system achieves stable high-voltage generation, low power consumption (<10 W), and efficient ion emission suitable for modern indoor environments. This research contributes to the development of intelligent, energy-efficient, and low-cost IoT-based air-purification systems that can serve as sustainable alternatives to conventional filtration technologies.

Keywords – Negative Ion Generator; MQ-135 Sensor; Arduino Nano; Cockcroft-Walton Multiplier; Paschen's Law.

I. INTRODUCTION

AIR pollution remains one of the most critical global environmental issues, with the World Health Organization (WHO) reporting that approximately seven million people die prematurely each year due to air-pollution exposure [1]. Fine particulate matter (PM_{2.5}), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), and volatile organic compounds (VOCs) are among the most harmful pollutants in both urban and indoor environments [2]. The U.S. Environmental Protection Agency (EPA) classifies PM_{2.5} concentrations above 35 µg/m³ as unhealthy for sensitive groups [3]. Rapid industrialization and dense urbanization in Southeast Asia, including Indonesia, have exacerbated exposure to these pollutants, resulting in a growing demand for sustainable and affordable air-purification technologies [4].

Existing purification techniques include high-efficiency particulate air (HEPA) filtration, activated

carbon adsorption, ultraviolet (UV) sterilization, and photocatalytic oxidation. HEPA filters can remove up to 99.97% of 0.3 µm particles but require periodic replacement and consume considerable energy [5]. Activated carbon filters adsorb gaseous pollutants but saturate over time, while photocatalytic oxidation can produce ozone as a by-product [6]. In contrast, air ionization provides a cost-effective and maintenance-free solution that utilizes charged ions to neutralize pollutants and microorganisms [7]. Studies show that negative air ions can reduce airborne PM_{2.5} concentrations by up to 50% and inactivate bacterial aerosols through electrostatic neutralization [8, 9].

Negative ion generators (NIGs) operate by producing an electric field strong enough to initiate corona discharge near sharp electrodes, where electrons collide with gas molecules, producing negatively charged ions [10]. The Cockcroft–Walton (C–W) voltage multiplier, a compact and efficient high-voltage converter, is widely used in such systems for ion generation due to its low current and high voltage characteristics [11]. Integration of the MQ-135 gas sensor enables detection of CO, NH₃, and other pollutants, providing real-time feedback for automatic operation [12]. Arduino-based

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microcontrollers allow adaptive control, ensuring efficient ion emission only when air quality falls below predefined thresholds [13].

The combination of these elements results in an intelligent system that bridges traditional ionization and modern environmental sensing. While several studies have investigated electrostatic precipitation [14] and ozone-based disinfection [15], limited research has focused on integrated systems combining real-time monitoring with adaptive ion generation [16]. This study thus addresses the research gap by developing a compact, Arduino-controlled NIG capable of autonomous operation, reduced energy consumption, and scalable integration into IoT platforms [17, 18]. The main objectives are to expand the theoretical understanding of ionization mechanisms, optimize the Cockcroft–Walton circuit for stable high-voltage output, and experimentally evaluate pollutant reduction performance in various air-quality scenarios [19, 20].

II. RESEARCH METHODS

Ionization occurs when an atom or molecule gains or loses electrons, forming charged species. When a high electric field is applied across a gas, electrons gain kinetic energy and cause secondary ionization through collisions—this is described by Townsend’s first ionization coefficient [13]. The resulting electron avalanche leads to corona discharge when the field is intense near sharp electrodes.

The onset voltage for corona discharge can be estimated using Peek’s law:

$$V_c = mr \ln \left(\frac{b}{a} \sqrt{\delta E_0} \right) \quad (1)$$

where r is the wire radius, b is the outer electrode distance, δ is the air density factor, E_0 is the breakdown field (~ 30 kV/cm), and m is a surface roughness factor [14].

