University of Kerbela
Collage of Science
Department of Physics

# Construction of Cold Atmospheric Pressure Plasma Jet System for Treatment of Germination and Growth of Iraqi Wheat

A thesis
submitted to the council of Collage of Science/ University of Kerbela in Partial Fulfilment of the Requirement for the (Ph.D.) Degree in Physics Science.

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بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيمِ

( يَا أَيُّهَا الَّذِينَ آمَنُوا إِذَا قِيلَ لَكُمْ تَفَسَّحُوا فِي الْمَجَالِسِ فَافْسَحُوا يَفْسَحِ اللَّهُ لَكُمْ ۖ وَإِذَا قِيلَ انْشُزُوا فَانْشُزُوا يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ ۚ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ )

صدق الله العليّ العظيم

المجادلة الاية ( ١١ )

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## Dedication

First of all profusely and all thanks are due to **Allah** lord of the whole creation who enabled me to achieve this research and peace is upon his messenger **Mohammad.**

To the first teachers my parents, **my father** in the eternal live, and **my mother** who devoted her live to my success.

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To everyone who stood with me, **my friends**. Additionally, to all those who complete the march of science.

I dedicate this thesis to all of them.

***With my best wishes***

***Sajjad Hussein Maan***

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***Sajjad Hussein Maan***

## Abstract

Cold plasma is promising and a safe technology that has succeeded in many applications such as medicine, biomedical, industry and agriculture. In this work Iraqi wheat seeds were treated by cold atmospheric pressure plasma jet (APPJ) system, the system was designed and constructed in advanced plasma laboratory in University of Kerbala, College of Science, Physics Department. A different types of electrodes (Al, Cu, and Ag) configuration were examined in order to diagnostics of the plasma characteristics to reach the optimum quality. Argon as a feeding noble, the optical and electrical properties were checked, the electron temperature and electron density were measured by spectroscopy Boltzmann plot method, the plasma plume jet, and the jet temperature were measured for each plasma jet.

The cold plasma that was produced by using argon gas by 98% and oxygen by 2% was investigated. The optical and electrical properties were determined and comprised with that of Argon plasma jet.

The longer plasma jet has been obtaind by using Al-electrode (3.8 cm) comparing with these of Ag-electrode (3.6 cm) and Cu-electrode (3.3 cm), with the same condition. The temperature of the atmospheric plasma jet with Al-electrode is 26.5 °C smaller than those of (Ag) 27 °C and Cu 28.5 °C electrodes. The electron temperature of the plasma when using the Al electrodes is equivalent to 0.8349 (eV), while the electron temperature of both Cu and Ag electrodes were equivalent to $0.8622\ (eV)$ and $1.2466\ (eV)$ respectively. The reactive species intensities of produced plasma with Al electrodes are bigger than those of others. The results showed that the quality of plasma jet with Al-electrode was the optimum one.

The plasma jet temperature and the plasma plume length of mixed plasma were determined and comprised with that of Argon plasma jet. The intensity of all produced reactive spices of mixed gas plasma jet is higher than of those of Argon plasma jet. The plasma jet length of mixed plasma is higher than that of argon plasma, the jet length of mixed plasma was 2.5 cm, whereas, it was 1.8 cm for argon plasma jet at 9kV. The plasma jet temperature for mixed gas is smaller than that of Argon gas plasma jet were 24.5°C and 25.5 °C respectively at 9kV.

The potential of the generated plasma for improving the Iraqi wheat germination and growth was investigated. Five Iraqi wheat seeds sample were treated by argon and mixed gas plasma jet with 2,4,6,8, and 10 minutes for each sample. Then the treated seeds and controlled sample were farmed in a growth cabinet at 25±1°C, illumination (1500-1800 Lux) and humidity of 60-70%.

The results revealed that there was a good enhancement in the growth and germination ratio of Iraqi wheat. Furthermore, the germination and growth ratio of treated wheat seeds by mixed gas (APPJ) was batter over than that of treated seeds by Argon gas (APPJ). The germinated ratio was 90% and the speed of germination was 10.26 seeds/day in case of Argon gas (APPJ). In addition, the germination ratio, and speed of germination were improved over that of mixed gas (APPJ), they became 92% for germination ratio and 12.8 for the speed of germination. Moreover, the seedling vigour index was 25.5 for treated seeds by mixed plasma and 13.5 for those treated by Argon gas APPJ.

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## List of Symbols and Abbreviations

| Sample | Diffination | Units |
|---|---|---|
| $\alpha i$ | Degree of lionization | |
| $\lambda$ | Wavelength | nm |
| $A$ | Transition Probability | |
| $I$ | Relative Intensity | counts |
| $J$ | Angular Momentum Quantum Number | |
| $g_u$ | Statistical Weight | |
| $n_e$ | Electron density | $e.m^{-3}$ |
| $T_e$ | Electron temperature | ev |
| $Ti$ | Ion temperature | °C |
| $T_n$ | Atom temperature | ev |
| $N_i$ | Ion density | $ion.m^{-3}$ |
| $Nn$ | Atom density | $atom.cm^{-3}$ |
| $K_B$ | Poltizman constant | J/K |
| $p$ | System pressure. | Pa |
| $n$ | Density number. | |

| | |
|---|---|
| SE | Single Electrode |
| DBD | Dielectric Barrier Discharge |
| DC | Direct Current |
| DFE | Dielectric Free Electrode |
| Eion | Ionization Energy |
| Eu | Energy of the Upper Level |
| EM | Electron Microscopy |
| LTE | Local Thermodynamic Equilibrium |
| AC | Alternating Current |
| APPJ | Atmospheric Pressure Plasma Jet |
| SDA | Sabouraud Dextrose Agar |
| OES | Optical Emission Spectroscopy |
| NIST | National Institute of Standards and Technology |
| ROS | Reactive Oxygen Species |
| RNS | Reactive Nitrogen Npecies |
| RONS | Reactive Nxygen & Nitrogen Species |
| SLM | Standred Litter per Minute |

# Chapter One

# Introduction to Cold plasma

# Chapter One
# Introduction to Cold Plasma

## 1.1 Introduction

Although the universe consists 99% of plasma, the earth has very small fraction of the cosmic plasma. The cosmic ray affects the natural atom within the earth atmosphere [1]. In other words, there is an interaction between the cosmic ray and free electrons of molecules or atoms. Plasma is classified as the fourth state of matter. When the solid-state matter receive heat more than certain amount, the matter will convert into a liquid state. Increasing the liquid temperature leads the matter into a gas state. Further heating of the gas will convert the ionized gas to plasma state [2]. Table 1-1 illustrates the differeces between the plasma and gas state in term of property.

Table 1-1 shows the difference between plasma and gas

| Property | Gas | Plasma |
|---|---|---|
| Conductity | Very low, insulator | Very high, conductor |
| Species | Usually one | At least two, electron & ion |
| Distribution | Maxwellian | Usually non- Maxwellian |

| | | |
|---|---|---|
| Interaction | Binary, short range | Colleactive, long range |

Ions, electrons and neutral particles are components of the plasma. The charged particles can interact, which produce a superabundant electric field. Whoever, the ions and electrons recombine in air. Therefore, the plasma does not exist in earth atmosphere. The quasi-neutral gas (consisting of electrons and ions ) can be defined as plasma if it exhibit collective behavior [3].

In the last decades, non-thermal, and low-temperature plasma techniques have a wide attraction in various fields such as biomedicine, material surface treatment, sterilization, and agriculture [4][5][6][7]. Atmospheric pressure plasma jets ($\approx 10^5$ par) (APPJs) have been constricted depending on the configuration designed of tube diameter, electrode types, and the distance between electrodes [8][9].

Due to the wide range of plasma jet applications, optimization of producing plasma jet system has become crucial for researchers, and workers. In addition, the enhancement of the produced plasma jet properties, such as plasma jet temperature, and the density of reactive species, has a widely interested[10].

Non-thermal plasma can be considered as a cost effective compared with other technic, and that make it a more convenient alternative comparison to low-pressure plasmas (<1 par) [11]. The efficiency of produced cold plasma dependents on many factors such as the electrode shape, material of electrode, and the thickness of the electrodes [12].

## 1.2 Plasma Ionization

Plasma is an ionized gas. Two ionization's processes that should be satisfied: momentum and energy conservation. First of all, impact ionization, where the ion and electron are separated as a result of electron and atom collision. Secondly, radiative ionization, when an atom absorbs a photon more than the binding energy. Therefore, the ion and electron will be created. The ratio of the created ions to the neutral atom ( $\frac{n_i}{n_n}$ ) is a function of ionization degree. Ionization gas can be classified either partially($10^{-6}$-$10^{-1}$) or fully(100%) ionized according to the generated free electron's energy [13] .

Plasma state has a unique phenomenon, called collective behavior. Which defines as follow: the plasma behavior depends on the whole reacts. That is mean the plasma behavior is the sum of each individual particle's behavior. In other words, the plasma behavior could be specified by the particles motion lay upon the applied of both electric and magnetic fields. Therefore, magnetic and electric field generated as a result of individual motion particles. The interacting between the applied magnetics and electric field will cause severe disturbance within the system, which in turn produces a reactive process that generates high energy [14].

## 1.3 Elementary Charged Particles in Plasma

Plasma can be considered as ions, and electrons. It has a huge number of moving charge particles. Plasma has not only charged particles but also sometime neutral one as well. Fully ionized plasma has equal numbers of both positive and negatively charged carriers. Therefore, the system tends to couple the oppositely charged particles, which in turns back to neutral electrical situation [15].

### 1.3.1 Electrons

Cold plasma may be generated with low-pressure discharged gas, as a special case, with the low-pressure state, the electrons could have several times thousands temperature of Kelvins, in other words, much hotter than the produced ions. In contrast, it is difficult to transfer their own thermal energy to natural atoms and heavy ions. Thus, the environment could not receive much heat and was still colder than electrons. Plasma can be diagnostic by electron, and neutral densities. The ions and electrons should almost have the same value ($n_i \approx n_e$) [15].

### 1.3.2 Ions

The ionization process generates electrons and ions, the created ion is simply a molecule or atom that donate its electron. The positive ion has heavy mass compared with electron mass Therefore, it receives very small energy from applied electric field. The required energy to generate heavy particles is called ionization energy. The magnitude of this energy differs according to the type of inert gas. Thus, the ionization is a crucial parameter for generated plasma. Additionally, there is a negative ion that is generated when the electron attaches to atom or molecule. The released energy is very small compared with ionization energy [15].

### 1.3.3 Elementary Processes of Charged Particles.

Elastic and inelastic collisions are the most important phenomena in plasma disturbance state. In an elastic collision, the internal energy of incident particles will still be the same after the collide and the structure of both particles does not change. Conductivity, diffusion, and absorption of electromagnetic radiation could happen as a result of elastic collision and kinetic energy transition. However, the kinetic energy converts to internal energy due to the inelastic interaction. Therefore, excitation, dissociation, and ionization can happen as a result of inelastic collision [16].

## 1.4 Thermal Plasma Classification

There are three conditions that an ionized gas must satisfy to be called a plasma. Firstly, If the dimensions L of a system are much larger than $\lambda_D$, then whenever local concentrations of charge arise or external potentials are introduced into the system, these are shielded out in a distance short compared with L. A criterion for an ionized gas to be a plasma is that it be dense enough that $\lambda_D$ is much smaller than L. Secondly, if there are only one or two particles in the sheath region, Debye shielding would not be a statistically valid concept. It can be computed the number $N_D$ of particles in a "Debye sphere".

In addition to $\lambda_D << L$, "collective behavior" requires $N_D \ggg 1$ . A third condition has to do with collisions. If ω is the frequency of typical plasma oscillations and τ is the mean time between collisions with neutral atoms, we require $\omega_\tau > 1$ for the gas to behave like a plasma rather than a neutral gas.

The three conditions a plasma must satisfy are therefore:

1. $\lambda_D << L$
2. $N_D \ggg 1$:
3. $\omega\tau > 1$:

Plasma can be classified into two types depending on the electrons, ions, and neutral atom temperature, it is divided into two main groups, as figure 1-1 shows:

- High temperature plasma
- Low temperature plasma
    1. Thermal plasma
    2. Non-thermal plasma [3].

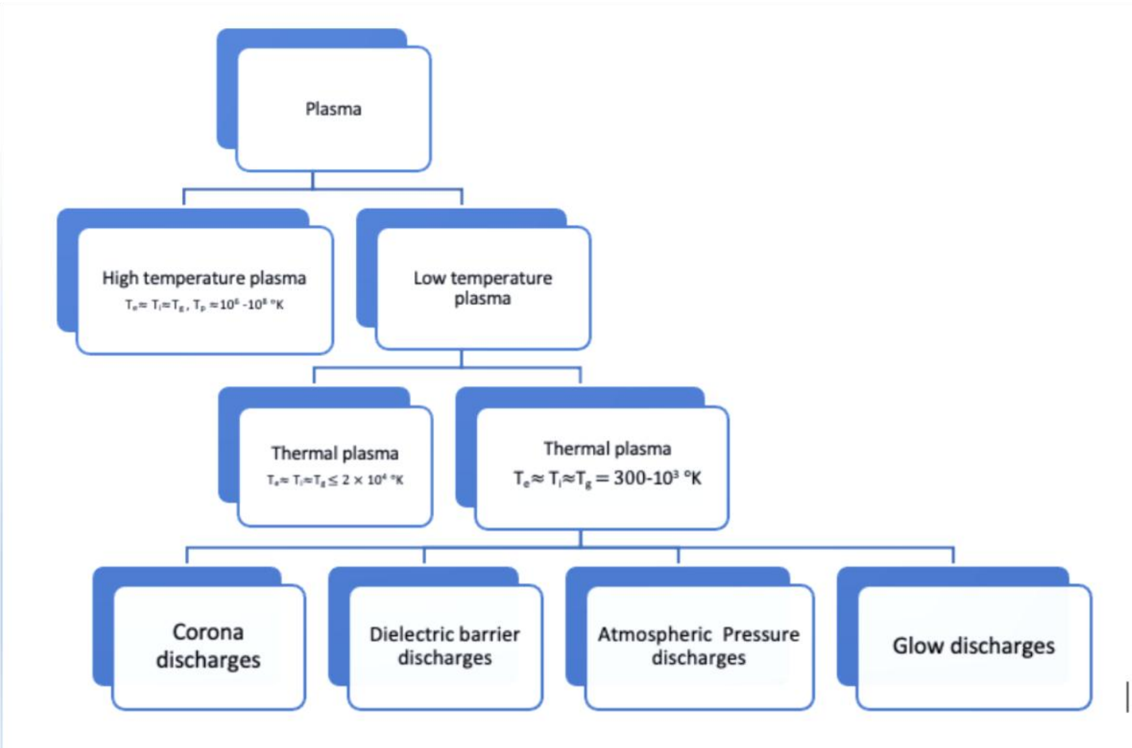



Figure 1-1 Plasma classification diagram [17].

### 1.4.1 High Temperature Plasma

The term of high temperature plasma can be released when the temperature of electrons, ions, and natural atoms are equalized ($T_e \approx T_i \approx T_n$). They may reach $10^6$-$10^8$ °K. In other words, a huge number of collisions between ions, electrons, and neutral atoms could generate hot plasma. Thermal plasma is characterized by two main parameters: high density besides a degree of ionization that reach almost one. Suns, stars, and the core of plants have this type of plasma [17].

### 1.4.2 Low Temperature Plasma

The other type of plasma is the low temperature plasma, which are non-equilibrium systems. It is characterized by the ion temperature which much less than the plasma temperature itself. Furthermore, the density and ionization are smaller than those of the hot plasma. Scientists divided the low temperature plasma into two types [18].

- Quasi- equilibrium plasma
- Non-equilibrium plasma

These types of plasma can be generated by chemical and physical medium that use free electrons with low gas temperature. Therefore, samples of materials with high temperature sensitive could be treated with non-thermal plasma [18].

#### 1.4.2.1 Thermal Plasma (Quasi-equilibrium Plasma)

The two criteria, which can be used to classify the plasma, are the temperature and density of plasma. The quasi-equilibrium plasma has the density and temperature between the range of the cold and hot plasma. Therefore, the electrons, neutral atoms and ions temperature are approximately similar, and they are equalized to:$\leq\ 2\times\ 10^4\ \ ^{\circ}K$ [19].

#### 1.4.2.2 Non-Thermal Plasma (Cold Plasma)

Plasma could be generated when applying high voltage with two electrodes about tube filled with noble gas. Reactive species, charged particles, photons, visible light, electromagnetic field and UV radiation are created with this type of plasma as illustrated in figure 1-2. The formed reactive species has a temperature close to room temperature $30-60\,^{\circ}C$. In other words, the electron temperature is higher than those of ion and neutral atoms, ($T_e\ >>> T_i, T_n\ =\ 300-10^3\ ^{\circ}K$). Therefore, this kind of plasma is preferred to use in many fields such as food industries and seeds treatment[20]. Cold plasma technique can be utilized in many branches, for instance, biomedical application, biomedicine, biochemistry and aviation engineering. Cold plasma can generated many important reactive species which can serve in agriculture branch for instant, it uses to increase the germination and speed growing of the farmed seeds[1].

The other properties of cold plasma are weak ionization, which is about 1% with low density of free electrons. Cold plasma is frequently classified as a non-equilibrium plasma state as a result of low temperature of ions ($T_e$>>$T_i$). Cold plasma can be turned on at a pressure $10\times10^3$ [21].

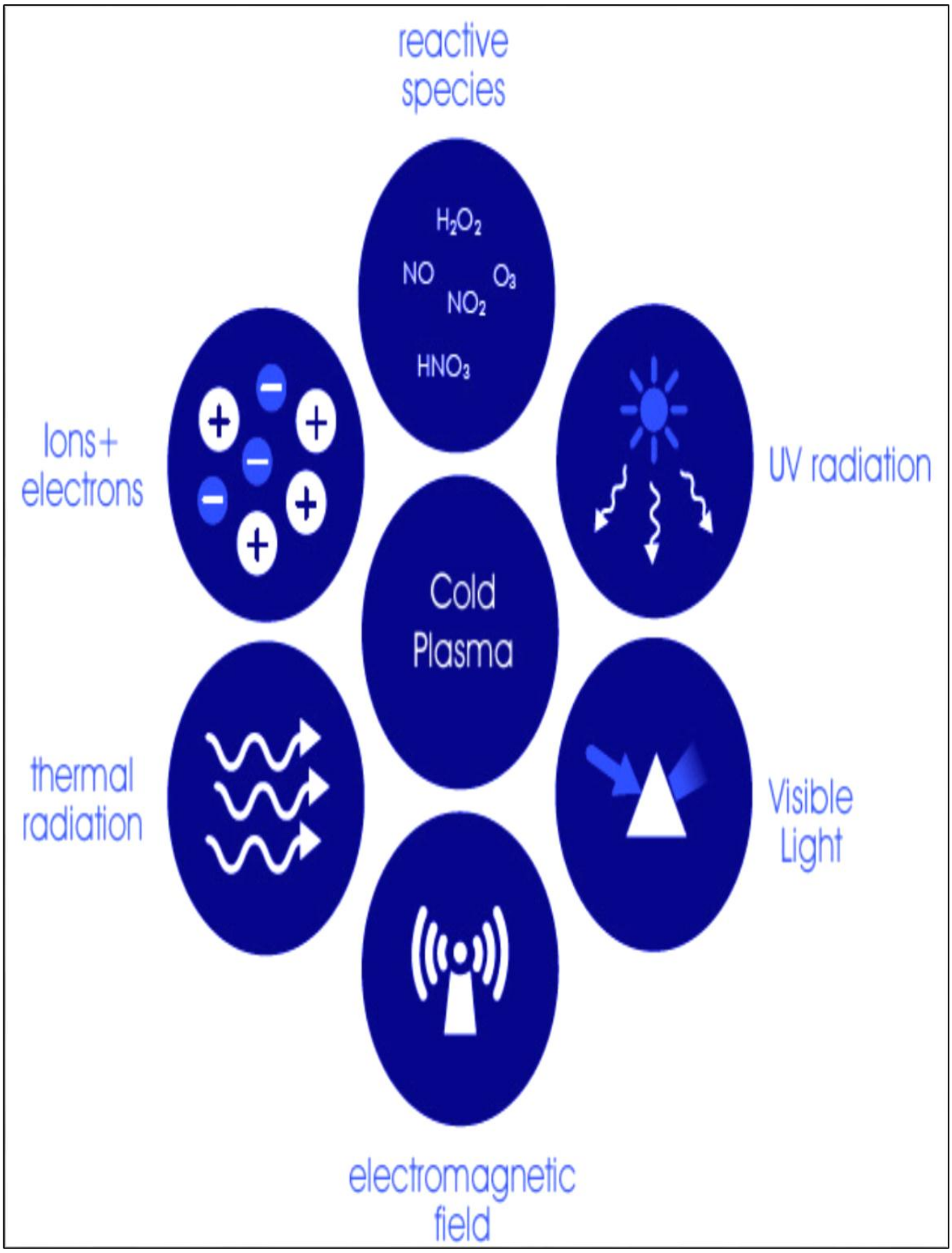



Figure 1-2 plasma components digram [21]

The particle number density could be utilized instead of the pressure in this parameter, according to Dalton's law and when the ionization degree is very small (<< 1) the Dalton’s law becomes Kinetic equilibrium magnitude is bigger for non-thermal plasma than the thermal one according to $(\frac{E}{P})$ criteria [22].

$$p = nKT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

$p$ = system pressure. $n$= density number.

