

Evaluation and Effectiveness of Corona Plasma Reactor as Controlled Ammonia Levels in Open House Broiler Henhouse

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Abstract: Ammonia (NH₃) is one of the common pollutants present in broiler chicken houses and produced by the breakdown of nitrogen in chicken feces. High ammonia levels are detrimental to the air quality inside the broiler houses and may affect the health and productivity of the animals. In this experiment, the researchers sought to determine the efficiency of a corona plasma reactor in lowering the levels of ammonia inside an open-house broiler chicken house. The experiment was done in a chicken house measuring 10 meters long and 5 meters wide, wherein there are four corona plasma reactors located strategically in certain areas. Ammonia levels were determined at five different points (points A, B, C, D, and E) for 90 minutes. From the findings, the effects of varying voltage and power on plasma current were observed to increase as both parameters increased since the strength of the electric field enhanced gas ionization. The effect of varying frequency was found to result in a reduction in plasma current as the frequency increased. Ammonia testing for concentration was observed to decrease from 2,5 ppm to 0,1 ppm within 90 minutes, indicating a reduction efficiency of 96%. Based on these findings, it can be concluded that corona plasma has the capability of producing reactive species that break down NH₃ into stable molecules.

Keywords: Ammonia; Open House System; Corona Discharge Plasma; Indoor Air Quality; Reduction Concentration.

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I. INTRODUCTION

One example of a fast-growing poultry commodity is the broiler chicken because it grows quickly, matures within 32-35 days, and has an effective system of management. For this reason, broiler chicken farming can be economically profitable and market demands for this product are rising [1]. Nonetheless, the success in producing them depends on the conditions in which the broiler chickens live. Under tropical conditions such as Indonesia, the broiler chicken coop might get hot and cause the chickens to be under stress. This situation will cause them to produce ammonia gas from the breakdown of nitrogen compounds from chicken waste [2]. Ammonia (NH₃) is known as one of the main pollutants causing unpleasant odors and air pollution in poultry houses,

especially in closed house systems. In many cases, ammonia concentrations can exceed safe thresholds, posing a risk to livestock, barn workers, and the surrounding environment. This situation has encouraged the implementation of more effective air purification technologies, one of which is corona plasma technology. This technology produces Cold Atmospheric Plasma (CAP) containing high-energy electrons, free radicals, and reactive oxygen and nitrogen species such as OH, O₃, NO, and O [3]. When air containing NH₃ passes through a plasma reactor, collisions with reactive particles break the N-H bonds, forming radicals such as NH₂ and NH. These radicals then react further to form intermediate compounds such as NO and NO₂, which are then converted into more stable and environmentally safe products, such as NH₄NO₃ and H₂O. This mechanism shows that corona plasma

not only reduces ammonia concentration but also converts it into safer compounds. Previous research conducted by [3] showed that CAP can reduce ammonia concentrations by up to 91.50% in closed house systems. However, research on open house systems is still limited, even though this type of housing is more widely used and has more dynamic environmental conditions. Differences in air circulation patterns and temperature fluctuations are thought to affect the performance of corona plasma. This study aims to determine ammonia concentration as a function of time in an open house broiler chicken housing system using a corona plasma reactor. The results of this study are expected to provide scientific contributions and practical benefits in more effective and environmentally friendly air quality control for poultry houses.

II. RESEARCH METHODS

Plasma consists of positively charged ions and negatively charged free electrons. The ionization of plasma can be either weak or strong. The process of generating plasma involves Dielectric Barrier Discharge Plasma (DBDP). DBDP is a type of charge discharge with a dielectric barrier that efficiently generates ozone, contingent upon reactor type and discharge characteristics. Several factors such as energy distribution and ionization have considerable effects on the behavior of plasma in relation to the medium, hence the significance of comprehending the physical attributes of plasma in industrial uses like

sterilization and oxidation of pollutants [4]. Plasma can be produced through the application of high voltage between two electrodes, thus producing ionization and electrical currents. The stability of plasma is affected by many factors including voltage, current, distance between electrodes, and the medium. From a composition standpoint, plasma is made up of neutral atoms, ions, electrons, and photons. It maintains a net neutral charge through balancing charge distribution[5].

Corona discharge refers to an ongoing electrical discharge which takes place in the non-uniform electric field with the application of voltage less than the critical value for arc discharge. The plasma is usually created in an asymmetric electrode arrangement such as the wire cylinder and falls under CAP (cold atmospheric plasma). Once the voltage becomes greater than the corona value, ionization of the gas takes place and forms electrons, ions, and ROS/RNS [6]. The current–voltage relationship follows a quadratic pattern, where the current is proportional to the square of the difference between the operating voltage and the threshold voltage [3]. Plasma is non-thermal, thus enabling its use at ambient temperatures for air purification purposes. The NH_3 decomposition process involves dissociation using high energy electrons and oxidation with ROS/RNS to yield stable products including ammonium nitrate (NH_4NO_3) and water (H_2O). It is highly effective, generates little secondary waste, and can be used in closed air circulation systems within poultry production facilities [3].