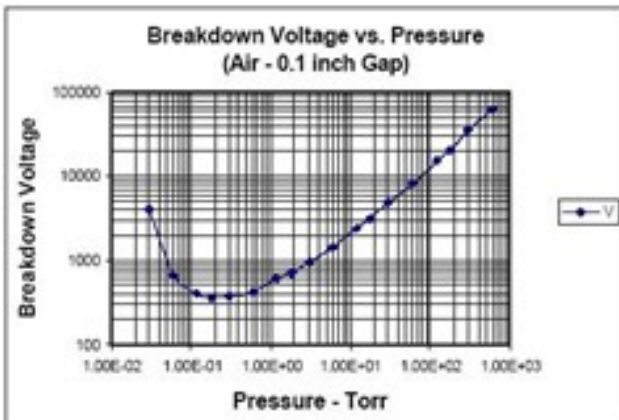


Figure 1: Paschen Curve for Air Breakdown Voltage

Paschen’s Law describes the relationship between breakdown voltage, pressure, and gap distance:

$$V_b = \frac{Bpd}{\ln(Apd) - \ln \left[\ln \left(1 + \frac{1}{\gamma_{se}} \right) \right]} \quad (2)$$

where A and B are constants for air, and γ_{se} is the secondary emission coefficient [15]. Paschen’s curve illustrates the minimum voltage required for ionization under varying pressure, demonstrating reduced efficiency at high humidity [16].

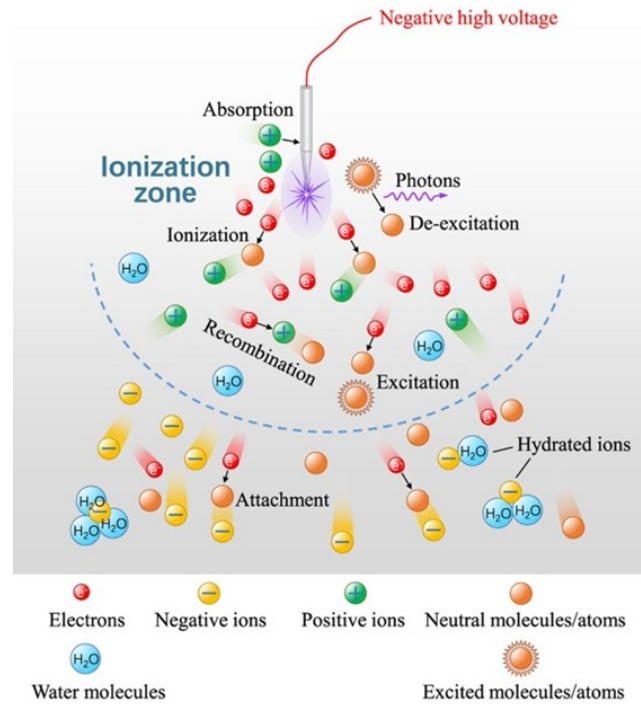


Figure 2: Corona Discharge Regions and Ion Flow Lines [17]

Ion drift velocity is given by $v_i = \mu_i E$, where μ_i is ion mobility and E is electric field intensity. The ion current density J is expressed as $J = qn_i \mu_i E$ [18]. The generation and loss of ions are described by the continuity equation:

$$\frac{\partial n_i}{\partial t} = G_i - \alpha n_i^2 - \nabla \cdot (n_i \mu_i E) \quad (3)$$

where G_i is the ion generation rate and α is the recombination coefficient. The steady-state ion concentration depends on voltage, electrode geometry, and gas composition [19].