$K$=Boltzmann constant. $T$= temperature system.

## 1.5 Plasma Production

plasma is produced in many ways, one of the well-known methods can be achieved, it can produce by applying electric to the inert gas with using two electrodes. This procedure may cause disturbance within the system. Plasma could be generated when electron is separated from molecules or atoms under the appropriate pressure. The atom or molecule, which gives the electron, will become positive ions. These generated ions and electrons are affected by the magnetic and electric fields in terms of motion. Scientists consider this behavior as the main difference between the ionized gas and plasma state. In addition, in lab many types of plasma could be produced, for example, glow discharges, arcs fluorescent lamps, neon signs electrical sparks thermonuclear, and fusion experiments homely[23].

## 1.6 Gas Discharge

Gas electric discharge achieves when applying electric current on gaseousmedium as a result of gas ionization. Scientists usually use sort of the design of high voltage electrical apparatus with lighting source design. There are many types of gas discharge, figure 1-3 points out three area that can be recognized as electric discharge with cold cathode and distinguished current voltage characteristics[24].

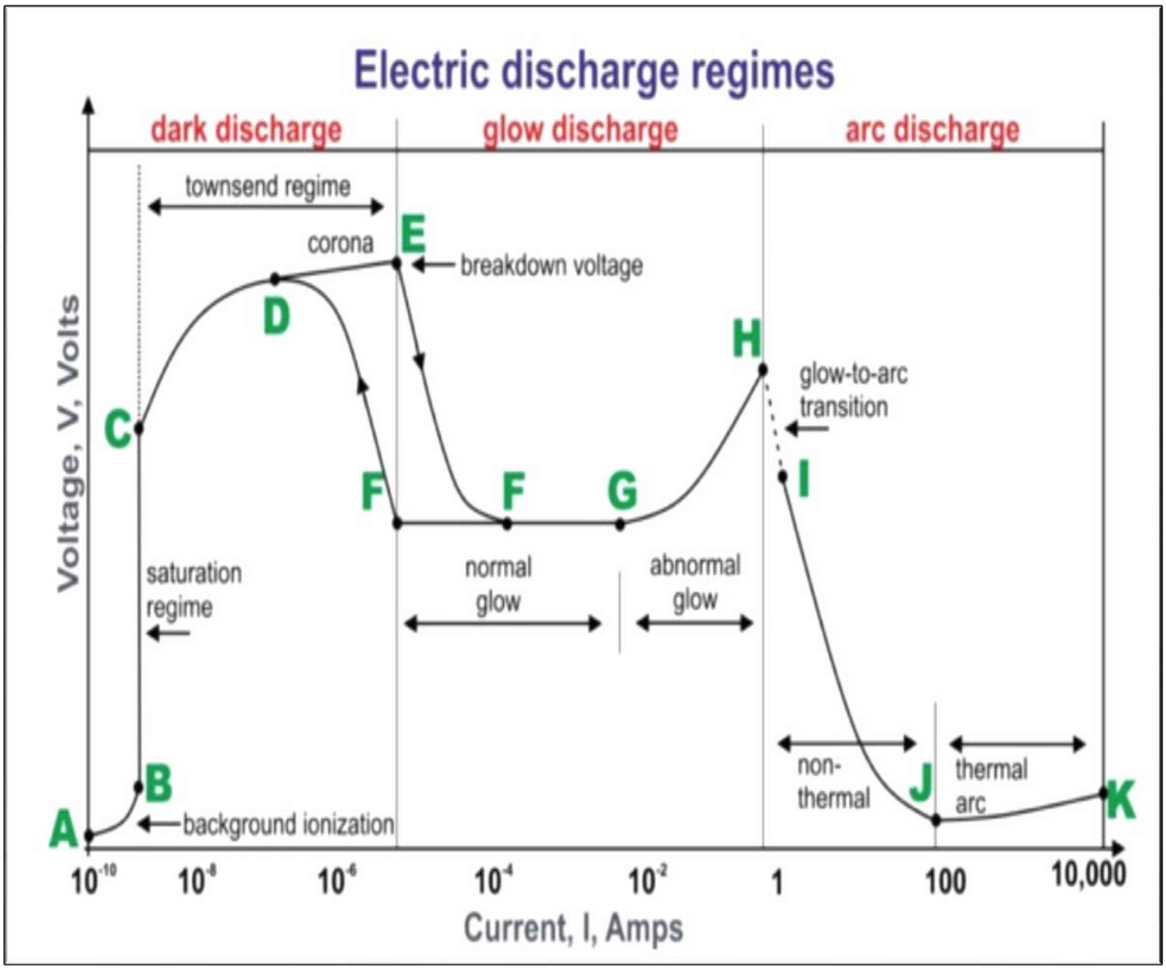



Figure 1-3 Electric discharge regimes in plasma[24]

## 1.6.1 Dark Discharge Region

Figure 1-3 shows this procedure in A-B region. The townsend discharge is a gas ionization process when free electron accelerated by sufficient electrical field give rise to electric conduction through a gas by avalanche mulitpliction caused by ionization of moulecules by ion impact [25].

$$\frac{I}{I_{\circ}} = e^{\alpha n d}$$

$\alpha$ = Townsend ionization coffecient.

$d$ = space between the plasma.

The voltage-current characteristics start tapering off the breakdown voltage and the glow will be visible.The neon fluorescent prototype is illustrated in figure 1-4. It consists of two disk electrodes at either ends of quartz tube connected to DC voltage power supply, by closing the ballast resistor, the voltage-current characteristic will be increased gradually with non-linear behavior. Therefor electron merges from cathode toward anode and collides with a neutral atom, in the same way ion merges from anode to cathode. In this region, the free electrons are increased as applied voltage rises, and gain more energy to cause ionization. The first region can be spotted is the dark region. It starts from low current until breakdown voltage area [24].

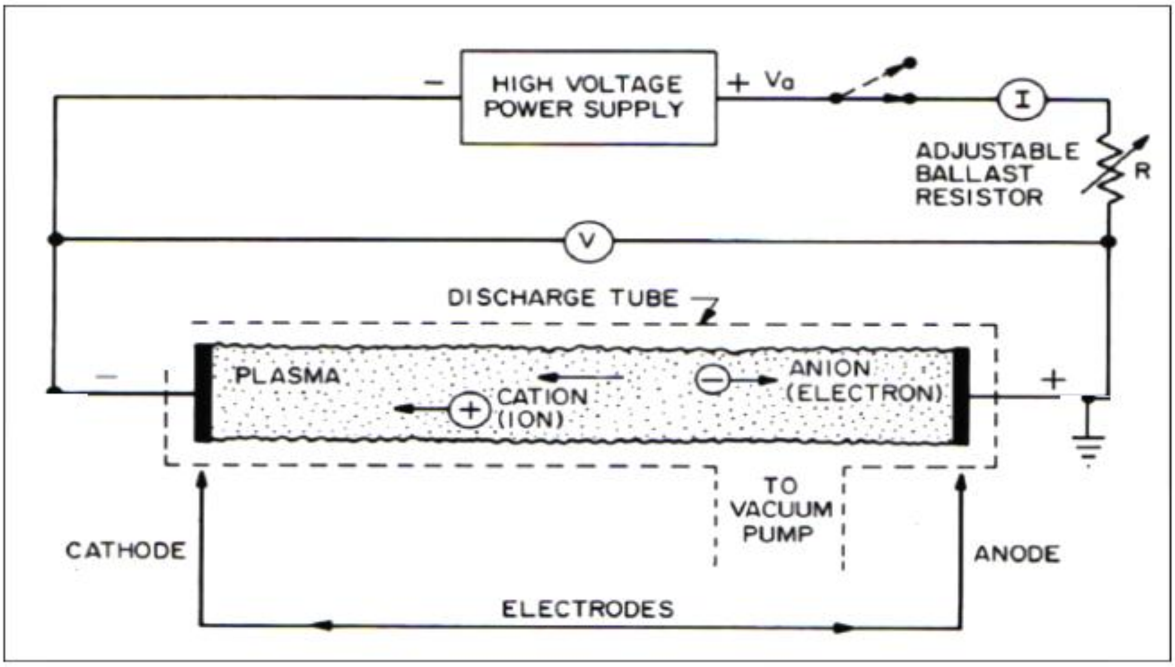



Figure 1-4 low pressure discharge[24]

## 1.6.2 Glow discharge:

Glow discharge stage starts after the breakdown voltage point. The voltage across the cathodes decreases quickly and the current grows to some milliampere scale as shown in figure 1-4. At small currents, the region of the cathodes and anodes are enveloped with the glow discharge. When increasing current value, the abnormal glow will be reached instead of normal one. The voltage across the tube progressively grows, and the glow discharge covers all the surface of the electrodes[25].

## 1.6.3 Arc discharge

Figure 1-3 shows that at point H the transition from glow to arc discharge starts. The current on the electrode becomes great enough to heat it to incandescence. After transition to the arc regime, the voltage decreases with increasing of the current till point J. in the I-J region the arc regime is non-thermal arc regime, with $T_e$ , $T_i$ and $T_g$ . The J-K region with a positive slope is the thermal arc regime with $T_e \approx T_i \approx T_g$ [25].

## 1.7 Production Non-thermal Plasma at Atmospheric Pressure

The plasma can be classified into two types a high and low degree of ionization. We are going to deal with the low one. The low degree of ionization has the total number density of neutral particles much higher than the total density of charged particles. Quasi-neutral plasma means that the sum of the densities of positive and negative charge carriers are equaled. This means that applying an electric potential difference will lead to the formation of an electric field, that transfers energy to charged particles. Therefore, the bulk of the gas (neutral particles) is not directly affected by the electric field [26].

The light mass of the electron relative to the heavier ion mass gives the advantage of a higher electro accelerating between one collision and another. The energy released from the collision is absorbed by other particles and even particles that participate in the same collision. If the pressure is small enough or the applied field is high enough, the electrons and part of the ions will have an average more kinetic energy than the energy required for the random movement of the particles[22].

This case is the nonequilibrium plasma type. On the other hand, if the pressure is high the electric field is so low, therefore, the particles cannot move very far before the next collision occurs. The kinetic energy of the particles may tend to the energy splitting system, that means they lose part of their energy in favor of the neutral kinetic energy in this case[22].

Plasma is classified as an equilibrium state, when it is at a high temperature. The number of collisions between particles increases at high temperatures to the point of distributing equally of energy to all particles. Therefore, hot plasma is often referred to an equilibrium and cold plasma as nonequilibrium plasma. Equilibrium plasma is often divided into groups depending on the mechanism used to generate the amount of pressure and the shape of the electrode, the most prominent of these divisions is the following [27]:

1. Glow discharge.
2. Corona discharge.
3. Silent discharge.
4. Radio frequency discharge.
5. Microwave discharge

### 1.7.1 Glow Discharge

The glow discharge is a discharge that occurs at low pressure, usually between flat-shaped electrodes placed inside a tube, and at a pressure of less than 10 mbar, and thus the field decrease as shown in figure (1-5).

The high energies of electrons excite neutral atoms and molecules and thus produce a special typical glow for each gas. The typical coefficients for glow discharge can be summed up and summarized as follows in table (1-2).

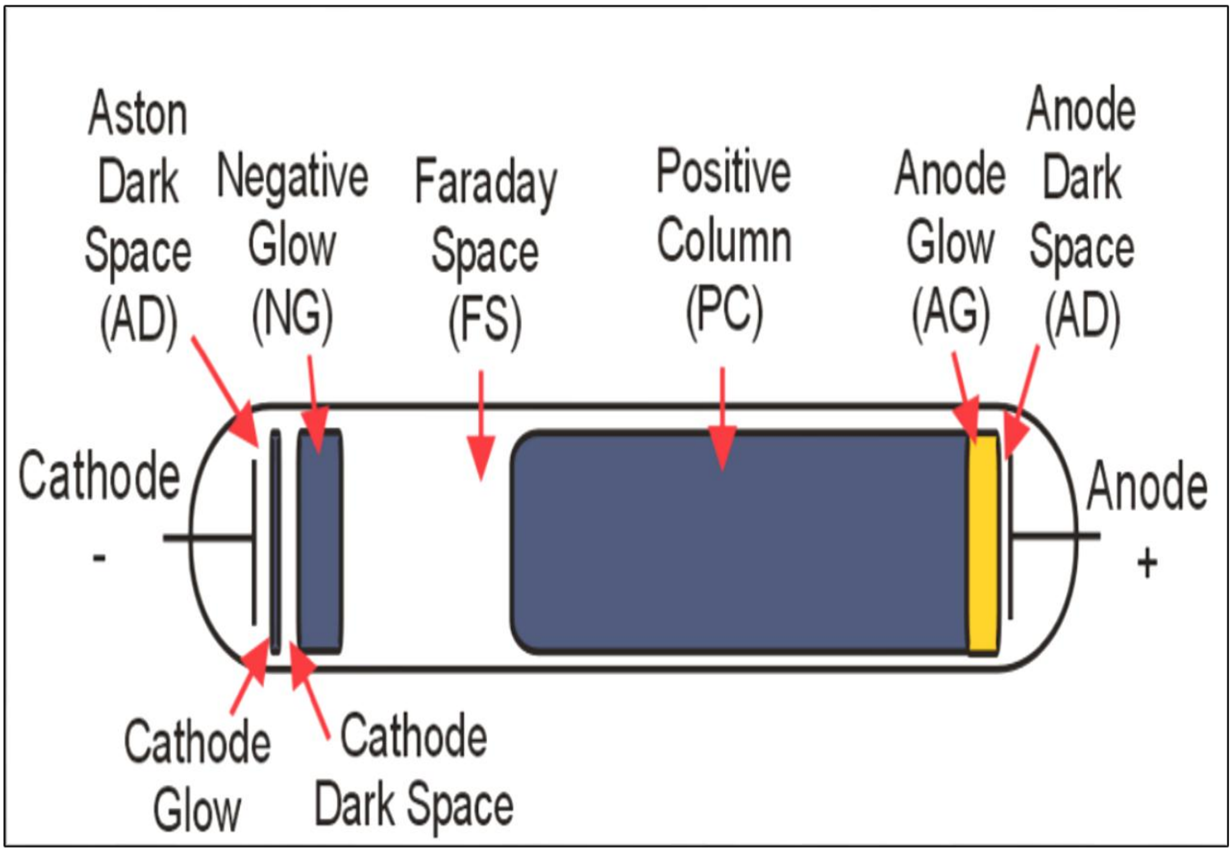



Figure 1-5 The Glow Discharge at low pressure [28]

Due to the relatively low voltage and current required to operate the glow discharge, made this type of electrode discharge an important laboratory tool for chemical plasma tests. Because of the pressure drop, the mass flow will be decreased, so it is not recommended for use in the chemical industry, whoever, it is utilized in the manufacture of fluorescent tubes, which is used in outdoor advertising[28].

Table 1-2 Glow discharge characteristic parameters [28]

| | |
|---|---|
| **Pressure** | 0.1-10 Torr |
| **Electric field** | 10 V/cm |
| **Electron energy** | 0.43-2 eV or 4989-23209 °K |
| **Electron density** | $10^8$-$10^{12}$ cm-3 |
| **Degree of ionization** | $10^{-6} – 10^{-5}$ |

## 1.7.2 ARC Discharge

High energy of the current will lead increasing of the electrode temperature, to become very hot, and therefore emits thermal electrons. The growing up of the electrode temperature has happened as a result of the gas electrical breakdown, therefore, the continuous discharge could lead to increase of the electric current in the insulator medium for instant, air and noble gas causing a spark known as the arc electric. This processing will defiantly lead to reduce in the breakdown voltage. In addition, the generated thermal field causes emitting electrons from the hot cathode as showed in figure (1-6).

The arc discharge could be characterized by its high current corresponding with glow discharge current, the electrons, and ions densities are high and significantly equal. Arc usually has a relatively small cathode voltage drop.

Welding and plasma cutting are the most known applications of arc discharge system[24].

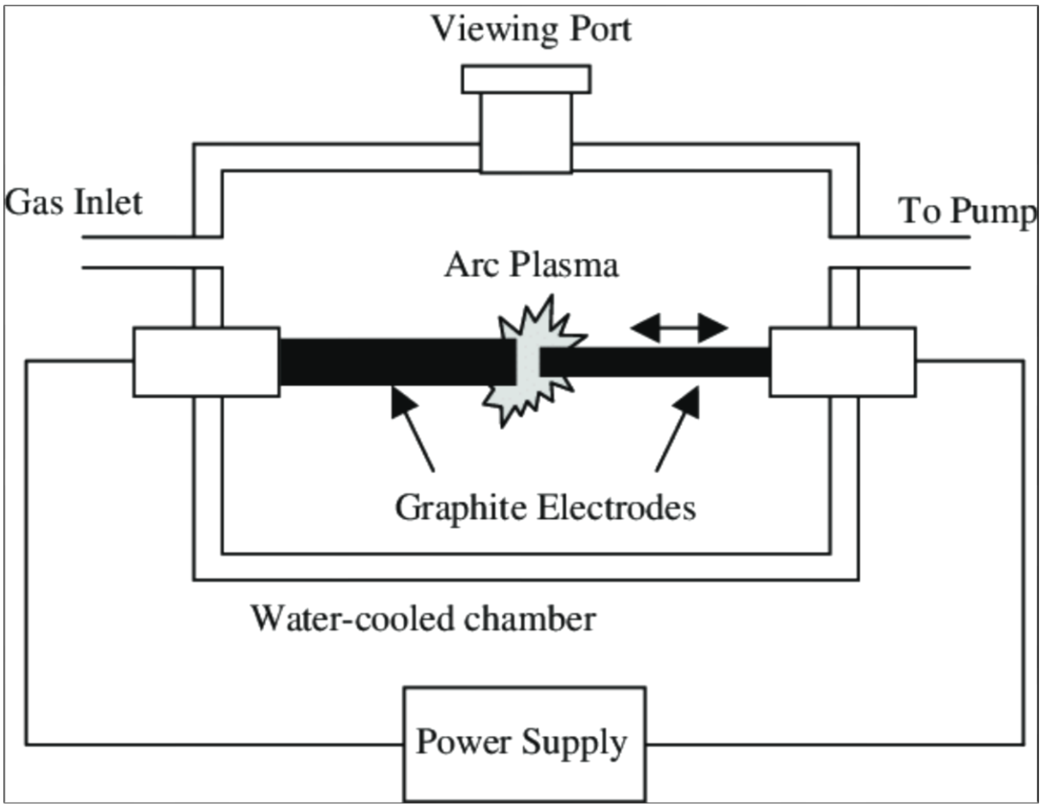



Figure 1-6 schematic of arc discharge device [24]

### 1.7.3 Corona Discharge

One of the well-known plasma secretions that occurs naturally or through human intervention is corona discharge, which can be described as a weak and irregular discharge and can occur at pressure close to atmospheric pressure near sharp points and edges on thin wires, Ionization with some luminosity and strong electric field are located near one of the electrodes, it can be formed to corona discharge positive or negative current. Corona discharge has also another form, which is pulsed corona discharge as figure 1-7 explain.