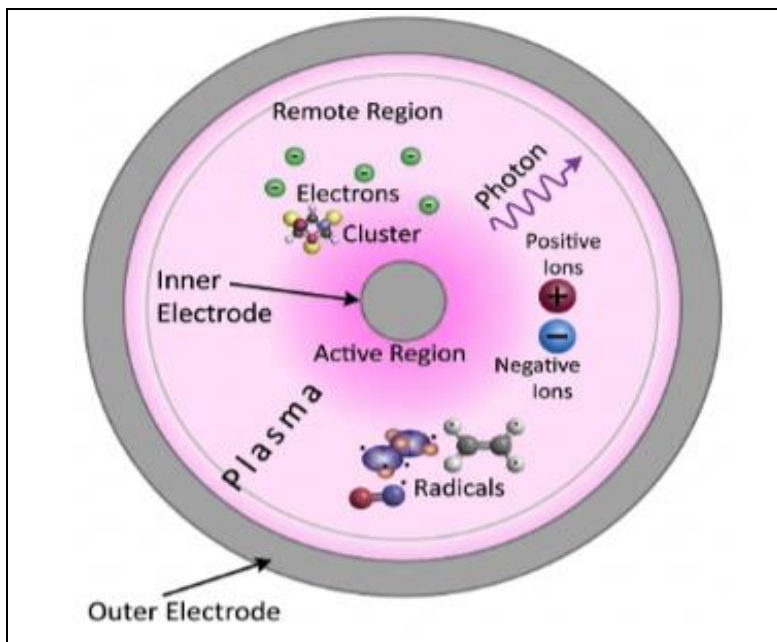


Fig 1 Illustration of Cold Atmospheric Plasma (CAP) Produced by Corona Discharge in a Wire-Cylinder Configuration.[3]

Study [3] It can be seen from that CAP is created by using a corona discharge, which uses a combination of wire-cylinder electrodes. These consist of a wire electrode as the inner one and a metal cylinder that acts as the outer electrode to which high voltages are applied. The plasma creates two areas – the active area in the vicinity of the wire as the place where ionization occurs, and the far area, where reactive

species are still present. Reactive species consist of electrons, ions, free radicals, and photons that assist in oxidizing pollutant molecules, among which ammonia (NH_3). When flowing in the plasma area, NH_3 undergoes dissociation and gets oxidized to form other molecules such as H_2O , O_2 , and NH_4NO_3 .

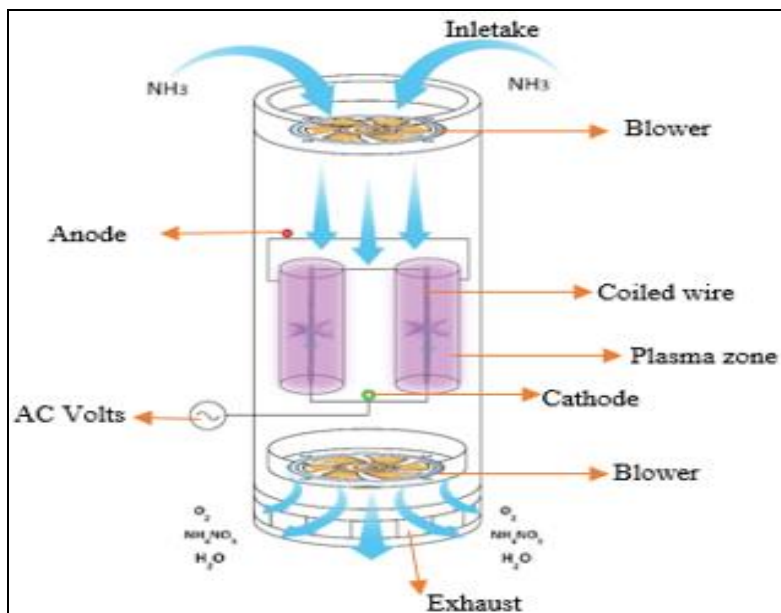


Fig 2 Corona Plasma Generator System Schematic.

The ammonia air moves into the reactor from the top using a fan. In the reactor, there is a plasma tube that is charged with electricity, creating reactive species like electrons, ions, and radicals. These reactants attack the

ammonia molecules, transforming them to a stable state like oxygen, ammonium nitrate, and water. The air is then discharged from the bottom of the reactor after being treated for ammonia removal.