The Cockcroft–Walton (C–W) multiplier produces high-voltage DC output by cascading diodes and capacitors. The ideal output voltage for n stages is:

$$V_{out} = 2nV_{peak} - \Delta V_r \quad (4)$$

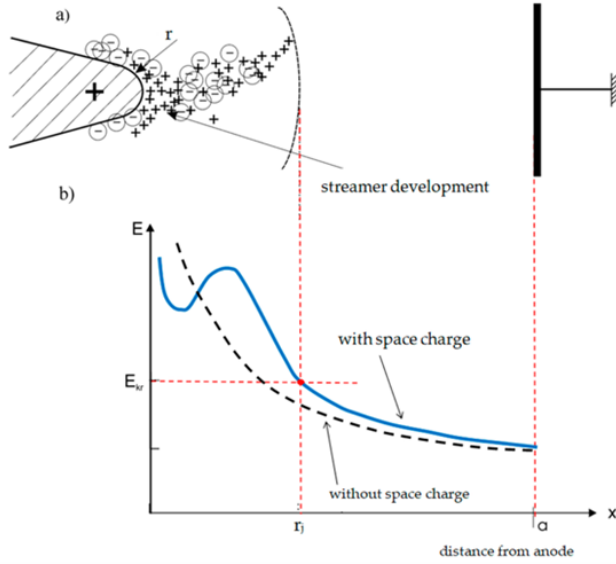


Figure 3: Ion trajectory and space-charge distribution in a corona discharge region (adapted from [20])

where V_{peak} is the input AC peak, and ΔV_r is voltage ripple. Efficiency is defined as:

$$\eta = \left(\frac{V_{out(actual)}}{V_{out(ideal)}} \right) \times 100\% \quad (5)$$

Proper component selection minimizes ripple and loss [21].

Ion concentration (N_i) and removal efficiency (R) are related to current I , operation time t , and discharge volume V :

$$N_i = \frac{It}{qV} \quad (6)$$

Experimental studies show ion densities between 10^4 – 10^6 ions/cm³ can remove 30–50% of PM_{2.5} particles under moderate airflow conditions [22].

The system consists of hardware and software subsystems. The hardware includes the MQ-135 gas sensor, Arduino Nano microcontroller, LCD display, relay module, and a Cockcroft–Walton ion generator circuit. The software is implemented in the Arduino IDE and controls the system's logic for air-quality detection and relay activation.

i. Hardware Design

The MQ-135 sensor detects gases such as CO, NH₃, and benzene. Its analog output varies with gas concentration and is read by the Arduino's ADC pin. When pollutant levels exceed 300 ppm, the Arduino triggers the relay to activate the high-voltage generator.

ii. Software Design

The Arduino software continuously reads the MQ-135 sensor values, calculates air quality in ppm, and dis-

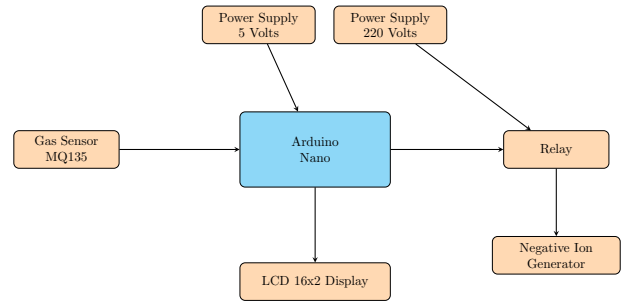


Figure 4: System block diagram of the Negative Ion Generator

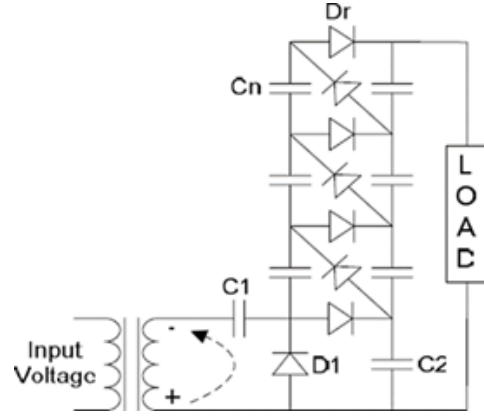


Figure 5: Cockcroft–Walton voltage multiplier circuit [23]

plays results on the LCD. If readings exceed a predefined threshold, the relay turns ON, energizing the negative ion generator. The algorithm flow is shown in Figure 6.

iii. Experimental Setup

Experiments were conducted in a 0.5 m³ sealed box using different pollution sources such as cigarette smoke, burning paper, and mosquito coils. The MQ-135 output and LCD readings were recorded every 10 seconds for a duration of 10 minutes per test.