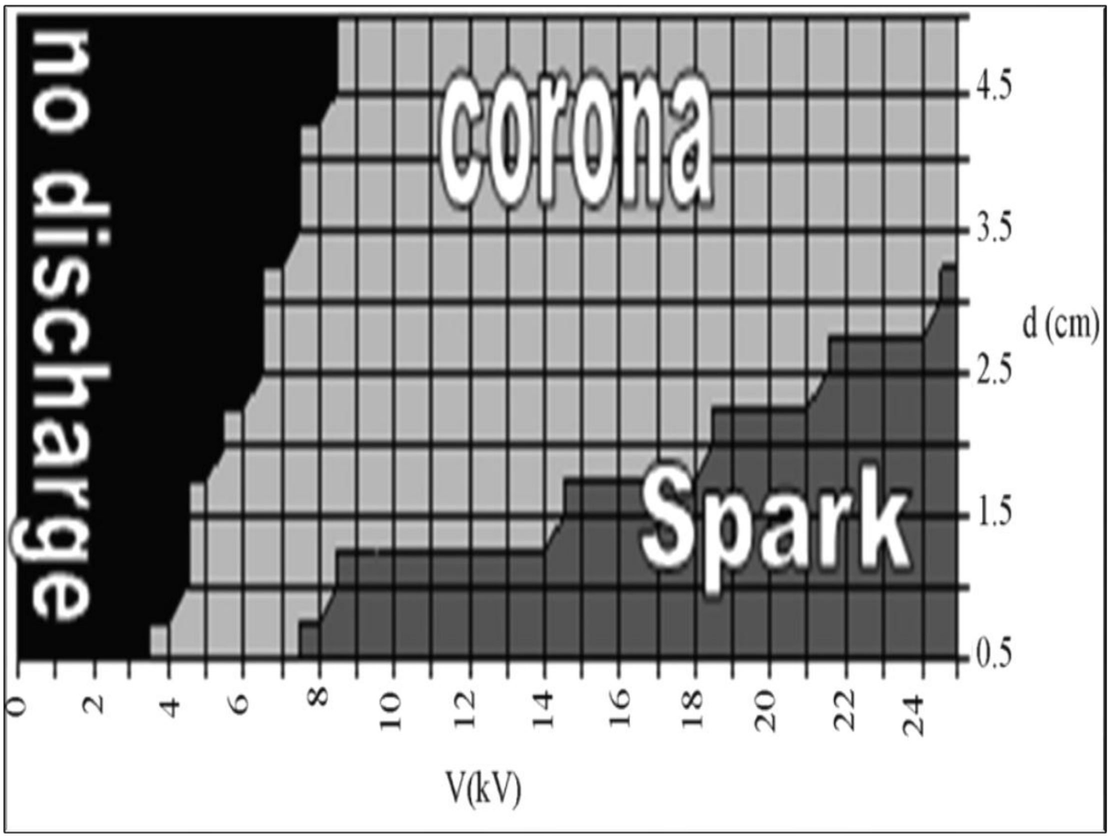



Figure 1-7 illustrates the efficacy of the voltage and distance on the type of discharge (arc or corona) [29].

Due to the limitation of continuously corona discharge by low current and power, there are many applications for materials and gas streams. In order to rise the corona discharge power (before the occurring of spark regime) the pulse- periodic voltage is utilized. The pulsed corona is relatively strong (10 kW) and very bright. The most common pulsed corona (pulsed and continuous) is formed near and around the sharp end to increase the size of the

active discharge in the corona discharge. In order to stabilize the discharge by accumulating charge around the corona point or the wire, a non-homogenous electric field is used. Stabilize the discharge processes could be utilized the pattern of charge accumulation on the capacitive barrier to stabilize the discharge around a point or at the end of a wire. Corona discharges are a preferred application for the breakdown of volatile organic compounds in sterilization and disinfection processes [29].

### 1.7.4 Radio Frequency (RF) Discharge

Rf discharge runs at frequency of one hundred mega Hertz or more. Rf may also utilize at pressure close to atmospheric pressure less than $10^5$ Pascal. RF electromagnetic fields can be generated in many ways, for instance by applying the RF voltage across two parallel electrodes or by circulating RF currents in coils or antennas, either immersed in the plasma or separated from it by a dielectric window[30].

Radio frequency discharge could be generated by passing a gas in an oscillating electromagnetic field as figure 1-8 illustrated. The formatting of Rf discharge system allows locating the electrode outside the charge tube, this feature prevents the contamination of plasma by electrode material vapor. Capacitance and induction could be used in order to generate the Rf discharge plasma. However, it can be generated at atmospheric pressure with high power comparatively especially with 100 watts or more. AC power supply may be used for providing the voltage through the capacitor, with another grounded electrode. Semiconductor, microelectronics and aerospace manufacturing are the well -known application of the RF discharge system[31].

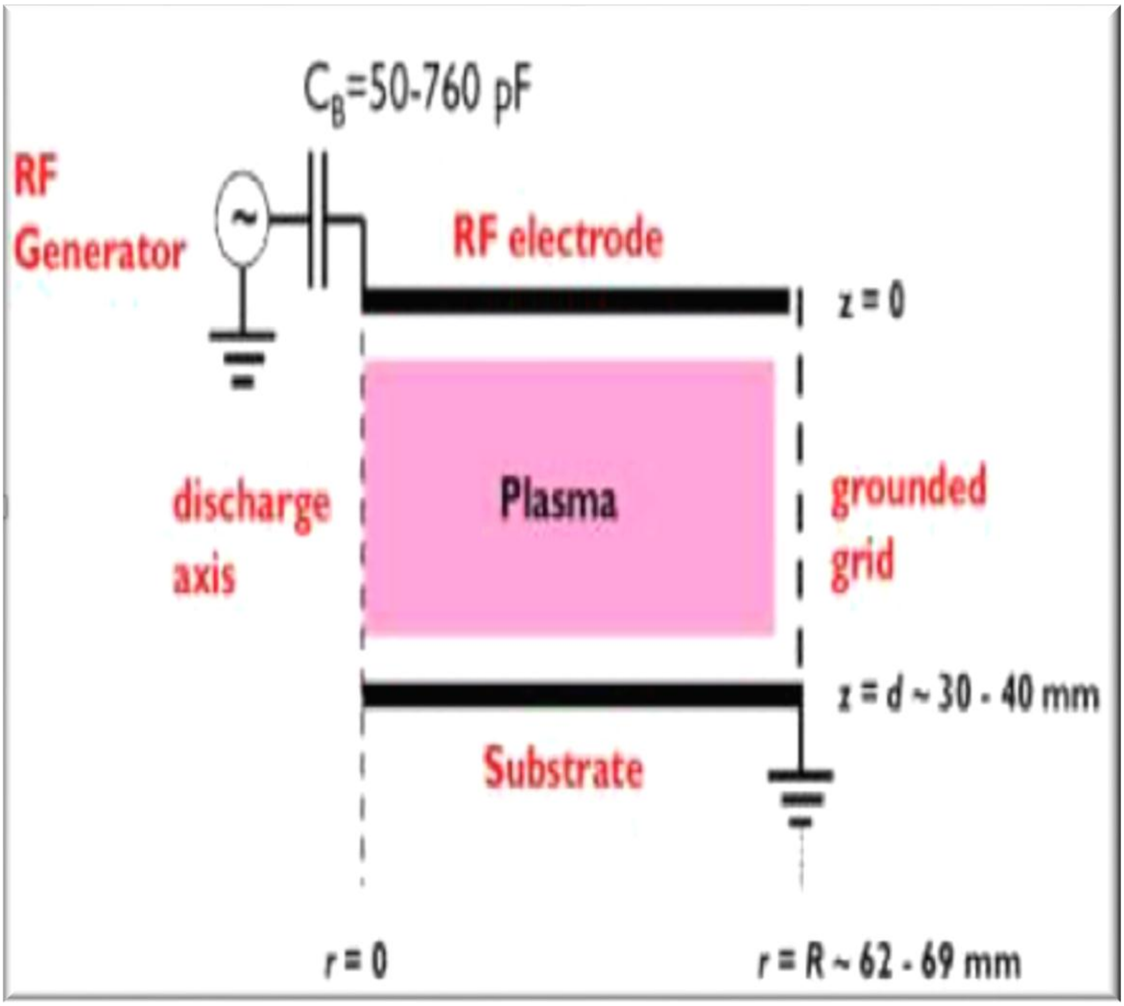



Figure 1-8 Reactors schematic of Rf discharge plasma, capacitively coupled [31].

### 1.7.5 Microwave Discharge

It is possible to generate quasi-equilibrium and nonequilibrium plasma by using microwave discharge and this method is widespread. Microwave plasma is generated at pressures ranging from 6.6- 13.3 *mbar* to atmospheric pressure in continuous sound wave systems at incident power, whose values are close to several watts to hundreds of watts. Plasma can absorb high enough energy and may reach 90% of its original value [32].

Microwave discharge can be defined as the generation of electrical discharge by using the electromagnetic wave with frequency of 300 MHz or more, figure (1-9) shows the schematic of microwave discharge system. The utilized microwaves wavelengths are in the scale of few millimeters to several tens of centimeters and should coincide to permitted frequencies of microwave for scientific, medical, and industrial applications. The most commonly frequency utilized is 2.45 GHz [33].

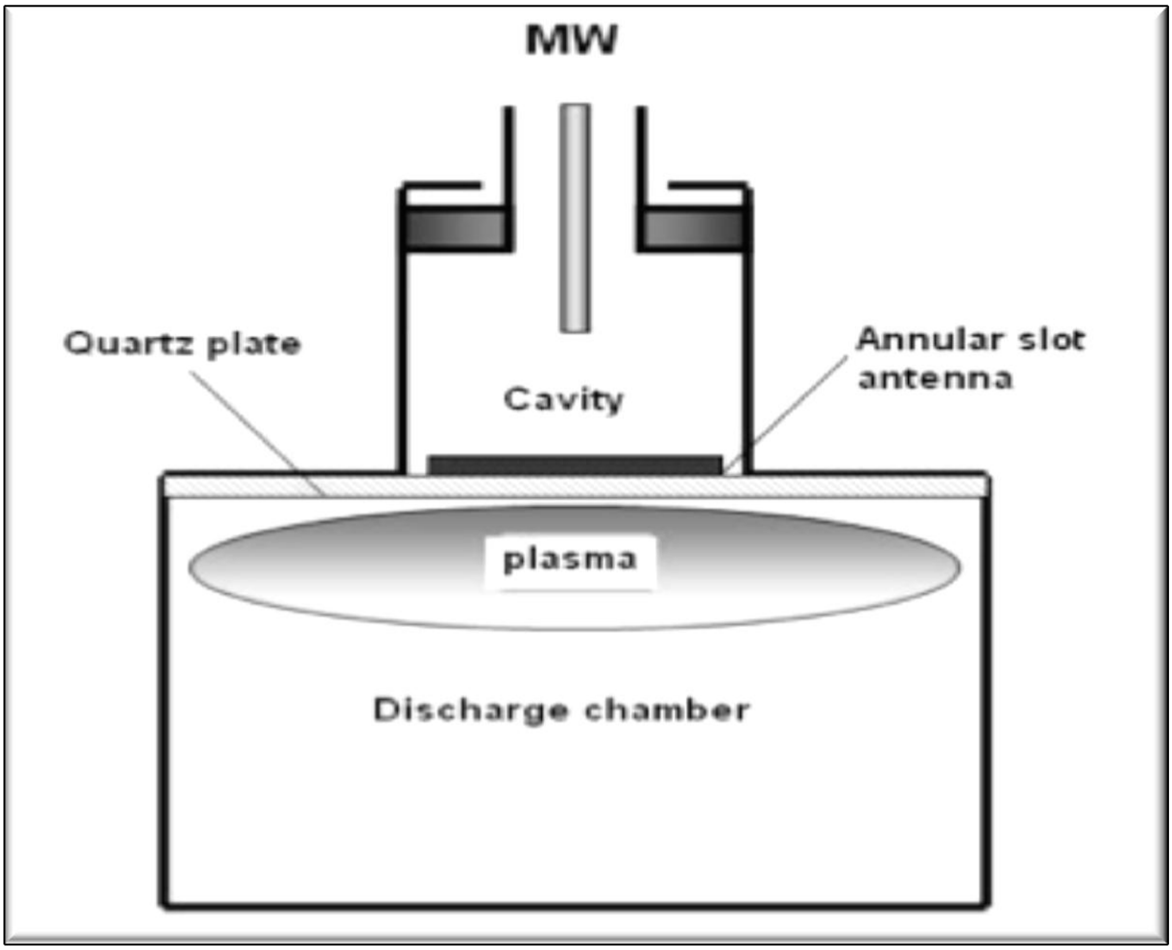



Figure 1-9 microwave discharge system [32]

## 1.8 Agriculture Field Challenges

When people think about the threat they facing the humanity, is tend to be climate change and antibiotic resistance. The needed for food possess is one of the biggest challenges to humanity as well. The most important challenge in agriculture is improving seed growth and germination [34].

The increasing in the world's population and the long-life expectancy, has led to the urgent need to increase wheat production and improve its quality. However, despite these efforts, nearly 700 million people are still lacking food supplies, which may reach 840 million by 2030 [35].

There are some challenges in agriculture face the storage procedure, for instant, dispersing of crop seeds in dry and mature states [36].

In germination process (when favorable conditions are available), the seeds will experience a complex process of germination and growth. The process of seed germination is a complex physiological process that has regular paths and signals that affected by the factors of the surrounding environment and the factors of internal germination [37].

One of the main and important objectives is to develop more efficient and sustainable crop production methods to meet basic food needs. Wheat (*Triticum aestivum L.)* is one of the most important strategic crop plants that contribute to global food security [36].

## 1.9 Aim of The Study

This project aims to design and construct a non- thermal plasma jet system and study the effect of cold plasma on the Iraqi wheat seeds and investigate the seeds germination and growth ratio as follow:

1. A non-thermal plasma jet system dielectric barrier discharge (DBD) type will be designed and constructed.
2. Characterize the (APPJ) system and optimize its performance.
3. Analyze the spectral emission of the yield plasma to determine the density and temperature of electrons so that quality of produced plasma can be evaluated.
4. Use the constructed system to treat the Iraqi wheat seeds to investigate the seeds germination and growth ratio.

# Chapter two

# Theoretical Part

# Chapter Two
# The Theoratical Part

## 2.1 Introduction

Discharge phenomena can be defined as the transition of the electrons and ions through the medium of gas (plasma). Plasma could be generated in many ways, such as vacuumed plasma, and DBD plasma. The ion-electron pair and flow current could be formed when the atoms and molecules of the gas breakdown electrically by using a very high voltage applied across the electrodes. The breakdown point could be characterized when the gas transition between poor and high electrical area is achieved. In addition, the breakdown potential may be characterized when the transition occurs as a function of the difference between two electrodes[38].

The gas density and identity, electrodes type, separation of inter electrodes and preexisting ionization degree are crucial parameters for determining the voltage breakdown. The created ions and electrons which are the result of the gas breakdown, the electric field may be developed in the area between electrodes dictating that the charged particles accelerated toward the cathode and anode. Separation charged could be observed as a result of collision processing therefore, the suitable voltage is important to achieve the self-sustaining, which is usually lower than the breakdown voltage[39].

## 2.2 Dielectric Barrier Discharge

The dielectric barrier discharge (DBD) is the discharge induced between two electrodes supplied by a high voltage and frequency (V ≈ (1-50) kV, f ≈ (1-50 kHz)) and insulated each other by an insulating layer located on one or both electrodes. Figure (2-1) illustrates the Dielectric Barrier Discharge diagram and a floating electrode DBD. The current consists of pair of components, the first one is the displacement current, which leads the voltage by 90°, and the second one is the conduction current as a result of the flow of electrons inside filaments of plasma transferring from the negative electrode to the positive one[40].

The displacement current of the DBD discharge is

$$i_D = C\frac{dv}{dt} \qquad (2\text{-}1)$$

Where $C = C_O + C_P$ .

C = the capacity of the discharge system.

Without Plasma the capacitance of the system is $C_O$. The capacitance of a DBD actuator grows when the discharge is ignited and the plasma is present. The plasma acts as an extension of the electrode. $C_P$ is the contribution of the plasma to the capacitance of the system. the conduction current flows into filaments with the ionization front, (Front of the filament propagating from the cathode toward the anode) [41].

- Filament diameter: ≈ 0.1 mm
- Velocity of the ionization front: ≈ $10^5$ m/s
- Filament life: ≈ 10 ns

The DBD electrical discharge characteristics are subject to many parameters for instance, the series capacitance participated by the dielectric and frequency of the discharge voltages, dielectric material, and modifying sandwiched of air gap by the electrodes. At atmospheric pressure, DBD is explained as either filamentary or diffuse depending on these parameters. By utilizing the generating of low temperature plasma, bacterial cell could be destroyed.

The multiple uses of non-thermal plasma have made it very popular, such as industrial ozone generation applications, controlling the proportions of gaseous pollutants, modifying the surfaces of materials, lighting and plasma screens [42].

## 2.3 Atmospheric Pressure Plasma Jet

Nowadays, the non-thermal atmospheric pressure plasma jet (APPJ) has an increasing demand because of its promising for many biological and industrial applications [43]. He, Ar, Air gas etc. have been utilized for generating the plasma, these gases are reactive species sources, which could participate in many chemical reactions. Many types of plasma apertures have been presented, based on applied voltage and plasma generation methods for instance, pulsed DC power supplies, DBD pencil, single and double electrode plasma etc. These apparatus have an advantage to generated plasma in area of discharging and deliver it into the ambient air. The difference between the non-thermal and thermal plasma in nature, which makes the non-thermal more complex in terms of the physics and chemistry, for example the ions particles remain close to room temperature while the electron temperature reaches many thousands of Kelvins. Therefore, it is suitable for applications of biomedical such as wound healing, blood coagulation, and electrosurgery. In addition, other advantages of non-thermal plasma, it does not require the complex and expensive vacuum operation methods and it is low coast for plasma generation[43].

The parameters of plasma plume for example, temperature of electron excitation ($T_{exc}$) and temperature of plasma ($T_g$), density of electron ($n_e$), and reactive species of plume, plume velocity. must be needed to understand to use it for applications of biological and industrial. The plasma jets are produced by

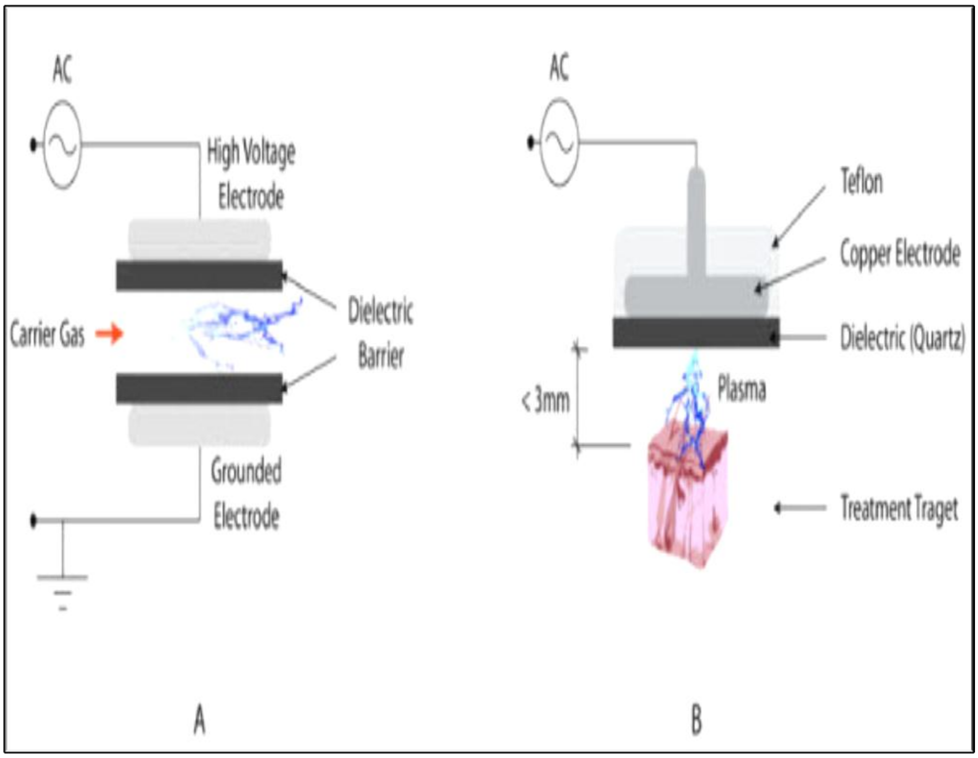



Figure 2-1 A Dielectric Barrier Discharge diagram and a Floating Electrode DBD. A. present plasma formation (DBD), and B. presents the Floating Electrode (FE-DBD) [44].

applying pulsed voltage or sinusoidal of some kilovolts with frequency variables from many hundred hertz to gigahertz. Because of the APPJ aperture does not need a vacuum chamber [44].