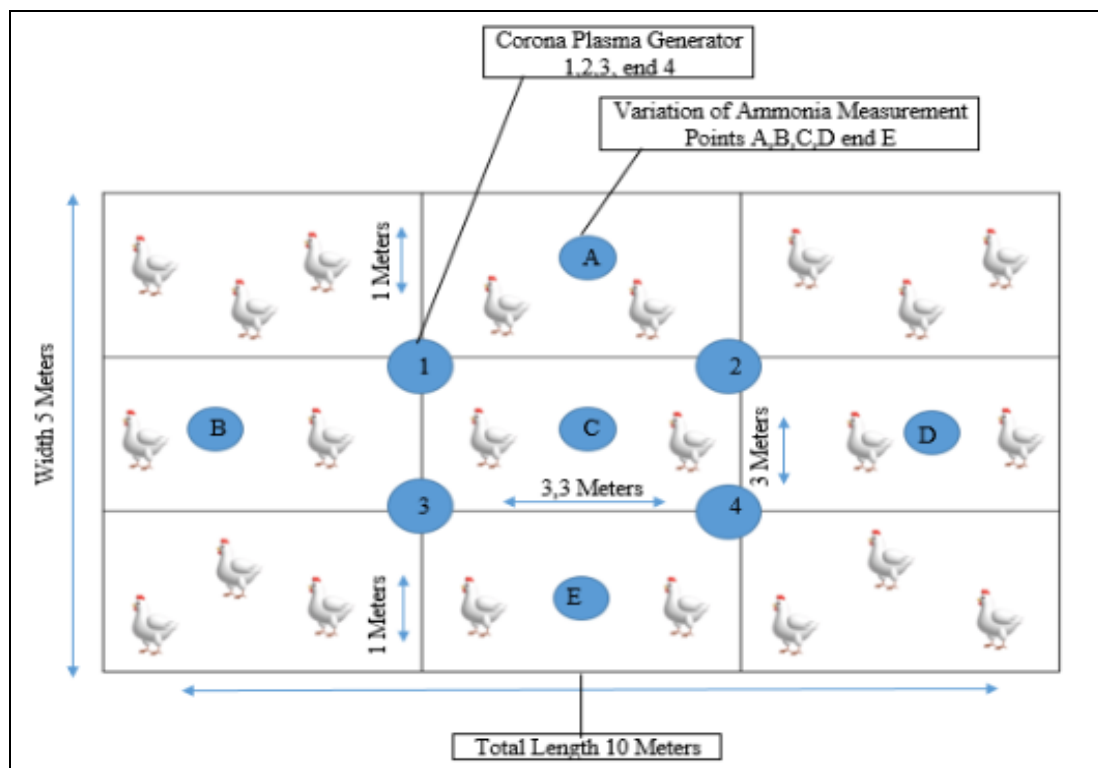


Fig 3 Placement of Corona Plasma Generators in the Field

This experiment was done inside a chicken coop measuring 10 m x 5 m and which had three major zones in order to determine the effectiveness of plasma treatment in reducing gaseous pollutants. There were four plasma generators used in this experiment and placed in appropriate positions. The spacing between generators 1 and 4 was set to 3 meters while the distance between generators 1 and 2 was

3.3 meters. In order to accurately measure the reduction of ammonia, five test points were established within chicken coop areas designated A, B, C, D, and E. The purpose of this design is to allow even coverage of the ionizing range from the plasma reactor in the coop with an estimated population of 1,500 chickens.



Fig 4 Image of the Placement of Four Corona Plasma Generators Directly in an Open House Chicken Coop

Figure 4 demonstrates an open broiler chicken house fitted with four corona plasma generators placed directly in the rearing pen. The placement of this apparatus occurred in 17-day-old chickens, considering that at this stage of their development, chickens are already in a stable developmental stage; therefore, the chances of experiencing any stress from either internal or external factors are minimized. With this stage of development, it can be assumed that since there has been the addition of excreta on the bedding materials of rice husks, there may be higher amounts of ammonia being produced. However, the installation of corona plasma generators would result in lower amounts of ammonia in the coop.