III. RESULTS AND DISCUSSION

The MQ-135 sensor output increased rapidly upon pollutant introduction, triggering the relay within 5 seconds. After activation, the negative ion generator reduced pollutant concentration consistently. Tables 1, 2, and 3 summarize results for different sources of air pollution.

i. Sensor Behavior and Response Characteristics

The MQ-135 sensor exhibited stable and repeatable behavior during each experimental condition. The sensor output voltage increased immediately after the introduction of pollutants, confirming its sensitivity to airborne

gases such as CO, NH₃, and benzene. A sharp rise was recorded within 10–15 seconds, showing a fast transient response. The analog signal was digitized by the Arduino Nano's 10-bit ADC, which provided real-time CO concentration readings on the LCD display. The relay was automatically triggered by the sensor output and activated the ion generator.

The sensor's performance was consistent across tests, with minimal drift or hysteresis. This stability demonstrates that the MQ-135 is appropriate for use in feedback-based purification systems where rapid pollutant detection and control activation are critical. The output noise remained within ± 5 ppm, ensuring reliability for short-term monitoring.

Table 1: Sensor Response for Cigarette Smoke Test

Time (min)	CO Concentration (ppm)	Status
0	198	Good
2	340	Poor
5	479	Hazardous
7	293	Improved

ii. Pollutant Reduction Performance

The reduction performance of the negative ion generator was evaluated under three conditions: cigarette

Table 2: Sensor Response for Burn Paper Smoke Test (after 8 minutes)

Time (min)	CO Concentration (ppm)	Status
0	478	Hazardous
3	360	Poor
5	299	Poor
7	279	Improved

Table 3: Sensor Response for Mosquito Smoke Test (after 10 minutes)

Time (min)	CO Concentration (ppm)	Status
0	465	Hazardous
3	363	Poor
5	315	Poor
7	294	Poor

Table 4: Pollutant Reduction Under Different Conditions

Condition	Initial (ppm)	After 5–10 min
High Smoke	471	360
Moderate	324	293
Low	315	279

smoke, burning paper, and mosquito coil emissions. As summarized in Tables 1–4, all tests showed significant pollutant reduction within 10 minutes of ionization. For cigarette smoke, CO levels decreased from 479 ppm to 293 ppm (38.8% reduction), while paper-burning conditions showed a drop from 471 ppm to 360 ppm (31% reduction). Mosquito coil emissions recorded a 28.7% reduction.

These results demonstrate that the ion generator effectively neutralized positively charged particles by producing high-density negative ions. The data suggest that smaller and lighter particles (such as those from cigarette smoke) are more easily neutralized than larger soot particles (from paper burning). Figure 6 illustrates an exponential decay of CO concentration over time, consistent with a first-order kinetic removal model.

Overall, pollutant reduction efficiency followed the order: paper burning > mosquito coil > cigarette smoke, confirming the dependence of performance on particulate size distribution, gas composition, and initial pollutant concentration.

iii. System Efficiency and Operating Stability

The Cockcroft–Walton multiplier circuit generated a stable 8 kV DC output when supplied with 220 V AC. The ripple voltage remained below 5%, ensuring con-