### 2.3.1 Types of Atmospheric Pressure Plasma Jet

There are four types of non-thermal Atmospheric Pressure Plasma Jet [45][44]:

- Dielectric Free Electrode (DFE) Jets.
- Single Electrode (SE) Jets.
- Dielectric Barrier Discharge (DBD) Jets
- Dielectric Barrier Discharge-Like (DBD Like) Jets

### 2.3.1.1 Dielectric-Free Electrode Jets

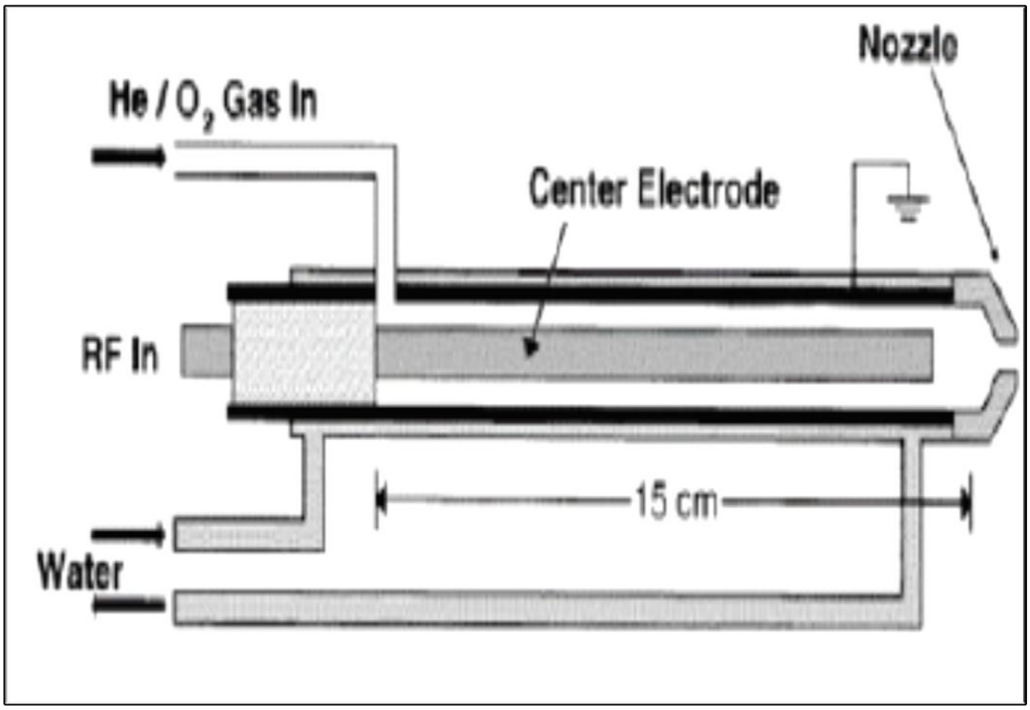



Figure 2-2 Schematic of (DFEJ) atmospheric plasma jet device [45].

Dielectric-free electrode jet (DFEJ) is run by a radiofrequency energy source of 13.56 MHz. An external grounded electrode and internal electrode, which couple to energy power supply are composed the (DBDJ) as shown in figure (2-2) In order to generate the plasma jet, therefore, the noble gas and one type of reactive gas may be introduced inside the space of annular between the poles.

RF power can range approximately between (50 -500) watt, and the plasma jet temperature could range between (50-300) °C. The water-cooling system is needed to prevent the overheating of the plasma jet system. Because of these drawbacks the (DFEJ) system does not appropriate for biomedical applications, whoever, it could be used for materials processing as long as sustainable the high temperature degree [45].

### 2.3.1.2 Dielectric Barrier Discharge-like Jet (DBD)-like

Figure (2-3) presents the DBD-like jets. The name of DBD-like is coming from that the plasma looks like a DBD when it is connected free with conductive object, whereas, it is not DBD if it is connected with conductive object, the discharge is observed between the high voltage electrode and the conductive object.

The DBD-Like system has a disadvantage, there is a high potential for electric arc generation, and depending on the type of used material (conductive or non-conductive), and the field application, whereas DBD systems, it does not have the risks of electric arc generation. The preventing of arc production gives the system many advantages[46]. In addition, firstly, RF power (kHz), AC power and even Pulsed direct current power are used to run the DBD-like jet system. Secondly, the hollow electrode may be used instead of the high-voltage electrode as explained in figure (2-3) (b). Injection of the first inlet by noble gas and the second inlet by active gas is going to increase the plasma jet [47].

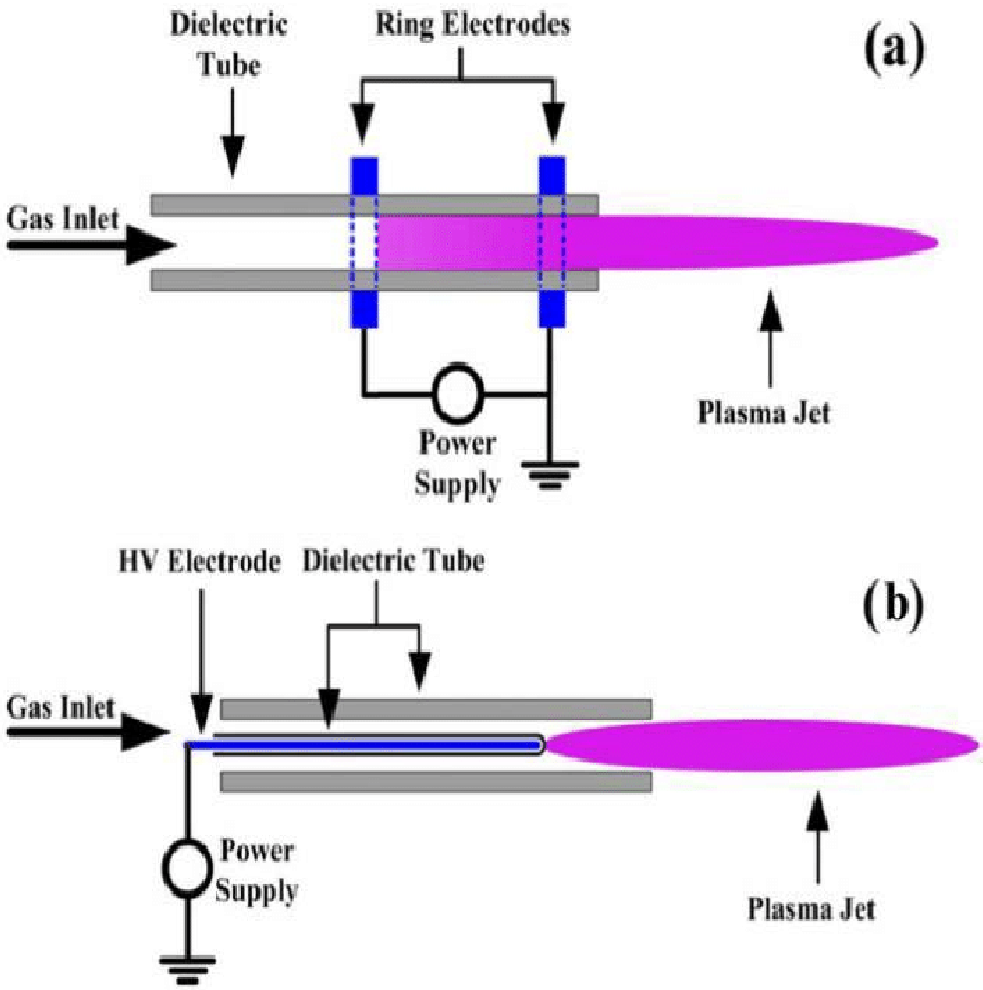



Figure 2-3 DBD-like jet schematic A. dubal rings electrode B. hollow electrode [48]

### 2.3.2 Single Electrode Jet (SE)

Single electrode jets (SE) consist of an insulating tube and electrode contacted to the power supply, the system could be fed by noble gas or an active gas as a working gas. There is a big similarity between the SE jet and the DBD-like jet in term of configuration except that the ring electrode outside dielectric tube is removed, therefore the directing of the frequency or pulsed direct current could be controlled according to the unique role of the dielectric tube[48]. The directed current, alternating current, radio frequency or pulsed direct current are used in order to run this type of jet [47].

## 2.4 Dielectric Barrier Discharge Jet (DBDJ)

Dielectric barrier discharge jets (DBDJ), distinguished by many configurations of jet with single or double dielectric barriers. Figure (2-4) (a, b) illustrates the first configuration of (DBDJ) which is recognized by the two metallic ring electrodes, which are located and surrounded on the outer side of the dielectric tube. The cold plasma jet will be generated as soon as, firstly: applying a high voltage of kHz across the electrodes, secondly, passing the noble gas through the quartz tube[49].

The researchers found that the plasma jet needs (a few watts) a low power to be generated. The temperature of the plasma gas is equal to the temperature of ambient, and that the plasma jet, which manifests to the observer of naked eye to be homogeneous, in reality, a bullet-like plasma volume with a high propagation velocity exceeds 10 km $S^{-1}$. By cancelation of the electrode as illustrated in figure (2-4) (e) the discharge inside the dielectric tube will be decreased. Replacing the high voltage electrode with pin electrode located in the center of dielectric tube is going to mend the electric field along the plasma jet. The researchers prefer the pin electrode for more reactive species, as illustrated in figure (2-4) (c, d) [49].

If the second ring electrode is eliminated as shown in figure (2-4) (f), the discharge inside the dielectric tube becomes weaker[48].

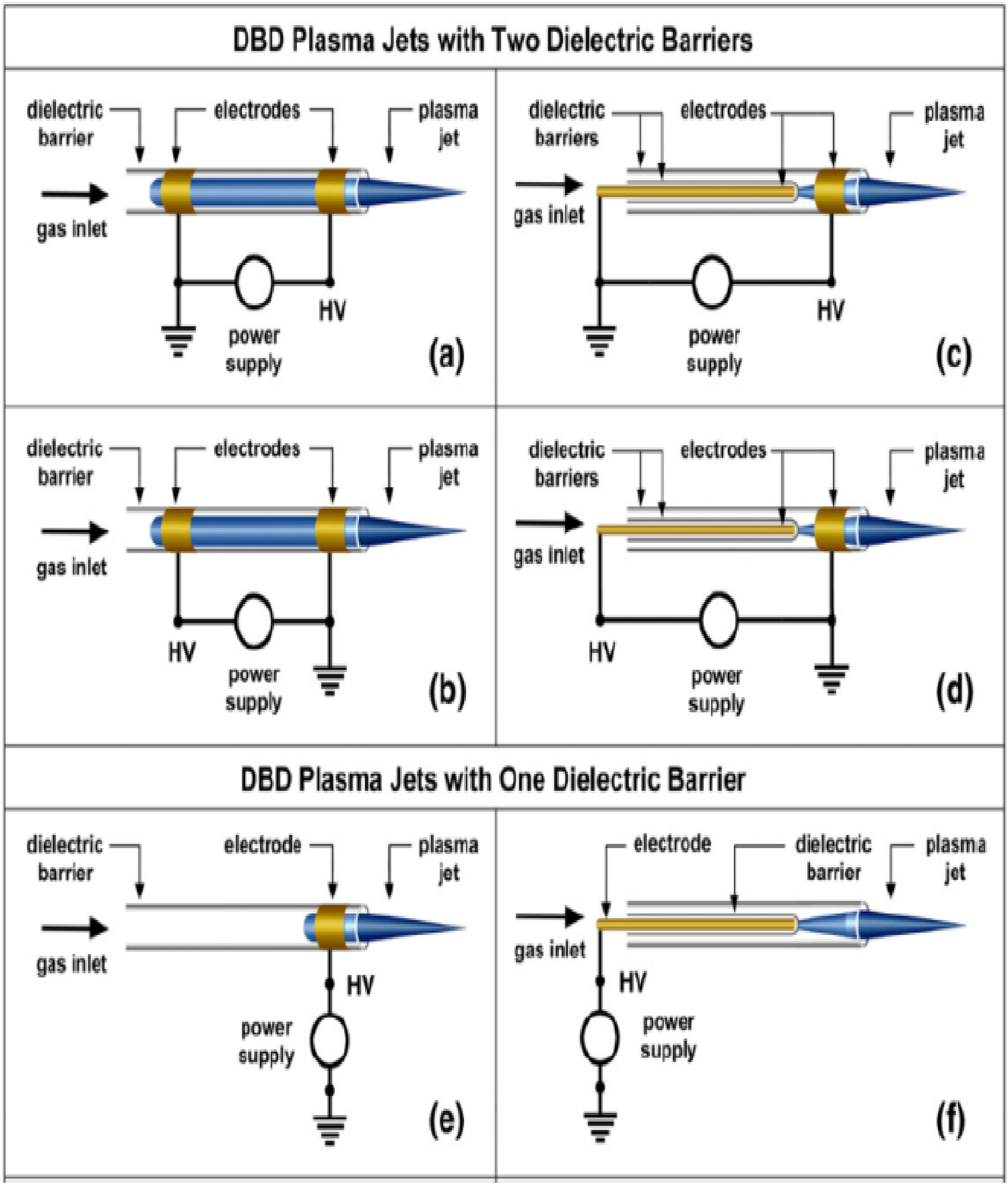



Figure 2-4 configurations of different DBD plasma jet [48].

## 2.5 Applications of Non-Thermal Plasma Jet

The non-thermal plasma jet is a promising technique that could be used in many fields, because of its properties, such as there is no side effects on the environment, and the coast of plasma jet system is unexpansive. Cold plasmas could be utilized for surface materials modifications, construction of chemical arterials, surface coating, and topographical changes as shown in figure 2-5.

Atmospheric Pressure Plasma jet technology offers revolutionary new technology for fast material and personnel decontamination, by choosing the appropriate collection of electromagnetic frequency, feed gas composition, and electrode geometry, the APPJ has ability to operate as a uniform, non-thermal discharge at atmospheric pressure. A high density of reactive species is produced by the APPJ system at relatively low temperature; therefore, it is possible to take advantage of the combination of the characteristics of the arc and the corona discharge. Previous studies have proven that cold plasma offers a range of methods that eliminate pathogens and toxins without generating any harmful or toxic components. This is because of the atmospheric pressure plasma operates at low temperatures and therefore provides a viable and important method for removing contaminants from highly sensitive equipment without any damage. [48].

Cold plasma has a very important role in destroying and inactivating harmful bacteria and therefore it is used as a highly effective disinfectant to sterilize surgical instruments that are used in surgical operating rooms. Recently, non-thermal plasma is used in health care and treatment of living tissues that suffer from diseases through high-precision control to remove damaged tissue parts of the body [50].

Seed germination and seedling growth are one of the crucial application of cold plasma in last decade, because of its potential to increase the germination percentage and the average seedling growth vigour [51].

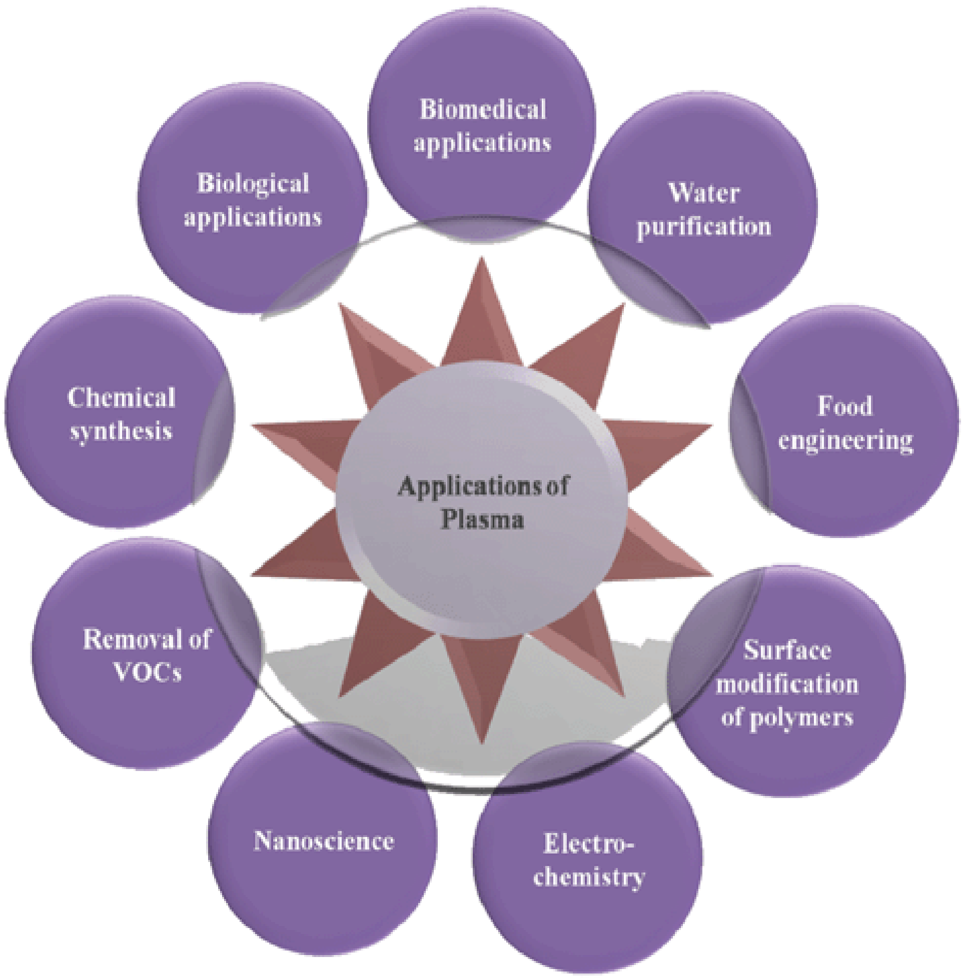



Figure 2-5 plasma applications diagram [11].

The emerging cold plasma technology is used to improve food safety and preserve it for a longer time, and it is widely used in the food industry, for example, cold plasma is used to kill and disrupt the activity of contaminated and active microbes in meat, fruits and vegetables without changing the basic composition of foodstuffs. Therefore, it has the characteristic of improving food safety without losing physical and chemical properties[52]

## 2.6 Reactive Species

The collision between the accelerated particles with molecules or atom gas could be producing the reactive plasma species such as, reactive oxygen and nitrogen species (RONS) by ionization, exiting or dissociate the molecules gas. Reactive oxygen species (ROS) are defined as highly reactive and oxygen-carrying molecules consisting of a superoxide anion ($O_2^{\bullet -}$) a hydroxide radical (OH), a single oxygen($^1O_2$), and hydrogen peroxide($H_2O_2$) [53].

Many parameters could affect and control the density of reactive species for instance, frequency, and the applied voltage. The noble gases, such as (He, Ne, Ar, Kr, or Xe), might be utilized as a working gas. In addition, Air, Oxygen, and Nitrogen could be presented with a very small amount for increasing the reactive species density[54].

RONS are suggested to treat the medical subject directly for two reasons: first of all, they have significant effect on the organism, and secondly, they have lifetime up to several milliseconds. The chemical reaction inside the generated plasma could be produced reactive oxygen species (ROS), when it has the $O_2$ or $H_2O$. Whereas, it can produce the reactive nitrogen species when it has apocopate nitrogen molecule.

Oxygen, hydroxyl radical, and ozone are the constant of ROS, while the RNS constant of $N_2$, NO, and $NO_2$. The reactive species are easily produced in ambient air, and water with enough lifetime to destroy the bacterial cell [52].