III. RESULT AND DISCUSSION

➤ Current Voltage Characteristics For Corona Plasma

The results of this observation show that the higher the voltage, the greater the electric current that occurs at a frequency of 20-50 kHz. When the voltage is quite low, namely between 10-12 V, the current flow occurs quite slowly with a value between 0.07-0.09 A, which means the ionization process is still small. However, with increasing voltage, namely between 12-14 V, the current flow begins to increase gradually with a value between 0.08-0.10 A. Meanwhile, when the voltage is quite high, namely around 14-17 V, the current flow increases significantly to between 0.10-0.17 A and forms a non-linear relationship pattern, which means the ionization process is quite high. In addition, the higher frequency of this phenomenon is caused by a greater voltage that will create a greater potential difference between the two electrodes which causes the formation of a stronger electric field [9]. This electric field makes the movement of charged particles such as electrons and ions move at a faster speed and results in a meeting or collision of particles with a higher frequency. In addition, the increase in

current that is also seen at high pressure becomes faster, indicating that there is an electron avalanche effect. This effect causes one collision to create more other charged particles in the circuit and strengthens the nonlinear element of the relationship between current and pressure. This condition shows that the influence of the I-V relationship can be determined based on the modification of the Robinson equation by Nur et al. 2017 [7]. In theoretical principle, the Robinson equation (1961) reveals that the current has a linear correlation with the square of the difference between the operational voltage and its threshold, which can be seen from equation (1). The application of the theoretical model and the resulting graphs ensure that this model is valid in the analysis of the listed conditions [8].

$$I_s = \frac{2 \mu_0 \epsilon_0}{d} (V - V_t)^2 \quad (1)$$

Where I is the saturation current (mA), μ_0 is the average charge mobility ($\text{cm}^2/\text{V}\cdot\text{s}$), ϵ_0 is the permittivity, V is the operating voltage, and V_t is the corona threshold voltage (volts). The determination of the formula is then developed by considering the electrode area and the medium between the two electrodes. Thus, the I(V) formula obtained from the Robinson model can be used for reactors with electrode structures using gas media and insulating materials such as glass. The characteristics of the current and voltage relationship after modification are stated as follows [7]:

$$I_s = \frac{2 \mu R T^e S}{d^3} (V - V_t)^2 \quad (2)$$

S represents the surface area of the passive electrode (cm^2) and d is the distance between electrodes (cm), while ϵ_e is the effective permittivity and $\mu R T$ indicates the mobility of electric charge carriers.

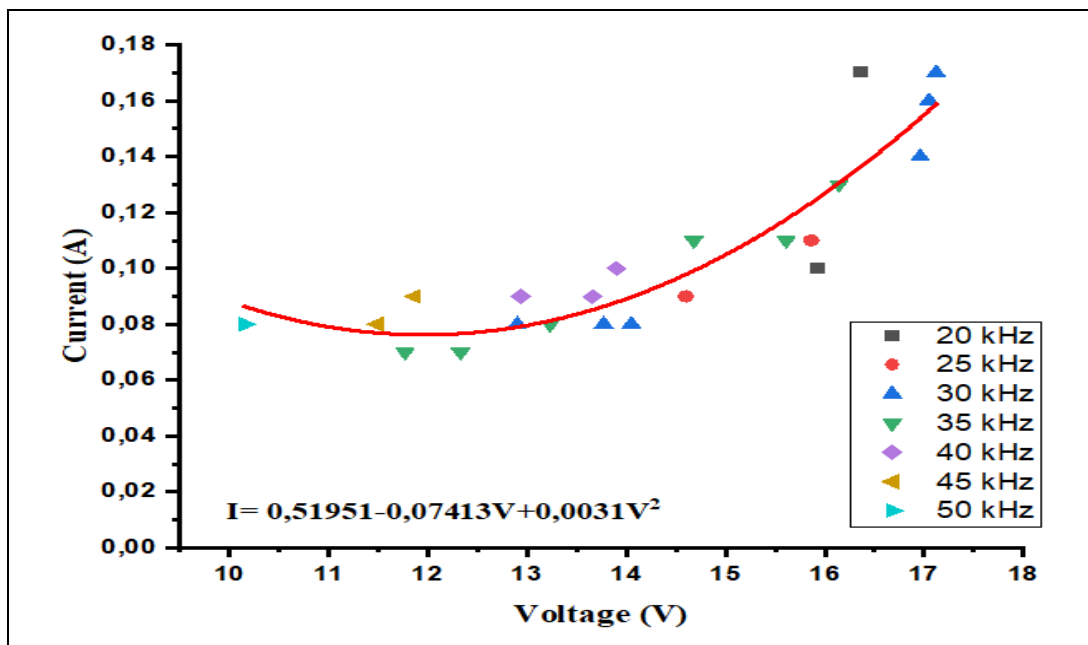


Fig 5 Graph of the Relationship Between Current and Voltage

According to the observation results, it can be seen that the electric current value increases consistently along with the increasing voltage value in the frequency of 20–50 kHz. For low voltages, namely 10–12 V, the electric current ranges from 0.07 to 0.09 A and is stable. When the voltage is adjusted to 12–14 V, the current increases gradually to 0.08–0.10 A, then increases significantly from 14–17 V to 0.10–0.17 A and has a nonlinear pattern. In addition, higher frequencies produce higher currents at the same voltage. The data was analyzed using a second-order polynomial model with the equation $I = 0,51951 - 0,07413 V + 0,0031 V^2$. The modeling results show a nonlinear relationship between current and voltage, characterized by the presence of a positive quadratic term. This finding is consistent with the