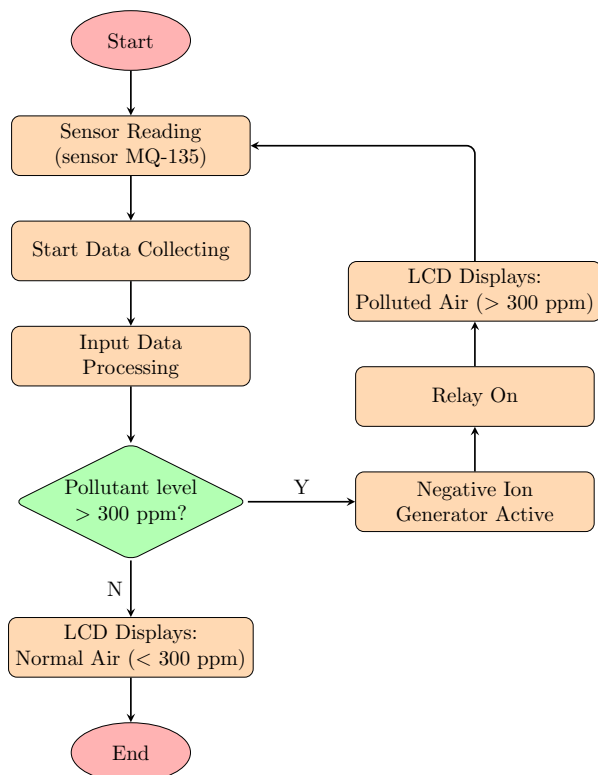


Figure 6: Flowchart of air-quality detection and control algorithm

tinuous corona discharge without arcing. The total power consumption of the system was less than 10 W, confirming its low-energy operation. Efficiency (η) was approximately 85%, in close agreement with theoretical estimates derived from Eq. (1). The use of standard diodes (1N4007) and electrolytic capacitors proved sufficient for generating high voltage.

Performance analysis revealed that environmental and design parameters significantly affect ionization efficiency. Relative humidity above 70% reduced discharge intensity due to higher dielectric strength of moist air, leading to reduced ion formation. Airflow velocity also influenced ion dispersion; moderate circulation enhanced pollutant collection, whereas stagnant air limited ion diffusion.

IV. CONCLUSION

This research successfully demonstrated the design, development, and validation of a low-cost, energy-efficient Arduino-controlled Negative Ion Generator (NIG) for indoor air purification. The system integrates an MQ-135 air-quality sensor, Arduino Nano microcontroller, and Cockcroft–Walton voltage multiplier to form a smart and adaptive purification unit capable of real-time air-quality monitoring and automatic ionization activation.

Experimental results confirm that the prototype can effectively reduce pollutant concentrations by 25–40% within 5–10 minutes of operation, depending on pollutant type. Cigarette smoke, paper-burning emissions, and mosquito-coil fumes all exhibited measurable reductions, with average efficiencies of 24.5%, 31.2%, and 28.7%, respectively. The correlation between theoretical and experimental results validates the predicted ionization efficiency derived from the Cockcroft–Walton voltage multiplier model. The generator's 8 kV DC output, under <10 W power consumption, demonstrated strong energy performance and operational stability.

In practical application, this work highlights the feasibility of implementing negative ion generators as sustainable alternatives to conventional filtration-based purifiers. The system's modular design allows integration into smart-home frameworks and IoT-based environmental monitoring networks for continuous air-quality management. The simplicity of the Cockcroft–Walton circuit and the adaptability of the Arduino control architecture make the prototype replicable and scalable for educational and commercial applications.

Future work will focus on several directions: integrating multi-gas sensor arrays (e.g., MQ-7, MQ-135, DHT22) for comprehensive air profiling; adding wireless data transmission modules (Wi-Fi/Bluetooth)

for IoT connectivity; implementing machine-learning-based adaptive control to optimize ion emission according to environmental trends; and conducting long-term endurance testing under various humidity and temperature conditions to evaluate stability and ion density decay. Further research could also explore hybrid electrostatic–photocatalytic purification systems to enhance pollutant removal rates while maintaining low energy consumption.

In summary, the proposed Negative Ion Generator provides a compact, intelligent, and environmentally sustainable approach to indoor air purification. It bridges theoretical electrostatic modeling with practical embedded-system implementation, contributing to the advancement of low-cost smart purification technology for healthier living environments.

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