## 2.7 Plasma diagnostic

There are many ways too diagnostic the plasma for example: electrical probes, magnatic probes, lineshape and optical emissin spectroscopy. The Boltzmann plot method is a straightforward, and well- known utilized procedure for spectroscopic measurement, especially for deducing the electron temperature of plasma by utilizing the relative intensity of more than two-lines spectra which are possessing a relatively huge energy difference [55]. The Boltzmann plot method is practically applied when the excitation level reached under the Local Thermal Equilibrium (LTE) [56]. The gas ionization is different according to gas type, for instant in despite of Hydrogen molecular dissociation approximately (3,500 K) requires energy, the ionization starts for pure argon at (8,000 K), Argon, and Hydrogen exhibit ionization energies at (15.8, and 13.6 eV) respectively [57].

The electron temperature ($T_e$) is an important parameter to describe the characteristics of an APPJ, the ($T_e$) can be evaluated from Boltzmann plot method using the relation below [58].

$$ln\frac{(\lambda I)}{g_{u\,A_{ki}}} = -\frac{E_u}{K_B T_e} + C \qquad (2\text{-}2)$$

where (I) is the relative intensity of the emitted line, $(\lambda)$ is the wavelength, $(g_u)$is the statistical weight of the upper level which can be calculated from the total angular momentum quantum number ($J$) by ($g_U = 2J + 1$), ($A_{ki}$) is the transition probability (the probability per second that an atom in upper-level state emits in a random direction, and is de-excited to a low-level state).

($K_B$) is the Boltzmann constant ($1.38 \times 10^{-23}$) ($\frac{J}{K}$), ($T_e$) is the temperature in kelvin, (C) is a constant, and ($E_U$) is the energy of the upper level. A graph plotted for different values of ($\ln \frac{(\lambda I)}{g_u A_{Ki}}$) versus the energies of the upper level ($E_U$) gives a straight line with a slope of ($\frac{-1}{T_e}$). ($\lambda$), ($A_{Ki}$), ($g_U$), and ($E_U$) obtained from the National Institute of Standards, and Technology (NIST), atomic spectra database levels form.

The electron density ($n_e$) can be determined using the Saha-Boltzmann equation. The electron density ($n_e$) can be determined from the neutral particle (atomic) and the singly charged ion (ionic) spectral lines which emitted from the plasma jet using the Saha-Boltzmann equation which given as [59].

$$n_e = 6.04 \times 10^{21} \frac{I^a \lambda^a g^i A^i}{I^i \lambda^i g^a A^a} T^{\frac{3}{2}} \times \exp\left[\frac{E^a - E_{ion} - E^i}{k_B T_e}\right] \qquad (2\text{-}3)$$

The upper indices ($a$) and ($i$) indicate to the neutral particle and the singly charged ion, respectively. E ion is the ionization energy of the neutral particle. The values of ($E^a$, $A^a$, $E$ ion, $\lambda$ &$g^a$) can be obtained from the (NIST) atomic spectral database.

## 2.8 Mixed Gas for APPJ.

In order to enhance the quality of the produced plasma jet, researchers used to add a small percentage of oxygen gas to noble gas to achieve the production of a highly efficient plasma type [60]. It can be said that adding a certain percentage of oxygen gas to the working gas will positively affect most of the properties and parameters of the produced plasma jet [61] .

Reactive neutral species play the main role in utilizing plasma especially for sterilization purposes. Some studies indicate that cold plasma is generated Reactive Oxidative Species (ROS), which causes morphological changes to coliforms, membrane depolarization, lipid peroxidation, and DNA damage, depending on the used dose[62].

## 2.9 Germination Rate and Growth Speed of Wheat

Wheat is an essential source of minerals, proteins, starch, and oil reserves in the early stages of plant germination and growth. However, the availability of these important elements in the composition of cereals made them of great nutritional importance to the majority of the world's population, despite that, farmers use chemicals to avoid diseases and pests to obtain optimal production. These chemicals used to cause severe damage to the soil and the environment surrounding the fields and thus constitute a clear threat to the environment [63].

The composition of wheat contains a high level of carbohydrates, proteins and dietary fibers, and a high percentage of vitamins, minerals and antioxidants such as carotenoids, phenols and phytosterols [64]. After germination, wheat sprouts are an analog of medicine and food, they are reach in bioactive compounds and can be consumed as raw juice, tablets and capsules, and therefore wheat germ juice is increasingly being studied. Therefore, improving the germination and growth of wheat seeds is of great importance in the industry. Various traditional methods are used to improve the germination of wheat seeds mainly on chemical treatments that can cause environmental risks; Therefore, new physical therapy techniques have been investigated for their potential enhancing effects on wheat seed germination and seedling growth [64]. The treatment of seeds by cold plasma is going to be depends on the type of seed, Therefore, the time of plasma treatment has to be optimized for each type of seed individually[65]

## 2.10 Wettability of Seeds

The germination percentage and the speed of germination are improved as a result of cold plasma treatment. Cold plasma jet modifies two properties of seed surface morphology and chemistry of surface, therefore the seed wettability increase [66]. Figure (2-6) illustrates the wheat seed structure. The structure consists of four area; pericarp, seed coat, endosperm, and embryo [67].

To discuss the possibility of increasing the rate of water absorption (hydrophilic) or the wettability of the surface of the seed, it is necessary to consider the chemical composition of the seed itself. The outer seed is encased in a casing called (Testa), which is a layer of dead cells that serves to protect the seed. In addition, many types of seeds are covered by the epidermis, which is a hydrophobic, waxy layer that protects the seeds from moisture [68] .

The consistence of cuticle is cuticular waxes, typically a mixture of long-chain, saturated, unbranched hydrocarbons, with polymeric support by the biopolymer cutin, long hydrocarbon chains with fundamental aliphatic polyester. Its chemical composition shows that the nature of the skin is hydrophobic, the skin has a hydrophobic nature[69].

The most important role of coat seed, the cuticle in particular, is to protect the mature seeds from moisture fluctuations as well as from excessive amounts of water and electrolyte leakage during the germination period [70].

However, the arrival of water to the embryo is crucial for initiating the germination process, and increasing the surface area will increase the wettability rate as a result of increasing the contact area between the water and the seeds. This procedure is going to increase the chances of forming a watery film on the surface of the seeds and speeding up the process of immersion of the seeds [71]. Moreover, direct and effective contact between water and the surface of the seed can positively affect the germination process. Modifying or improving the wettability of the seeds is very important and has a clear effect on increasing the process of germination and growth. It is known that treatment with cold plasma will improve the wettability of seeds, including polymers [72].

Plasma seed treatment increases the wettability of the seed surface as a result of modifying two properties, namely the chemical composition of the surface and reshaping the surface. It is noticeable that the increase of wettability depends on the combined effect of these two properties. Plasma penetration to the surface reaches tens of nanometers in depth. Generally, the thickness of the seed epidermis is from 0.1-10 nanometers, and the thickness of the epidermis of the Arabidopsis seed is about 300 nanometers, and therefore the modification is limited to the outer layers of the seed. However, ultraviolet radiation (UV)may penetrate the organic matter more[66].

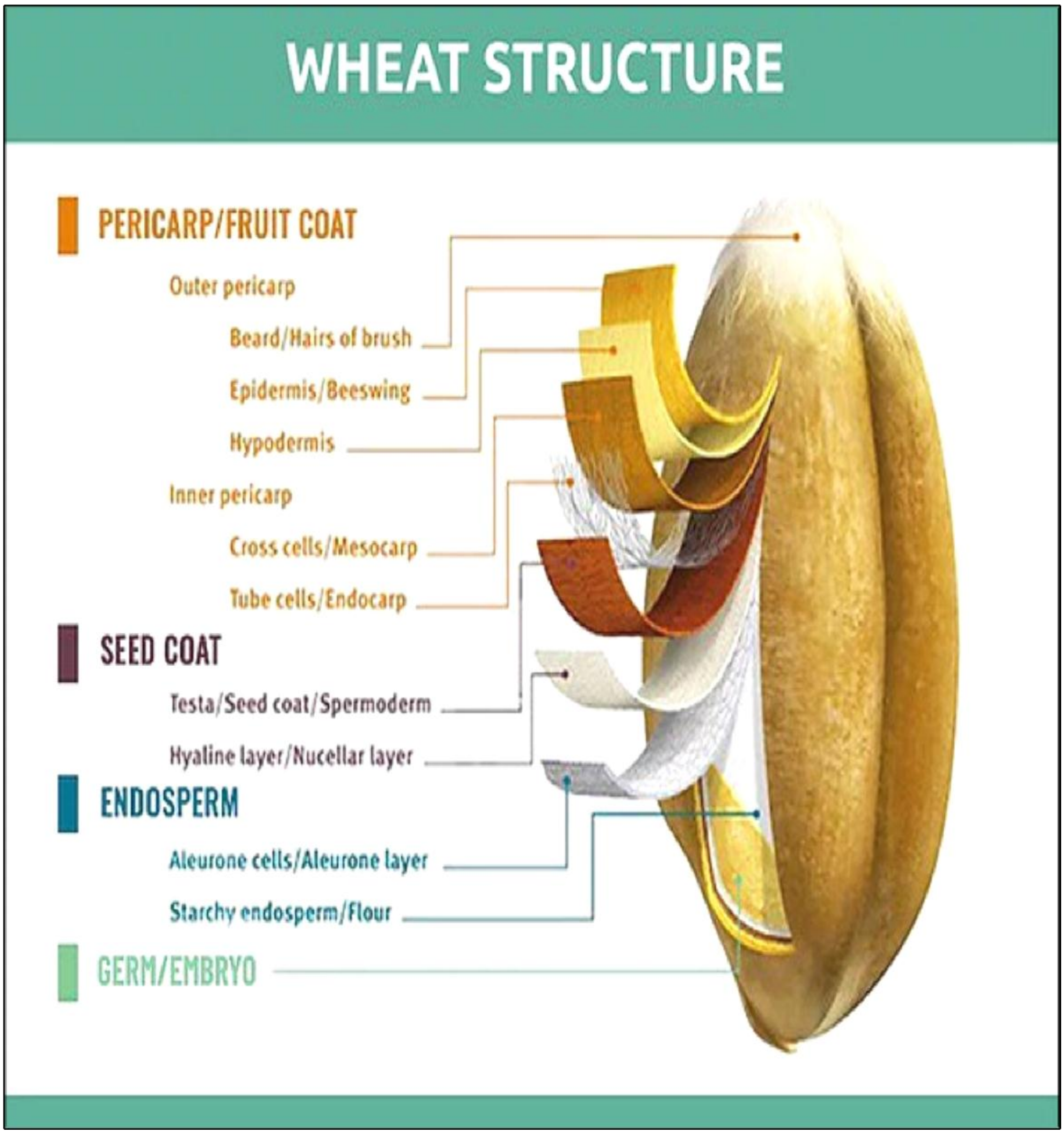



Figure 2-6 Wheat seed stricture [73]

## 2.11 Literature Reviews

In 2007 Selcuk et al, showed that the cold plasma had great efficacy in inactivating the pathogenic fungi Aspergillus and Penicillium present on the surface of the seed. The study tested several seeds such as tomato, wheat, beans, chickpeas, soybeans, barley and oats, where the fungal contamination was treated through a gas-felled process followed by plasma discharge for a period of 5-20 minutes, where the results showed a decrease in the level of fungi to less than 1% without affecting, the quality of seed germination and also confirmed that the aflatoxin-producing fungi from the surfaces of seeds and nuts[74].

In 2011 Binna Kim et al, reported that there are many technologies, including conventional thermal treatments, have been used to control microbial decay in foods and animal food origin products. Such as, thermal sterilization is traditionally used for decontamination and inactivation of pathogens[75]. Nevertheless, H. J. Kim et al, reported that many issues are related to the thermal quality of food processing as a result of the negative impact on the value of nutritive and the properties functional, and sensory qualities. There are several drawbacks with these technologies, for instant a high price of application, consuming time of processing, and poor efficiencies[76].

In 2012 P. Kumar and J. H. Han, reported that the cold plasma is an electrically energized matter consisting of highly reactive species, which includes molecules of charged and gas with particles in the form of negative particles and positive ions, and free radicals at room temperature. It is an emerging technology in non-thermal food preservation in the application of sterilization [77].

In 2013 Herrmann et al, pointed out that the D value (the time needed for killing most microorganisms) has a high value with Oxygen absent. The D value was over 20 minutes for pure helium plasma in order to kill 90% of Bactria, whereas it was 10 minutes for the mixture of oxygen and helium, in addition, the D value was 20 seconds for air to kill 90% of bacteria [78].

In 2013 D. Bermúdez-Aguirre, shows that the reactive species in plasma have been widely associated to the direct oxidative effects on the outer surface of microbial cells membrane. The lipids are assumed to be significantly affected by the reactive oxygen species (ROS) due to their location along the surface of bacterial cell, which allows them to be bombarded by these strong oxidizing agents. Micro-organisms are exposed to an intense bombardment by the radicals most likely provoking surface lesions that the living cell cannot repair sufficiently faster [79].

In 2014 J. Jiang et al, pointed out that the increasing of wheat crops, improving germination, growth promotion, and physiological wheat level increasing, were improved as a result of the cold helium plasma treatment. In addition, a dormancy breaks can be done by treating the wheat seeds with non-thermal plasma reactive species like UV radiation, radicals, and chemical reactions [80].

In 2014 K. M. Ahmed, explained that the reactive oxygen species (ROS) and the reactive nitrogen species (RNS), are often components of generated atmospheric pressure plasmas jet. They are crucial and effective components for biomedical purposes. In addition, the study suggests that ROS/RNS are significant and perhaps even central actors in the actions of antimicrobial, antiparasite drugs, cancer therapies, wound healing therapies and therapies involving the cardiovascular system [81].

In 2014 K. M. Ahmed, et al, said that cold plasma is very effective in the process of decontamination of products contaminated with microorganisms located on their surface. It is also possible to take advantage of ultraviolet rays in the process of removing pollution, as the advantage of plasma flow around the objects, which means ensuring that all parts of the product are treated easily and without shadow effects[81].

In 2014 J. Jiang et al, pointed out that the treatment of seeds by cold plasma is going to be depend on the type of seed, therefore, the time of plasma treatment has to be optimized for each type of seed individually [80].

In 2016 P. Puligundla, T. et al, designed of a novel non-thermal plasma device used for the inactivation of Enterococcus faecalis bacteria and surface sterilization of the packaging materials that used in foods preservation [21].

In 2016 N. Misra et al, pointed out a new decontamination technique developed for powdery foods by using non-thermal plasma device type a cylindrical DBD, which operated at atmospheric pressure. The device was driven using a power supply delivered 2.5 kV at frequency of 5 kHz. The technic applied in order to deactivate Escherichia coli connected to the tea powder, the model has been carried at atmospheric pressure in a pin electrode configuration [39].

In 2016 N. Misra, et al, improved that the oxygen plasma treatment causes in a higher level of breakdown in the amorphas materials of potato and corn starch, while effects significantly on the C6 position for starch of wheat, as a result of conversion of group of hydroxyls to carbonyl group. In addition, researchers showed that using the cold plasma treatment of seeds will change the features of surface physically and chemically, and fall down the apparent contact of lentils angle ,bean and wheat, as a consequent the wettability of seeds is improved remarkably [1].

In 2016 S. Sadhu, R. et al, the plasma treatment significantly increases the destruction rate of amorphous materials. The effects of cold plasma on the surface features of seeds are known to have a positive effect on the wettability of the plant seeds. For instance, the decrease in the contact angle of various grains, such as wheat, lentils, and beans, has been observed[82].

In 2017 T.Darny et al, employed an atmospheric pressure plasma jet (APPJ) device which formed in pure helium gas to generate cold owing plasma at the system conditions of 18 kV and 15 kHz, the configuration of this device was constructed as a needle-to-ring electrode. This technique has great effect on the the reactive species production over the target, and it has a crucial for biomedical applications [83].

In 2017 P. J. Cullen et al, point out that new and different designs for processing food products such as air discharge designs, active water with plasma, atomizers, and integrated technology showed processing treatment for various types of foods that require a range of batches to continuous processing and dry wet processing and from small spherical materials to large size materials[84].

In 2019 R. Nisha, and R. Narayanan, improvement of germination, longer shoots and roots of the seedlings, and higher yields plasma-treated seeds have been reported by several authors using various seeds, including wheat, maize, soybeans and tomato [85].

In 2017 P. Attri et al, in a study conducted on weak wheat flour, the researchers found that the secondary structure of the protein improved after the air treatment. However, they noted that the increase in the DBD plasma treatment caused the loss of an orderly structure weak [86].

In 2016 N. Bahrami et al, the uses of oxygen plasma has been shown to improve the dough strength, did not affect the total non-starch lipids concentration , and the total proteins were not remarkably effected by treatment, the study confirmed that the cold plasma has a potential to modify the functionality of wheat [87]

In 2018 R. Thirumdas, reported that the seed germination rate can be increased on application of cold plasma by both direct and indirect treatments. Recently, the indirect treatment through the application of plasma activated water (PAW) has drawn some attentions [88].

T. Raviteja, et al., 2019, showed that there is an increasing in the plasma-based treatment for food employed to inactivate the food borne pathogens seen in recent years. The study recollects the activity of the plasma agents on the microbe population, surface decontamination of the raw produce in the food processing and future novelty in food technology [89].

In 2019 M. López et al, a study investigated the effect of tube materials made of glass and ceramic on the characteristics of an atmospheric pressure cold plasma jet. The configuration of plasma jet device was a single-electrode, the plasma jet was use as a potential application of non-thermal atmospheric plasma in the agri-food sector, apart from decontamination of food [38].

E. Feizollahi et al, 2020, give some insights on cold plasma technology exploitation for enhancement of seed germination, The research showed the atmospheric cold plasma efficacy for treatment of barley grains to reduce Deoxynivalenol levels and enhance the quality of barley grains by atmospheric cold plasma treatment. [90].

In 2020 Boeckmann et al, illustrated that the cold atmospheric plasma was used clinical studies is mainly limited to the treatment of chronic wounds. Whoever, cold atmospheric plasma has been shown to reduce microbial load without any known significant negative effects on healthy tissues, and this should enhancement its possible application to any microbial infection site. It has also been shown to have antitumor effects. In addition, it acts proliferative on stem cells and other cultivated cells, and the highly increased nitric oxide levels have a very important effect on this proliferation[91].

In (2022) Tavakoli, L. et al, pointed out that the treated of weak seed of wheat by an atmospheric pressure cold plasma led to stable of gluten ratio in secondary structure of wheat. In addition, they reported that the parallel and antiparallel β-sheets structure was increased remarkably when increased in DBD plasma treatment with 60 kV and 5 minutes, so the orderly protein structure will disappear. As a consequence, the dough strength and optimum mixing time in both weak and strong weak flours are enhanced in terms of mix graphic studies[92].

# Chapter Three

# Materials and Experimental Setups

# Chapter Three
# Materials and Experimental Setups

## 3.1 Introduction

In this chapter, the design and configuration of APPJ plasma jet device constructing will be explained and shown details of (electrical, optical and thermal measurements). The manufactured device is going to be used to treat the Iraqi white for testing the growth speed and germination ratio. Figure 3-1 shows the manufacturing the cold plasma jet.

## 3.2 Plasma Device Constructing

The plasma jet system was constricted and built as illustrated in figure 3-1. It consists of many parts as followed:

1. Oxygen tube.
2. Argon tube.
3. Built Power supply.
4. Pyrex tube.
5. Electrodes.
6. OES sensor.
7. High voltage prob.
8. Argon flow meter.
9. Oxygen flow meter.
10. Oscilloscope.
11. Laptop.


Figure 3-1 Photograph of APPJ plasma jet system (1. Oxygen gas tube, 2. Argon gas,3. Power supply, 4. Pyrex tube, 5. Electrodes, 6. OES sensor, 7. High voltage prob, 8. Argon flow meter. 9. OES device, 10. Oxygen flow meter, 11. Oscilloscope, 12 labtop.

The designed and built atmospheric plasma jet was characterized at room temperature with different electrode types (Aluminum, Copper, and Silver). After that, electrical properties, electron temperature, and optical properties are calculated. Finally, the optimum plasma was determind.

## 3.3 Materials, and Experiment Setup

The starting point of this project was to study the effect of several electrode types on the efficiency of the non-thermal plasma jet production, which is investigated in the advanced physics lab. A diagram of the constructed of plasma system, and a drawing of the built plasma jet system, which is used to produce (APPJs) as shown in figures 3-1, and 3-2 respectively.