formulation proposed by Nur et al 2017. [7], which states that the I–V characteristics follow a quadratic pattern.

➤ *Relationship Between Voltage and Electrical Power at Variations in Frequency*

In order to determine how changes in voltage and frequency affect the generation of electrical power, measurements were conducted using a range of voltage from 10 to 17 volts at a frequency of 20 to 50 kilohertz. The measurement data are shown in graph format to display the pattern of the voltage-power relationship at different frequency variations.

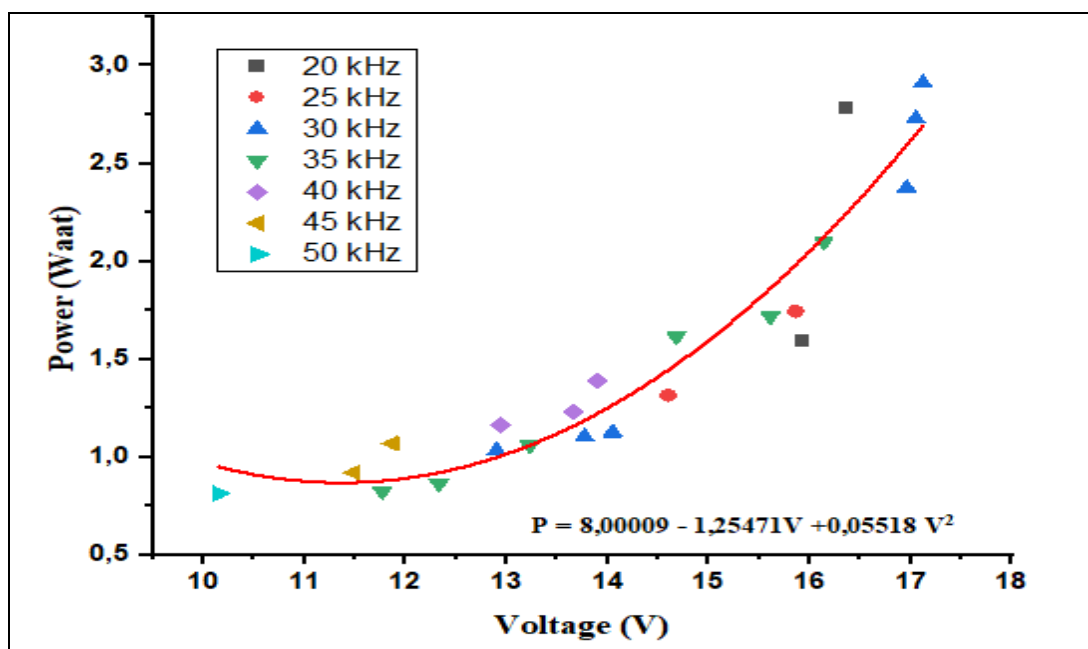


Fig 6 Graph of the Relationship Between Current and Power

Input power (P) can be determined based on the results of current and voltage measurements or through I-V characteristics, and can also be calculated by multiplying the relevant electrical quantities.

$$P = I V \tag{3}$$

Equation (2) substituted into Equation (3) produces the input power calculation based on the modified Robinson formulation [7]:

$$P = \frac{2 \mu R T^e S}{d^3} (V - V_t)^3 \tag{4}$$

Through this equation statement, it can be concluded that the input power is directly proportional to the cube of the voltage ($P \approx V^3$), and based on the experimental results and fitting presented in the 6th figure, it can be seen that the electric power shows an increase along with the increase in voltage at a frequency of 20 to 50 kHz with a non-linear pattern, which is finally analyzed through a second-order polynomial equation $P= 8,0009 - 1,25471 V + 0,05518 V^2$.

The result obtained indicates that there is non-linear dependency between input power and voltage, where the presence of a positive quadratic term represents higher power increment for high voltages. The fitting results agree with the trend observed from experimental data and suggest that the relationship between voltage, current, and power within the system follows the quadratic model. Moreover, this finding supports the application of the modified Robinson formulation in explaining electrical behavior, not only in the coronal electrolyte systems but also in the double dielectric barrier discharge configuration.