The double-ring electrode structure effects the generating plasma. When using

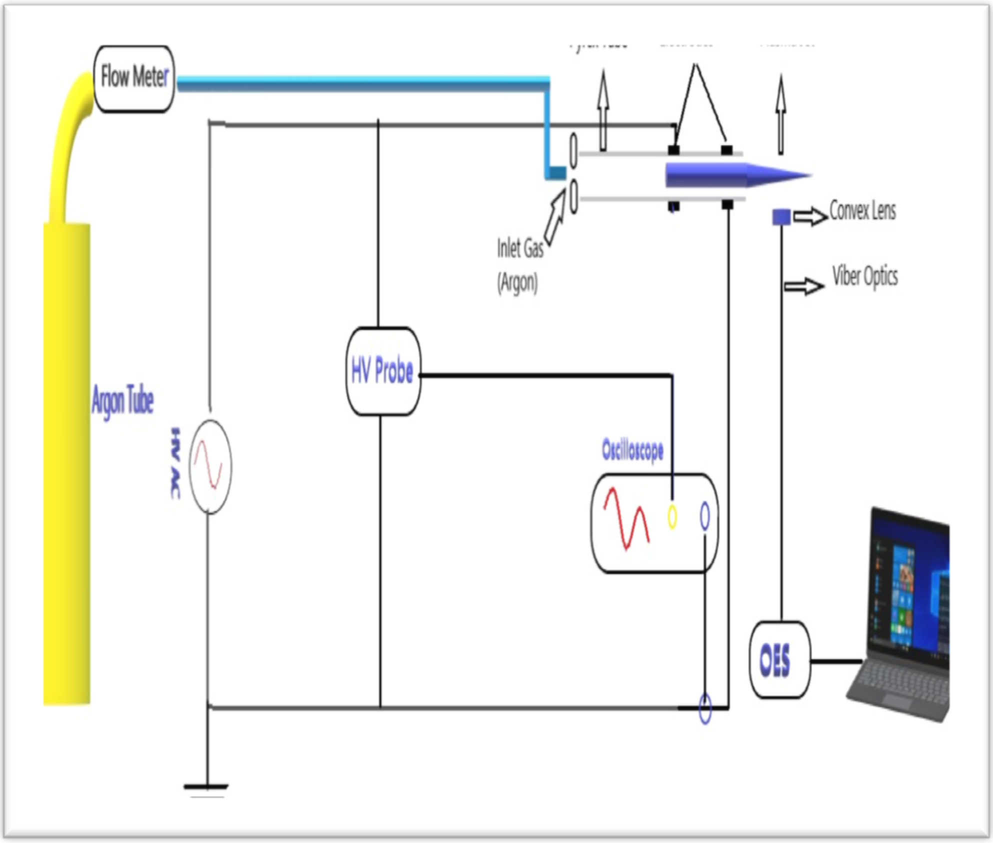
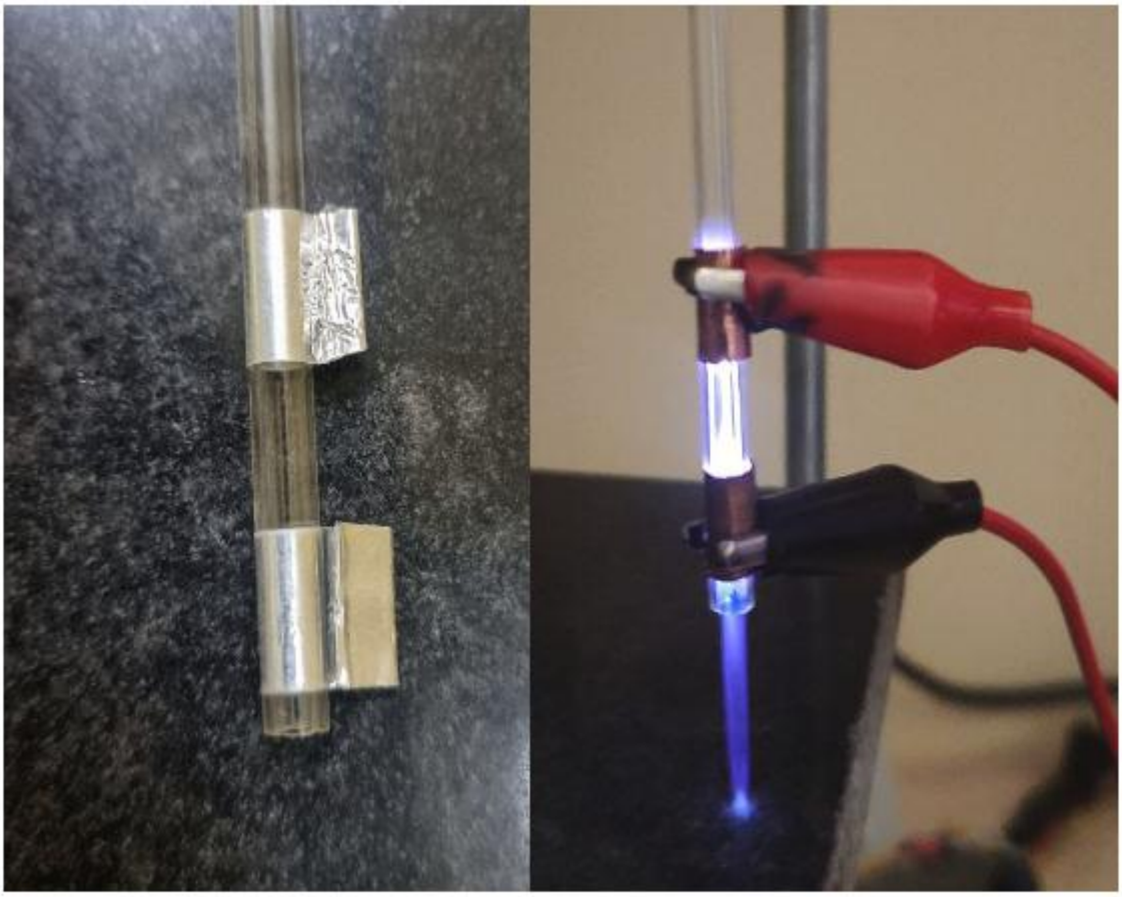



Figure 3-2 The plasma jet system schematic

different electrode types, the optical properties, electron temperature, the temperature of plasma plum, and the plasma plume depends on electrode type, which is used in plasma system configuration [11]. Therefore, all those parameters will be discussed, and studied in order to determine the optimum produced plasma jet.

## 3.4 Configurations of Tubes and Electrodes

The procedure of this configuration is, firstly, DBD jet consists of a dielectric tube (Pyrex tube) with double metal ring electrodes (Aluminum, Copper, or Silver), which are located at the external side of the tube as shown in figure (3-3).



A B

Figure 3-3 configuration of Pyrex tube with A. Aluminum electrode B. Copper electrode

Also, electrodes are connected to the high voltage power supply. Secondly, the length, and outer diameter of the quartz tube are (155, and 5 mm) respectively. The thickness of the quartz tube is (1 mm). The axial length, and diameter of ring electrodes are (10, and 2 mm) respectively. The distance between the two electrodes is (11 mm).

In addition, the distance between the ground electrode, and the nozzle of the Pyrex tube is (3 mm), as illustrated in figure (3-3).

The double ring electrodes configuration is used, and subjected to (7 kHz) supply frequencies, and, (9 kV) supply voltages. Finally, in order to test and check the electrical and optical properties of created plasma jet. Argon gas is used as the working gas, and the gas amount is fixed by flow meter at 4 standard liter per minute (SLM). The (SLM) can be defined as a unit of volumetric flow rate of a gas at standard circumnutates s for temperature and pressure [93].

## 3.5 High Voltage Power Supply

The plasma jet system was driven by local bulit high voltage AC power supply device, as shown in figure (3-4). The range of power supply output (peak-to-peak values) is (0-20kV) with frequency up to (150 kHz), and (220 V) as input power voltage. An overload, open circuit earth leakage is connected to the power supply.

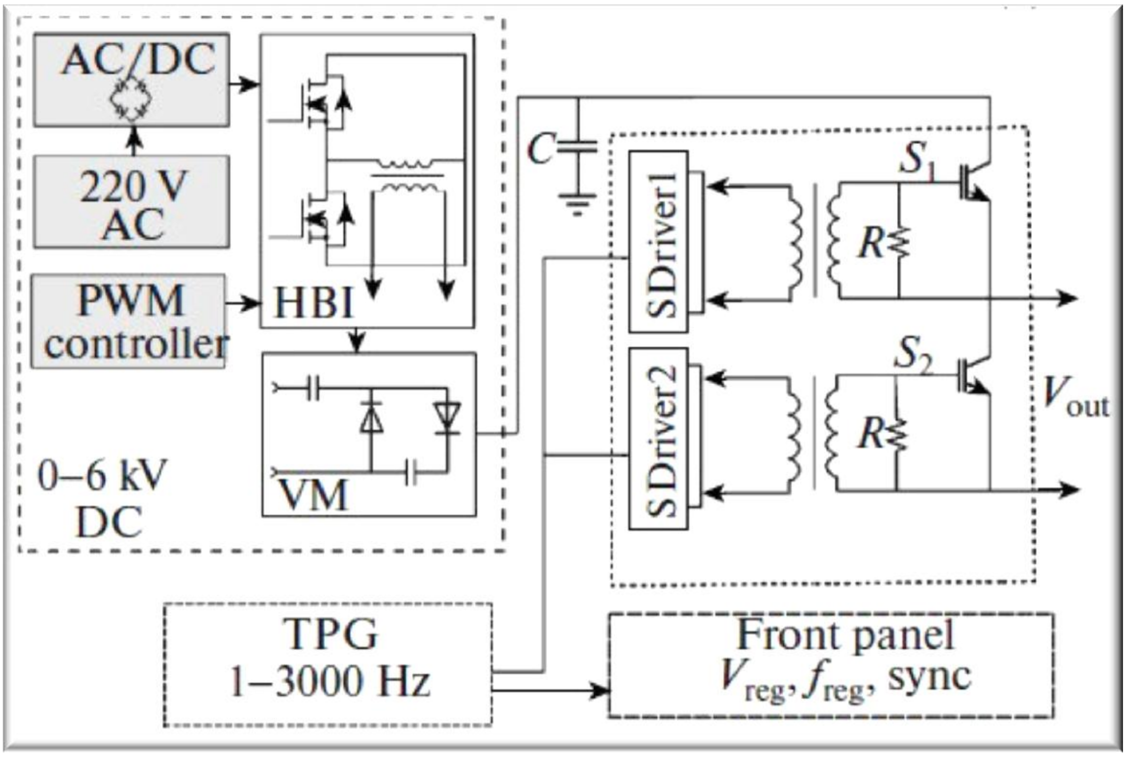
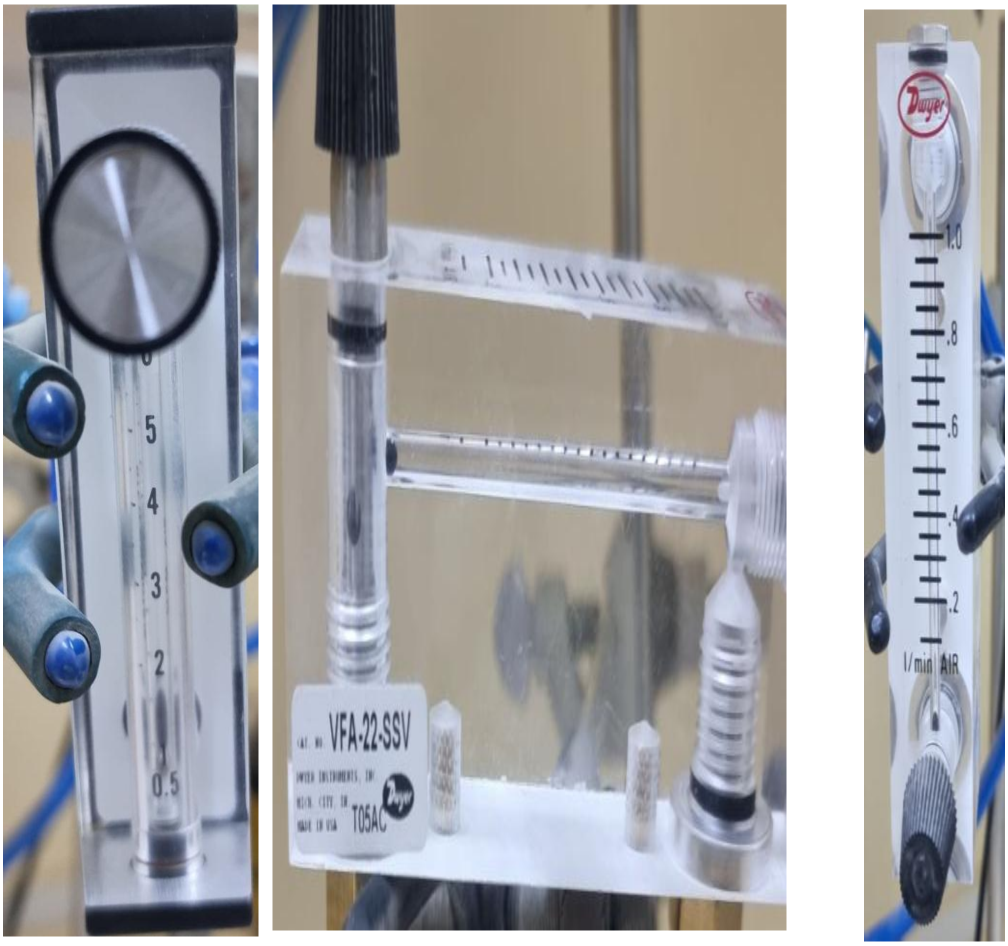



Figure 3-4 The (peak to peak) high voltage power supply schematic [94].

## 3.6 Gas Flow Controller

Two types of gas flow meter (needles valve) were used, the first one is the (VFA-22-SSV (Dwyer, USA), with (1-6) SLM range), which is fed via a flexible plastic tube. The second one is 11420 (Mathesen, USA) with (0-1) SLM range) was controlled by double stage regulator (BOC, UK), as shown in figure (3-5).

Argon gas with commercial grad 99.998%, and Oxygen gas with commercial grade 99.999% are utilized. The flexible plastic tube was connected to the top edge of the Pyrex tube by plastic lock from one end, and connected with gas tube with another end.




A

B

Figure 3-5 A. the Argon flowmeter, B. the Oxygen flowmeter. They are used in order to control the ratio of the flow gas (Oxygen and Argon)

## 3.7 Effect of Tube Thickness on the Efficiency of Plasma Jet

The researchers showed that decreasing the wall thickness of the tube will improve the cooling power, and lowers the thermal stress of quartz tube, therefore the plasma jet plume will be cooled [95]. They pointed out that the tube wall thikness of (1) mm was the optumm for the generation of plasma [96].

## 3.8 Characterization the Plasma Jet System Parameter

### 3.8.1 The Electrical Characteristics

A high-voltage probe (Max 28 kV ac 40 kV dc cat III) is used to determine the electrical wave front for the generated plasma, it has a division ratio (1000:1) and bandwidth of 75 MHZ, as in figure (3-6). The connection way, which is used, the downstream electrode has connected to the ground lead, and the upstream electrode of the Pyrex tube has connected to the tip part of the high voltage prob.

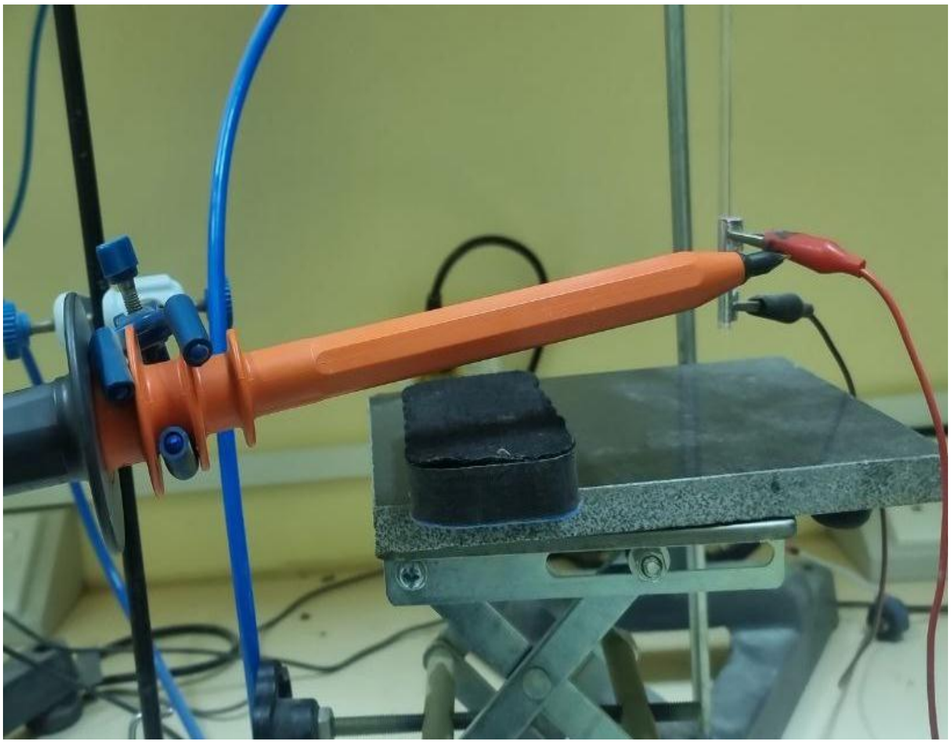


Figure 3-6 The high voltage prob

In order to determine the bandwidth of the voltage, the input channel of the oscilloscope (Hantek, China) is connected to the voltage prob. The oscilloscope has three input channels, as shown in figure (3-7) and with a bandwidth of 20 MHZ. The wavefront can be observed by connecting the apparatus to a laptop computer. In addition, the waveform of the discharged current is measured in the same way.

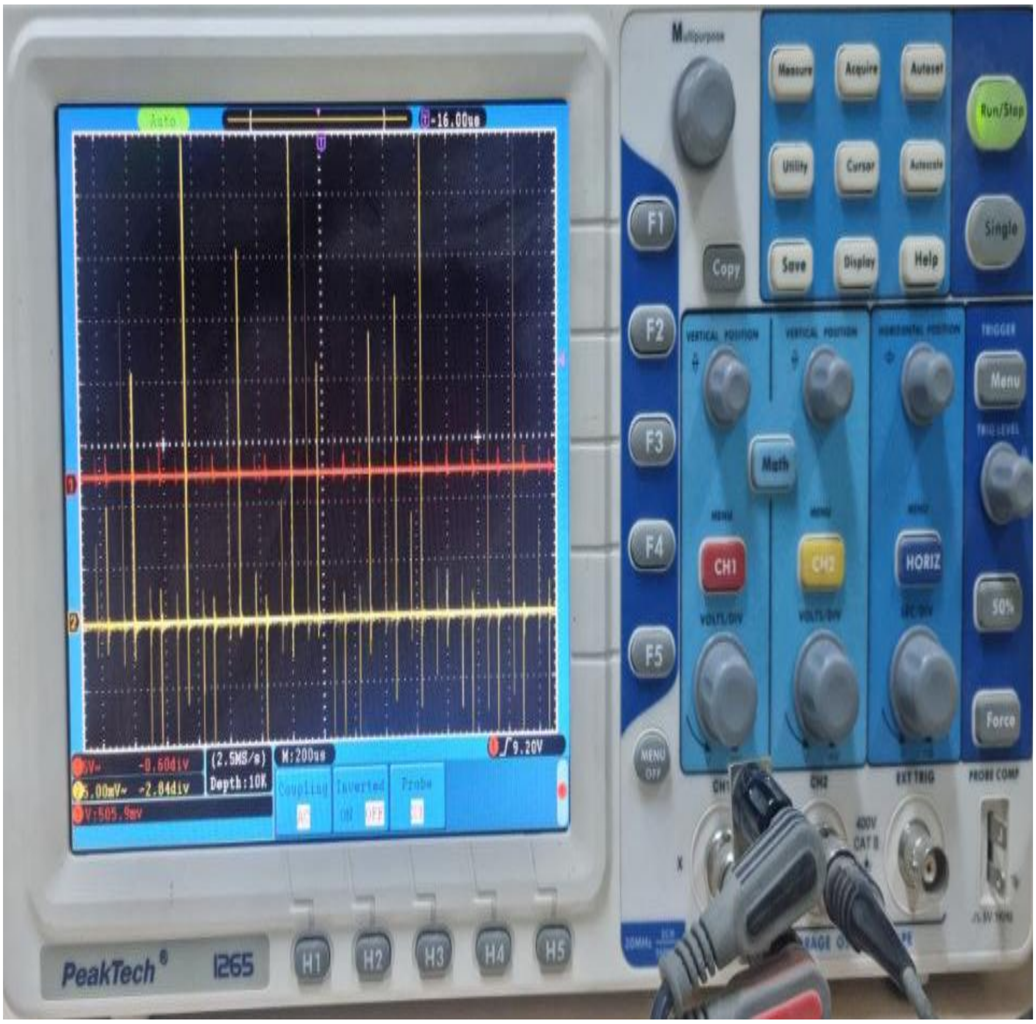



Figure 3-7 input channel of oscilloscope for the high voltage prob

### 3.8.2 Plasma Jet Temperature Measurement

Another important character of cold plasma parameter is the temperature of plasma jet. It was determined by using mercury thermometer, as figure (3-8) has showed, the heat sensitive part may be located at various distances from the tube nozzle with different gas flow rates.