➤ *Current Frequency Relationship for Coronal Plasma*

In order to find out the influence of frequency to the current in the plasma reactor, the experiment of measuring the current is conducted under several conditions of frequencies with various voltage readings. The results of the experiment from V1 until V7 are then provided as illustrated in the following diagram of the relationship between frequency and electric current.

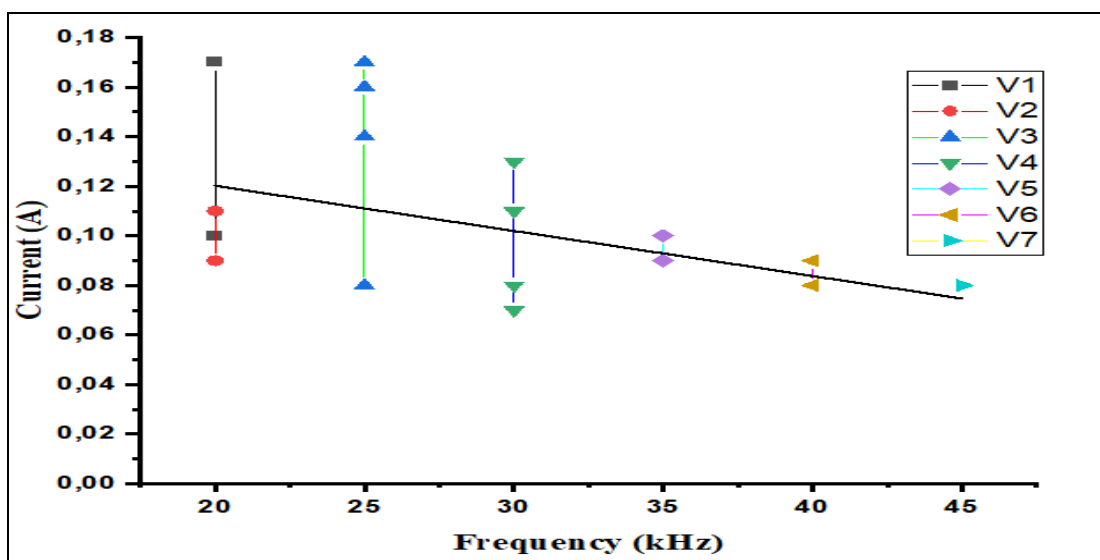


Fig 7 Graph of the Relationship Between Current and Frequency

In the above figure, the variation of frequency (kHz) versus electric current (A) at different voltages is illustrated, which reveals that there is an inverse relationship between the current and frequency as the frequency ranges from 20 kHz to 45 kHz, and the current decreases. Thus, the higher frequency results in smaller values of the plasma current despite having a higher voltage. The reason for such behavior could be due to the impedance effect or shortened ionization process of the gases, with the maximum current value of 0.17 A at frequencies ranging from 20 kHz to 25 kHz.

➤ *The Relationship Between Ammonia and Coronal Plasma*

One of the pollutants that contribute to air pollution and foul smell in closed chicken houses is ammonia gas (NH₃). The NH₃ gas emanates from the process of decomposition of nitrogen present in chicken droppings and always surpasses the permissible limit leading to detrimental effects on animal,

environmental and worker health. In such a case, application of efficient techniques of air purification becomes essential, including corona plasma. Corona plasma is able to generate cold atmospheric plasma (CAP) containing energetic electrons, free radicals and reactive species of oxygen and nitrogen such as OH-, O₃, NO- and O- [3]. In this collision, the N-H bond breaks down to create NH₂ and NH₂ radicals. These radicals react with O₂, O₃, and OH radicals to produce intermediary products like NO and NO₂, which are later converted to safer compounds such as NH₄NO₃ and H₂O. This research shows that corona plasma does not only decrease the concentration of ammonia but also helps convert it into safer compounds. The efficiency of the process increases with time because polluted air keeps flowing through the plasma region where electrons, ions, and radicals are plentiful.