Figure 3-8 Determination of plasma jet temperature

### 3.8.3 Measurement of the Plasma Plume Length

The other crucial cold plasma parameter is the plasma plume length into the ambient air. This parameter is investigated and measured by utilizing the metric rule at different gas (Mixed or single gas) flow rate in order to determine the plasma plume (length of plasma jet), as shown in figure (3-9) and applied various ranges of voltage, in order to determine the optimum plasma jet length.

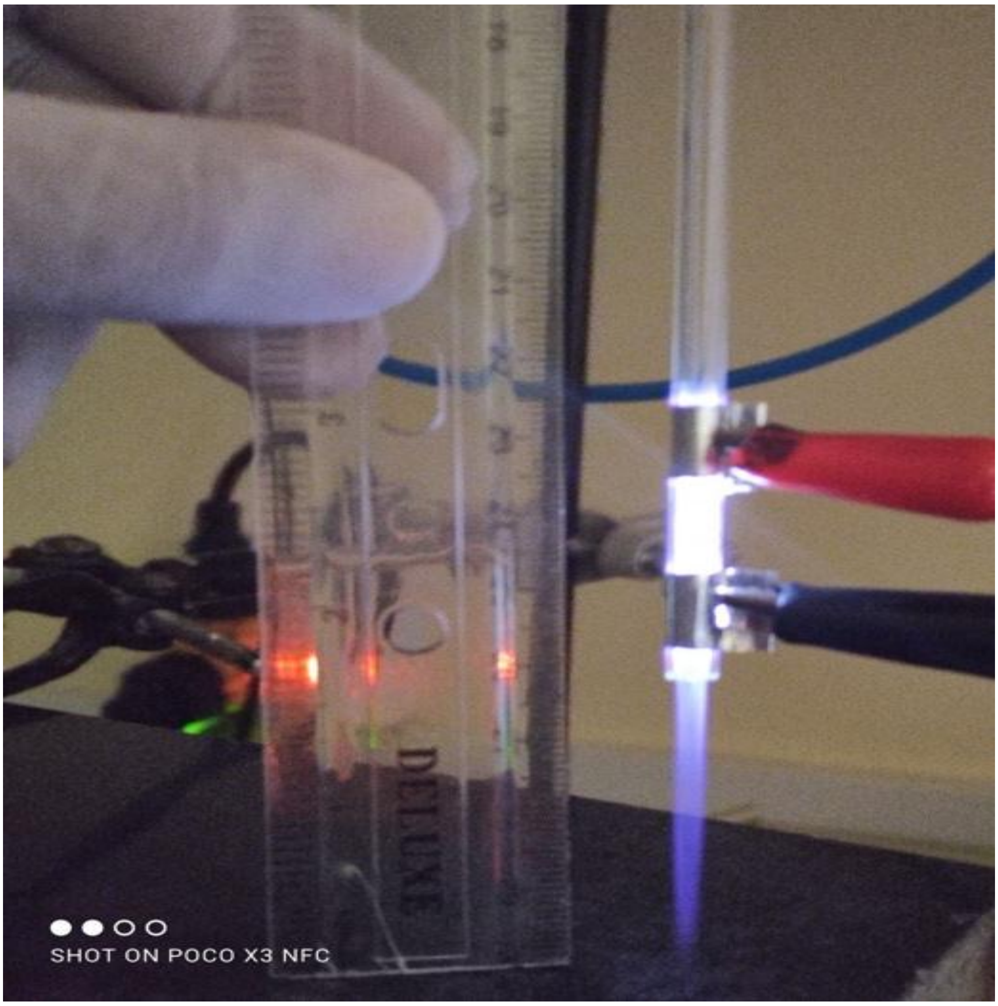



Figure 3-9 measurement of the plasma plum length

### 3.8.4 Measurement of the Optical Diagnostics

The ultraviolet visible near-infrared (UV-Vis-NIR) spectrometer apparatus is utilized for determining the emission spectra of the plasma jet. It has a wavelength range (150nm-1000nm).

The device has been connected to an optical fiber cable M92L01 (Thorlabs, USA) in order to read and record the spectral emission, as shown in figure (3-10).


Figure 3-10 Near-infrared (UV-Vis-NIR) spectrometer (813) 855-8681

Avoiding the plasma radiation dispersion is a crucial factor, thus, a collimator has been used for assembling the radiation emitted from plasma, as shown in figure (3-11).

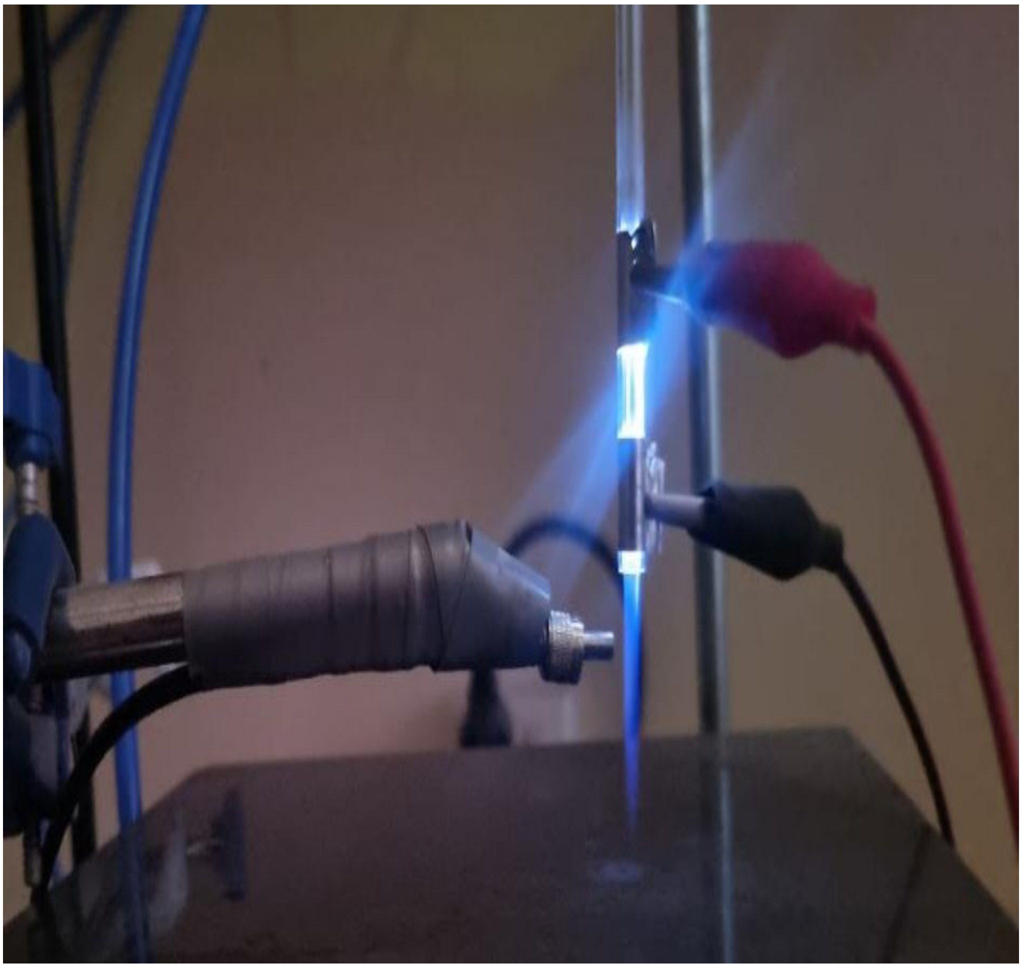


Figure 3-11 An optical fiber cable with a collimator

It is located at 10 mm from the Pyrex tube (axial direction) edge and 10 mm from the wall of the Pyrex tube (radical direction). The spectrometer device is connected to the laptop computer which records and reads the data.

### 3.8.4.1 The optical system

Optical emission spectroscopy involves the collection, spectral dispersion, and detection of light. Because OES from plasmas is often very strong, the light collection and detection efficiencies need not always be optimized. However, efficient detection is needed when rapid analysis is important and only a small fraction of the surface is being processed. Emission from a specific volume in the plasma chamber is imaged onto the entrance slit of a spectrometer by a lens. The required spatial resolution can be achieved. Since emission from 200–1000 nm is often collected, UV-grade fused-silica lenses should be used. The location of the imaged volume could be laterally scanned by moving the collection lenses or, in research reactors only, by translating the plasma reactor itself [97]. In this expermint the convex lens with 10 mm focal lens was used.

## 3.9 Preparation and treatment of wheat samples

An Iraqi wheat sample is used to investigate the effect of created cold plasma on germination and growth. We used 35 seeds in every Petri dish for all the tests. The Petri dish is treated with ethyl Alcohol in order to sterilize it. The Petri dish is located at a determined distance (at the end of the jet) from the system nozzle as shown in figure (3-12). The wheat seeds should be put at end of the plasam jet in oreder to insure that the generated reactive species reach the cover of wheat seeds, and prevent the electron of plasma to touch the seeds because of its high temperature compared with that of ion. According to [98] The wheat seeds were treated with cold plasma jet for different duration 2 ,4,6,8, and 10 minutes. In addition, the treated wheat seeds were farmed in ideal environment.

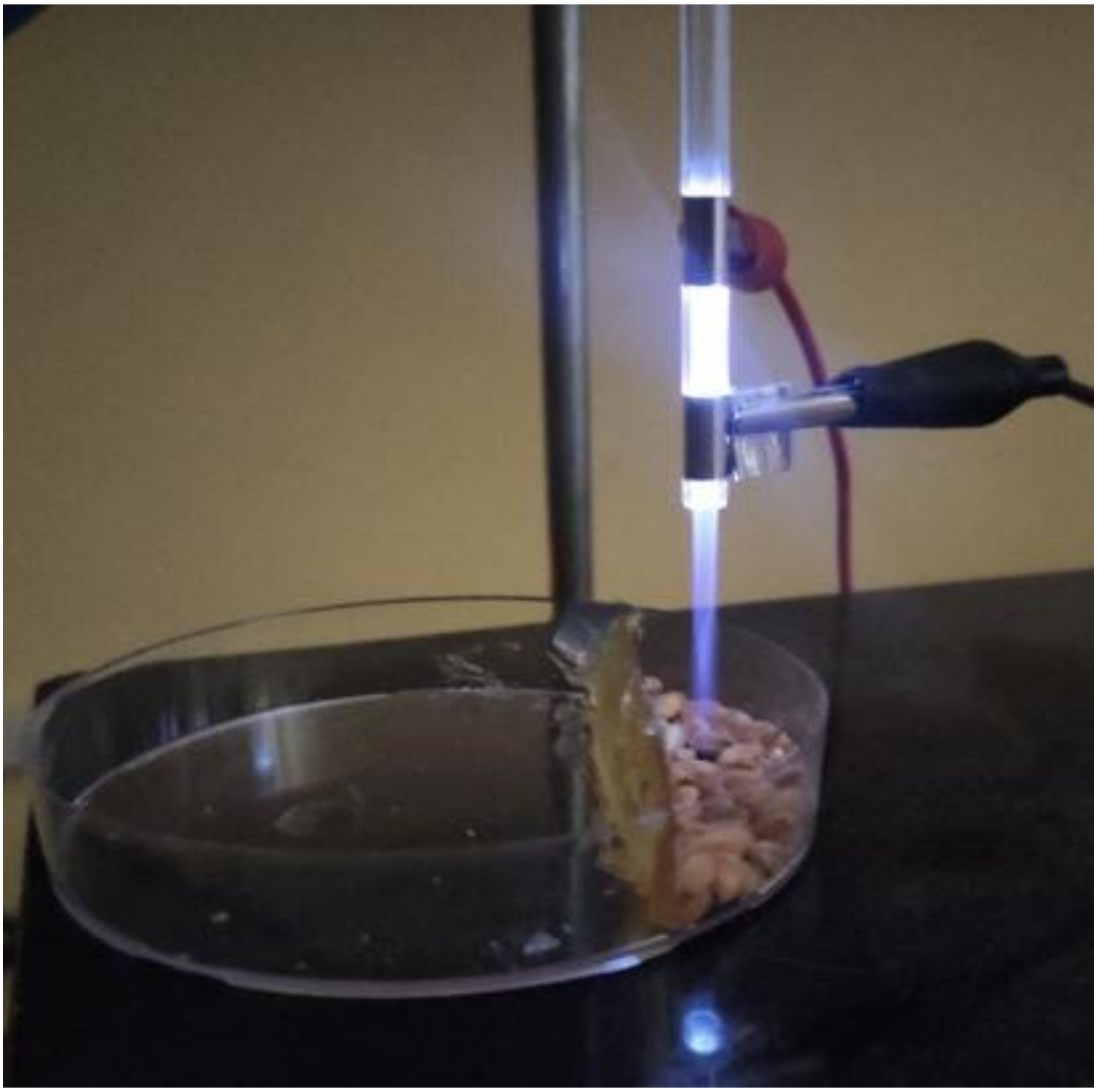


Figure 3-12 Petri dish with Iraqi wheat during the treatment operation

## 3.10 Calculate the Germination and Growth

Thirty-five (35) seeds of wheat (*Triticum aestivum L.*), were germinated in sterile sawdust (Binder GMBH, Germany) as illustrated in figure (3-13) supplied with Hoagland solution (half strength) after soaking in current water overnight. Seedling growth was carried out in a growth cabinet at 25±1°C, under continuous illumination supplied by warm white fluorescent tubes (1500-1800 Lux) and relative humidity of 60-70%.

Figure 3-13 sterile sawdust (Binder GMBH, Germany)

Starting from the fourth day, the germination percentage data were recorded for each day by calculating the number of germinated seeds until fifteen days to calculate the speed of germination.

In order to calculate the germination rate and growth speed, it can be used the following equations:

$$\text{Speed of germination} = \frac{\text{å x}}{\text{N}} \tag{3-1}$$

$$\frac{X}{N} = \sum_{1}^{n} \frac{x_1}{n_1} + \frac{x_2}{n_2} + \frac{x_3}{n_3} + \cdots \frac{x_n}{n_n}$$

å = number of measurments

$$Where, X = no. of\ normal\ seedling;\ N = no. of\ days$$

To calculate the percentage of germination, the overall germinated seeds were divided by the total number of seeds for each replicate, as explained in the following equation [99]:

$$Germination\ \% = \frac{Number\ of\ seeds\ germinated}{total\ number\ of\ seeds} \times 100\% \tag{3-2}$$

$$Seedling\ vigour\ index = Germination\ \% \times Seedling\ dry\ weight \tag{3-3}$$

We use accurate scale to calculate the leg and root weight , and metric ruler to mesure the leg and root long.

# Chapter Four

# Results and Discussion

# Chapter Four

# Results and Discution

## 4.1 Introduction

In this chapter, the DBD plasma jet system will be described and discussed in term of results. Three types of electrodes matireal, with a (1) mm tube wall thickness, were utilized. The comparison between the created plasma jets (with different electrodes types) is utilized, to obtain the optimal configuration. The electrical and optical characteristics were evaluated. The electrical characteristics (effect of the discharge current on the stability of the plasma plume) were investigated. In addition, the length of plasma plume, jet temperature for argon and mixed gas (Argon 98% & Oxygen 2%), applied voltage effectiveness and gas flow rate jet were measured.

The effect of the flow rate and applied voltage on the reactive species line intensity was investigated for both the Ar and Ar: $O_2$ APPJ. Finally, the effect of the plasma jet (Argon & mixed gas) on the Iraqi wheat was studied in term of growth speed and germination rate through treating the Iraqi wheat seeds with the plasma jet for different time duration (2, 4, 6, 8, & 10) minutes. The germination and growth wheat rate were calculated and compared with untreated sample (controlled sample).

## 4.2 The Optical Properties

The emission spectra were recorded by using the optical emission spectroscopy device in order to detect, and analyze the process of the transition of exciting atoms, and molecules. In order to detect the generated reactive species (ROS), and (RNS) in Ar plasma jet, the optical emission spectroscopy was studied.

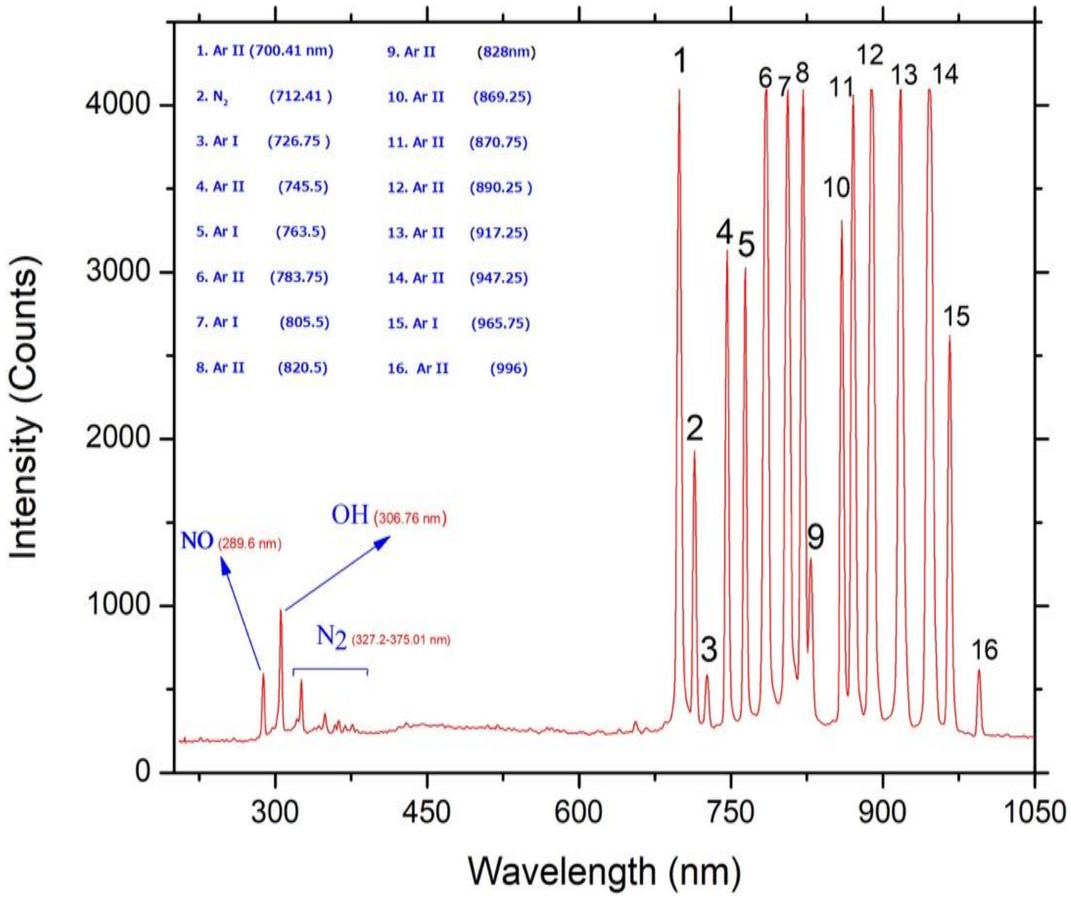



Figure 4-1 illustrates the spectrum of Argon plasma jet with Al electrode

The optical emission spectrometer device (Stellar Inc.) is utilized to record the jet emission spectra. Figure 4-1 illustrates the OES spectrum for produced plasma with Al electrodes. The generated reactive species were much more (in term of the intensities, types of ions, and the number of ions) than those with

Ag, and Cu electrodes as shows in figures 4-2, and 4-3 respectively. As pointed out in figure 4-1, the OH species has a higher intensity than that of the produced plasma with Cu, and Ag electrodes as indicated in figures 4-2, and 4-3.