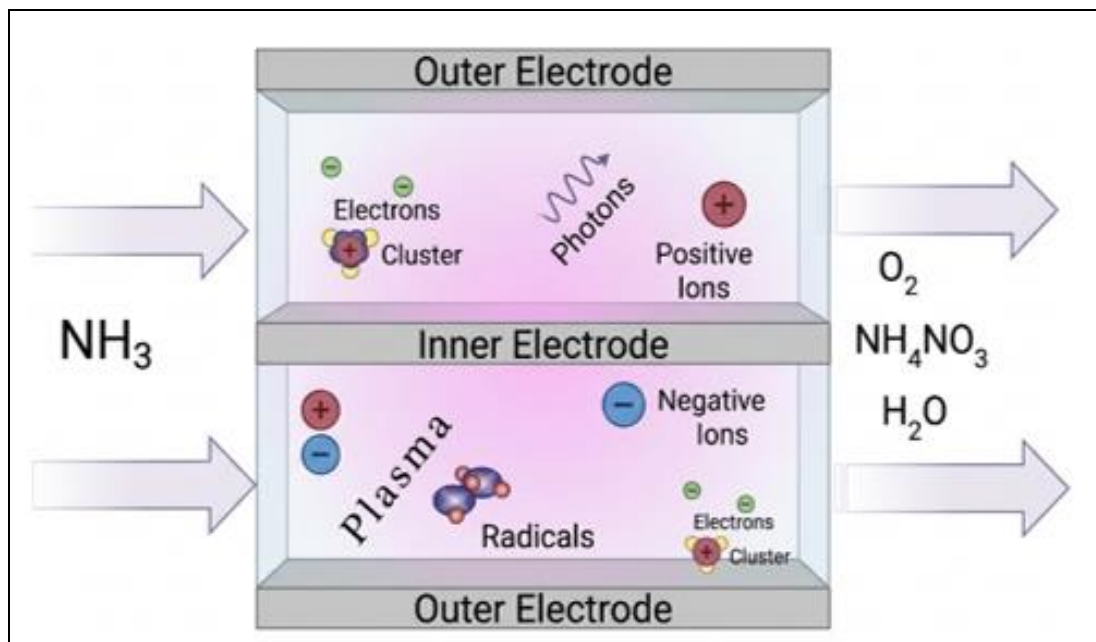


Fig 8 Indicates that Corona Plasma Decomposes Ammonia into More Stable Compounds [3]

The scheme demonstrates how the corona plasma formation between the electrodes leads to the creation of active particles, like electrons, ions, and radicals, responsible

for the decomposition of ammonia (NH_3) to form more stable products, such as O_2 , NH_4NO_3 , and H_2O .

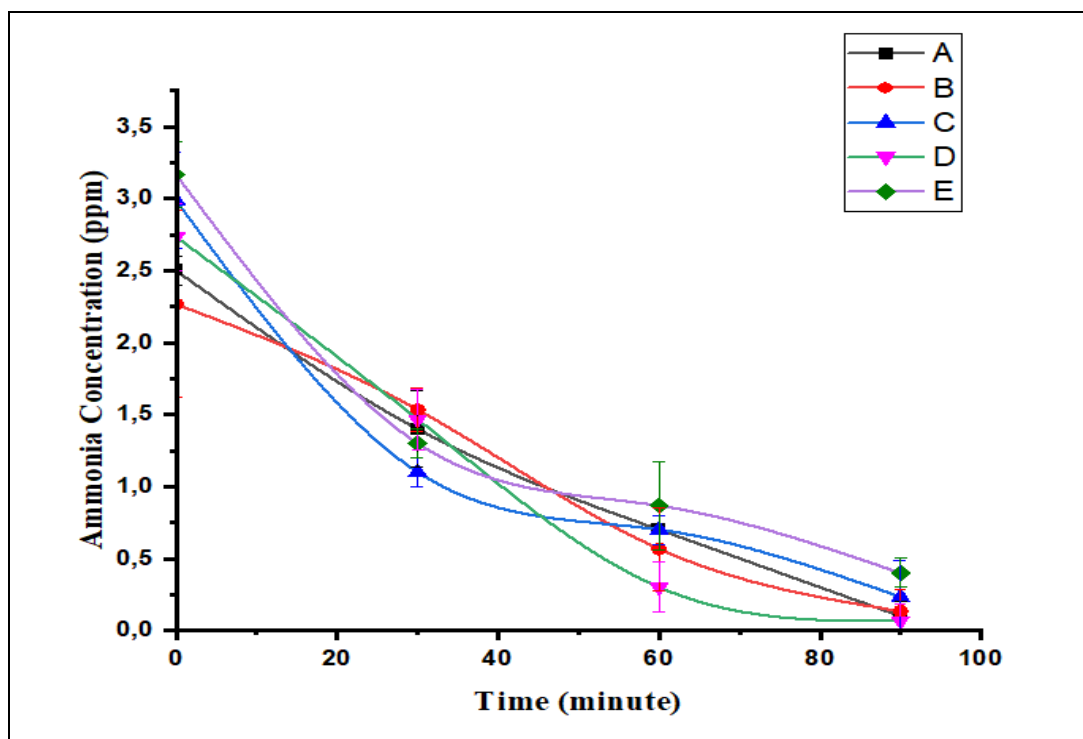


Fig 8 The Time-to-Ammonia Relationship Graph Shows a Decrease in Ammonia Under Several Conditions.

Based on the graph in Figure 8 regarding the results of the ammonia study in open house cages, it can be said that, from the data provided regarding the ammonia concentration values (in ppm) versus time (in minutes) for five different samples (A, B, C, D, and E), it can be seen that all of them experienced a decrease in concentration that occurred over time. Initially, the samples with the highest and lowest

ammonia concentrations were sample E at 3.1 ppm and sample B at 2.4 ppm. At the end of 90 minutes, the lowest ammonia concentration was sample B at 0.1 ppm and the highest was sample E at 0.6 ppm. It should be noted that the decrease in concentration occurred most rapidly from the 10th to the 20th minute, after which the decrease became more gradual.

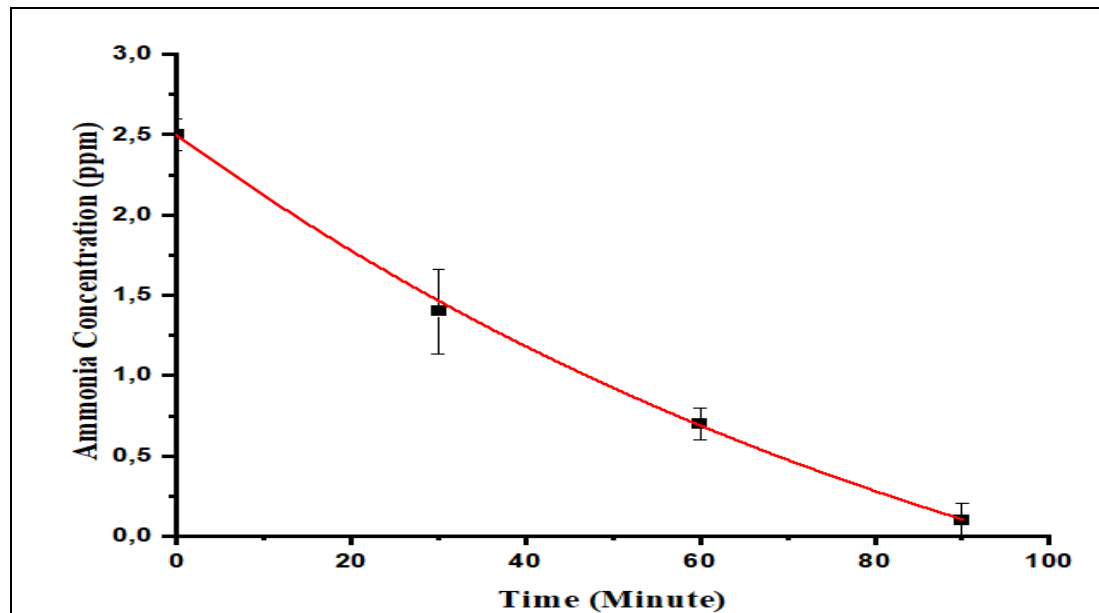


Fig 9 The Graph of the Relationship Between Time and Ammonia Concentration Shows an Exponential Pattern.

As can be seen from the graph, the longer the duration of time, the lower the concentration of ammonia (NH_3). The initial concentration of NH_3 was found to be 2.5 ppm, falling down to 1.4 ppm at 30 minutes, to 0.7 ppm at 60 minutes, and to 0.1 ppm at 90 minutes. The percent decrease in the concentration of NH_3 was calculated using the formula for reduction efficiency $\eta = \frac{c_0 - c_t}{c_0} \times 100\%$ in this way, the reduction efficiency for the range of values 2.5 ppm and 0.1 ppm is equal to 96%. The red curve in the graph depicts how the NH_3 level falls with an increase in the processing time. The rate of fall is faster in the early stages and slows down gradually as the NH_3 level falls.

IV. CONCLUSIONS

The research has proved that the corona plasma reactor is able to lower the NH_3 concentration in open-house broiler chicken sheds. The electrical properties test results reveal that the higher the voltage and power used in the corona plasma reactor, the higher the current. It implies that the higher voltage and power provide a stronger electric field and energy, leading to more efficient gas ionization in the reactor. However, the higher frequency in the system leads to a decline in current due to variations in impedance and reduced ionization time. In terms of the ammonia concentration test, it is evident that the NH_3 concentration lowered from 2.5 ppm to 0.1 ppm within 90 minutes. Such a high reduction rate shows that corona plasma is effective in generating reactive agents that break down NH_3 molecules to form other compounds.

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