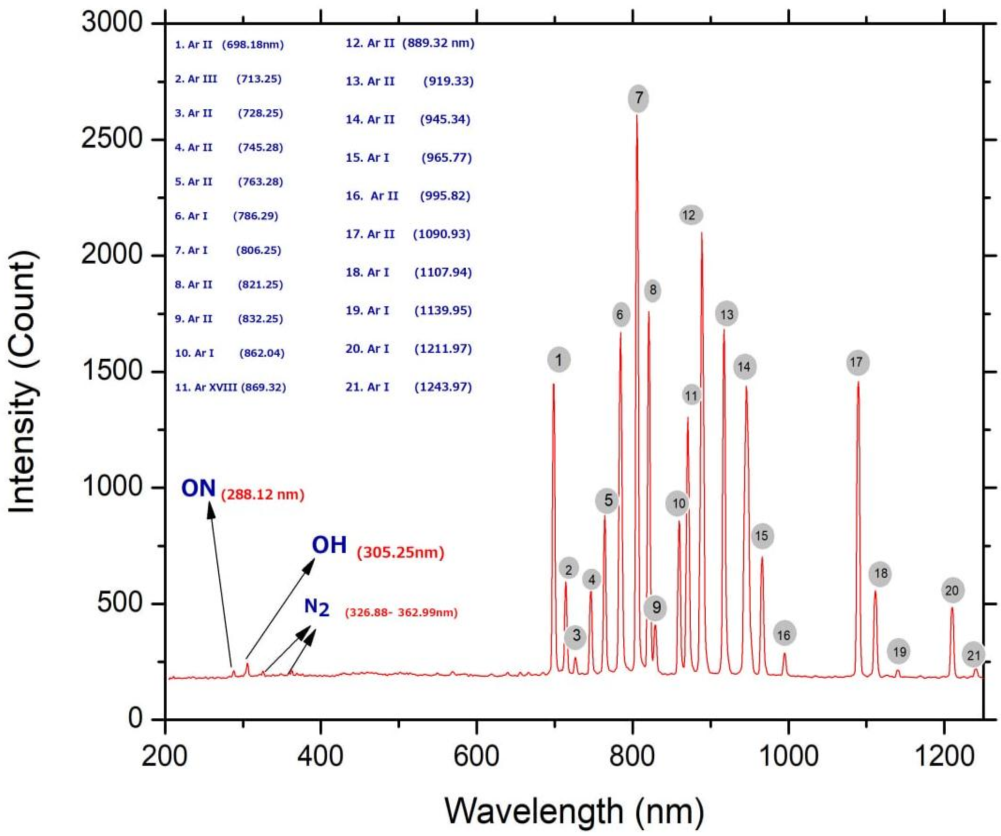



Figure 4-2 illustrates the spectrum of Argon plasma jet with Cu electrode

In addition, Nitrogen molecules were seen in the spectrum of the produced plasma with Al electrode, whereas the Nitrogen molecules have weak intensity or are not produced in that of produced plasma spectrum for both Cu, and Ag electrode types. For all results which we got, the spectral properties are reflected (in reality) of the excitation of the plasma species, to atomic levels, they were considered as a result of the electron collisions. Therefore, they emit photon at the specific wavelengths [100]. In other word, the efficiency of the plasma will be improved

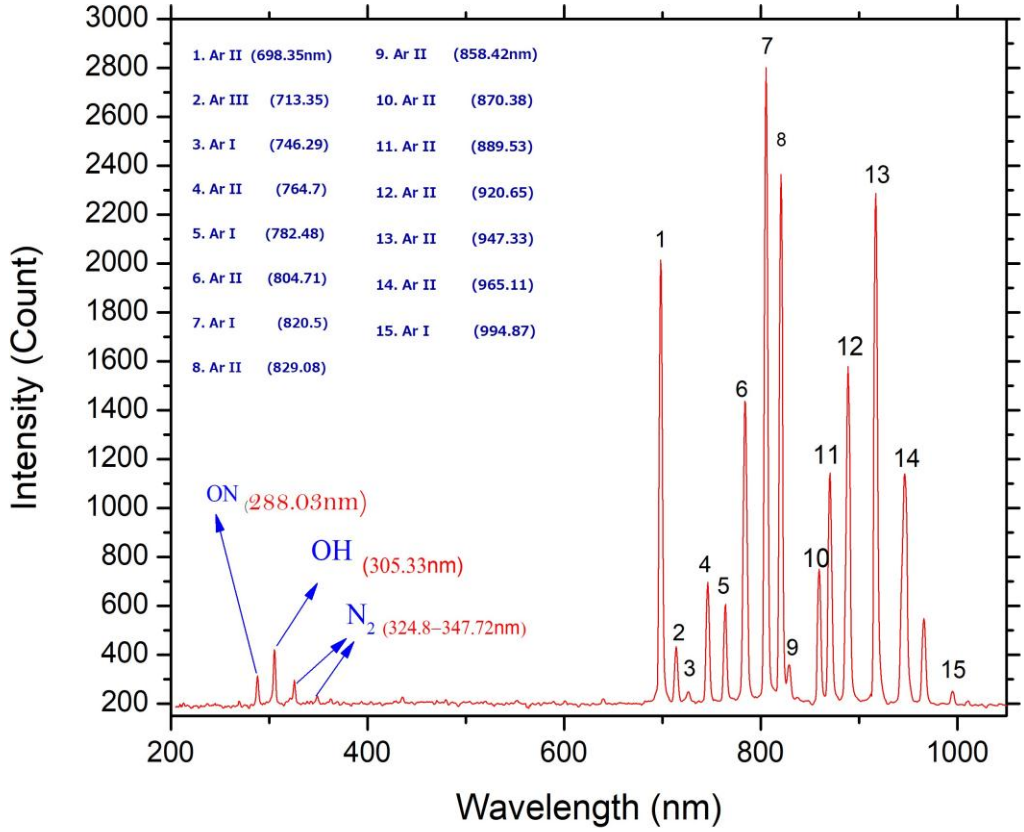



Figure 4-3 illustrates the spectrum of Argon plasma jet with Ag electrode

depending on the atomic level transition. Therefore, the efficiency of the produced Plasma jet with Al electrodes material is better than that with Cu, and Ag electrode types. The distribution of electric field in the plasma source, and chemical kinetic of plasma subjects on the material kinds of electrode [101]. Also, that could mean the degree of ionization of the gas is stable with

Al more than with Cu, and Ag electrodes, so the efficiency with Aluminum electrode is proffered.

## 4.3 The Wavefront Measurement

The plot of Al electrical properties is the best one in term of matching with the typical wavefront plot of Argon APPJ as shown in figure 4-4.

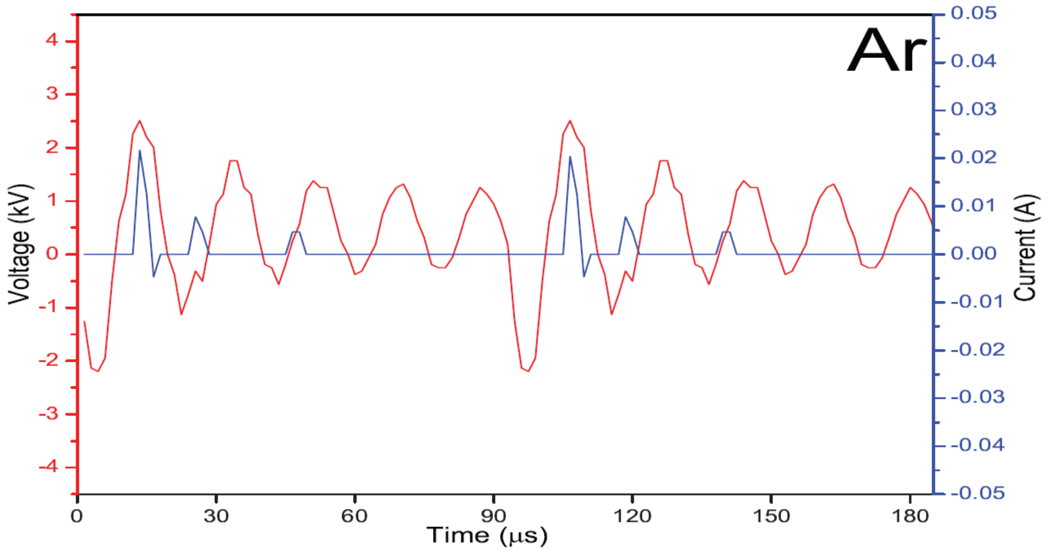



Figure 4-4 Typical waveforms of the ignition voltage and the discharge current of argon plasma jet [102].

The electrical properties for the APPJ were tested. Figures 4-5 demonstrates the electrical properties results for (A) Al electrode, (B) for Cu electrode , and (C) for Ag electrode APPJ. If the waveform cycle of applied voltage includes many pulses of the discharge current waveform, the electrical discharge in this case can be considered as a glow discharge and it is a uniform breakdown.

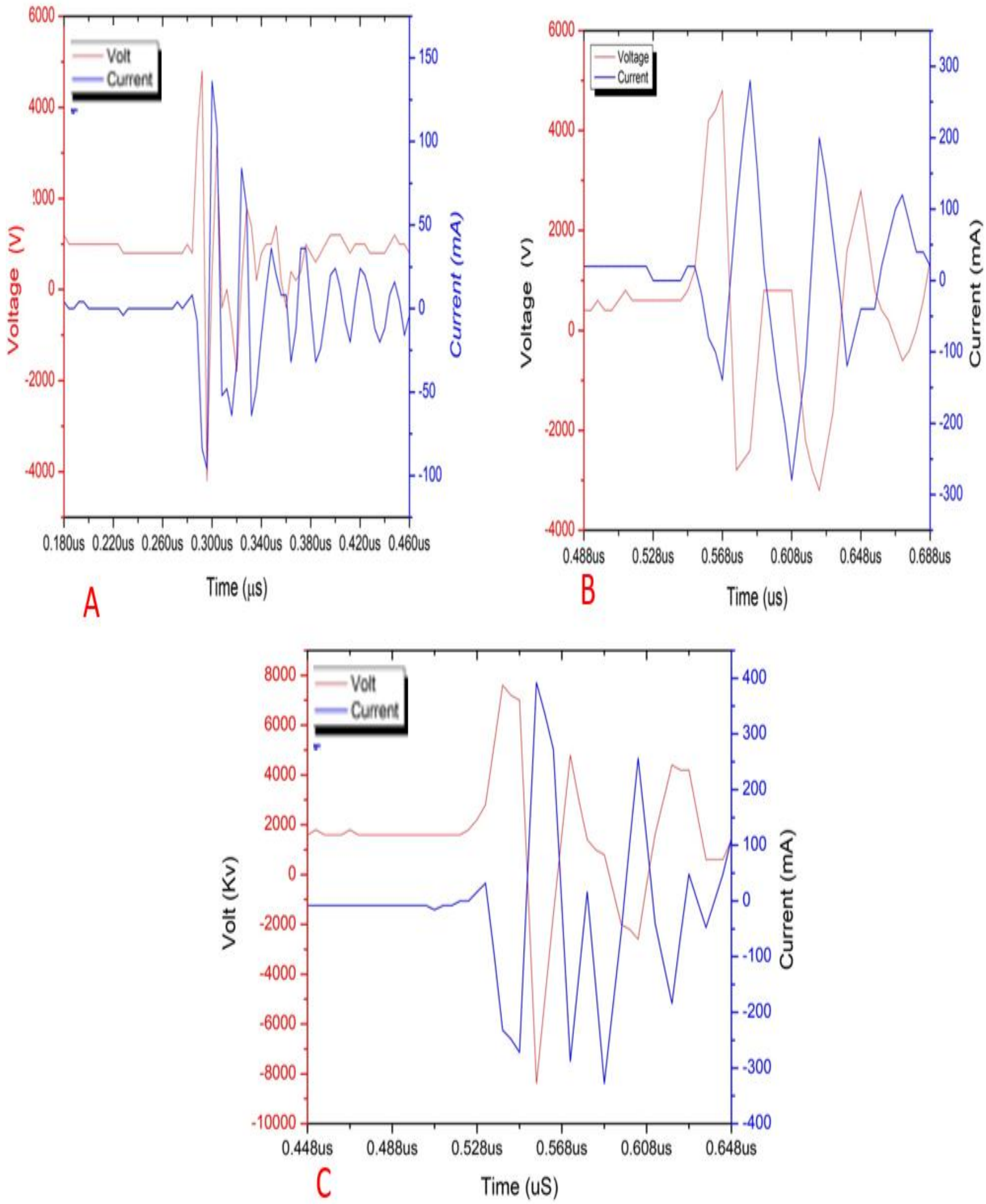



Figure 4-5 The electrical properties test (A) Al electrode, (B) Ag electrode, and (C) Cu electrode.

## 4.4 Electron Temperature Measurement by Boltzmann Plot Method.

Figures 4-6, 4-7, and 4-8 illustrate the relation between the ($\ln\frac{(\lambda I)}{g_U A_{Ki}}$), and (E). The ($T_e$) for Al, Cu, and Ag are deduced for all produced plasma by using equation 2.3.

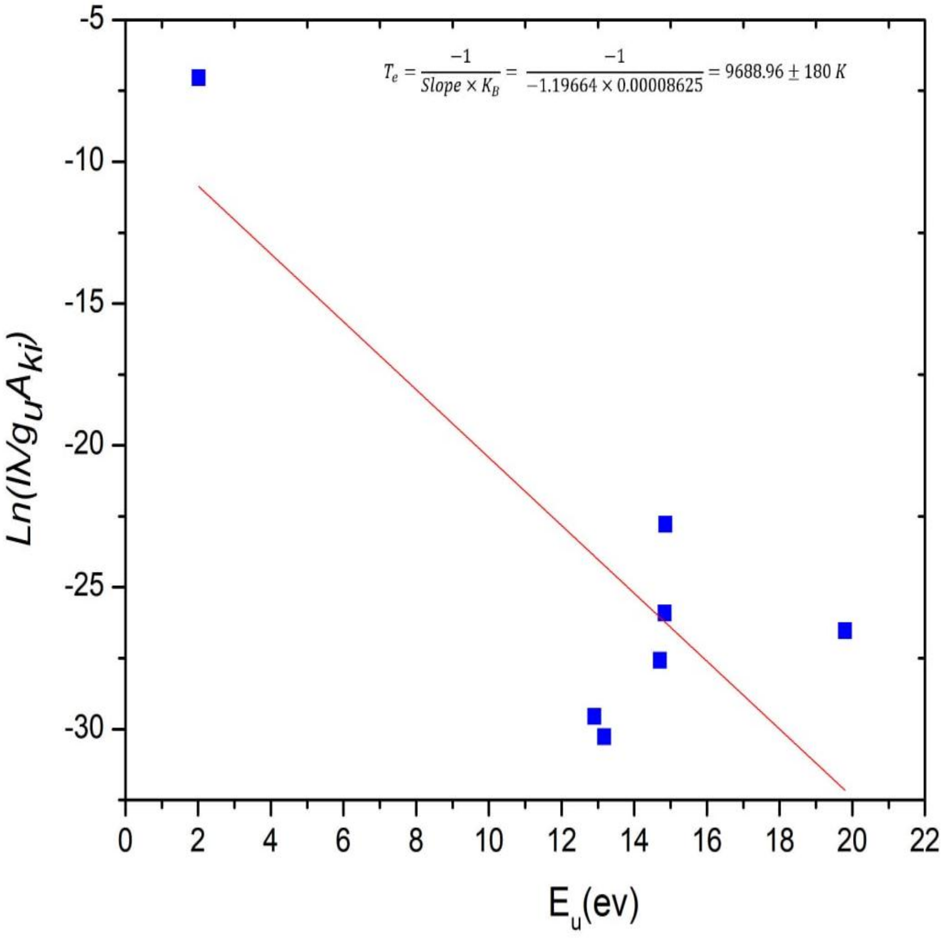



Figure 4-6 Boltzmann plot for calculating electron temperature of the Aluminum electrode.

Figure 4-6 shows the electron temperature of the plasma when using the Aluminum electrodes equal to 9688.96 $(°K)$ which equivalent to 0.8349 (eV), by using the parameters in table (4-1).

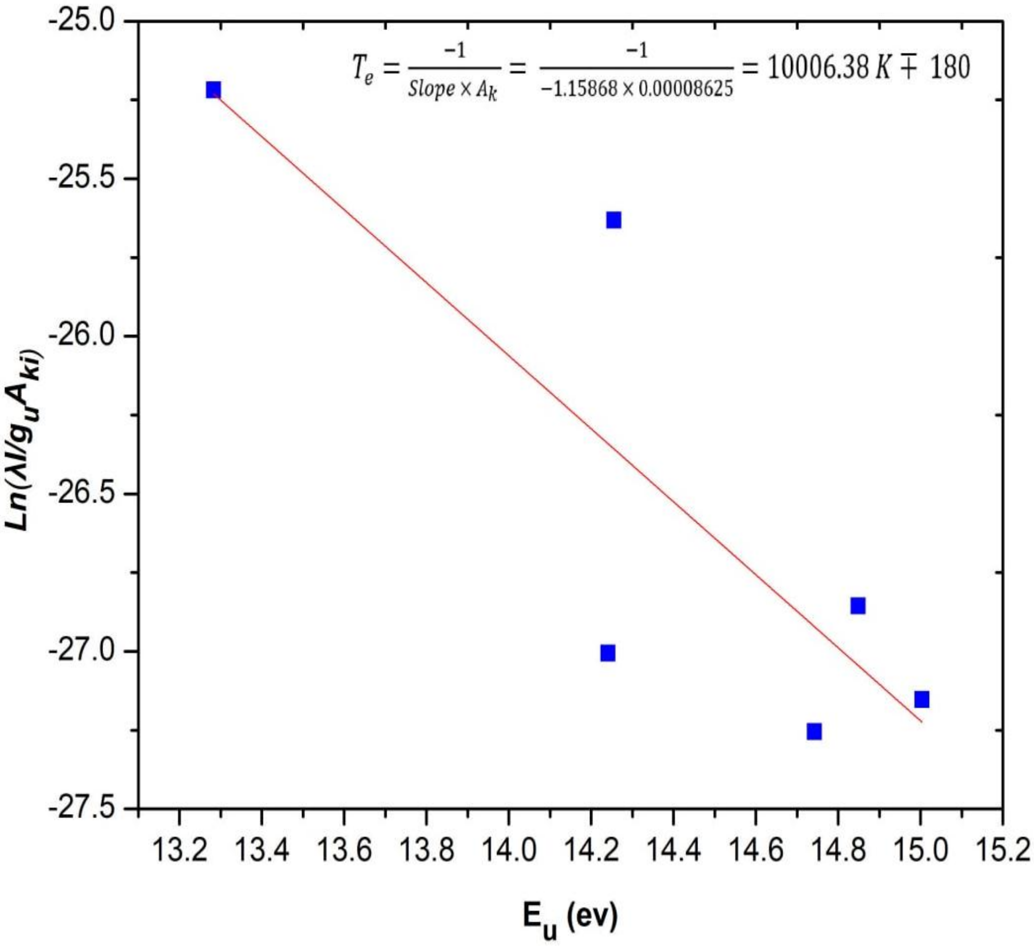



Figure 4-7 Boltzmann plot methode for calculating electron temperature for the Copper electrode

In addition, by the same procedure, the electrons temperature of both $(Cu)$, and $(Ag)$ electrodes are calculated as shown in figures 4-6, 4-7, and 4-8, they are found equal to $10006.38\,(°K)$ equivalent to $0.8622\,(eV)$ and $14467\,(°K)$ equivalents to $1.2466\,(eV)$ respectively.

In other words, all the ($T_e$) for all produced plasma in range $(0.8 - 1.3)$ eV which is approximately agreed with the range of $(0.79 - 1.3)$ eV [103][[104].

Table 4-1 Parameters of atomic Argon lines used the Boltzmann plot for Al electrode

| **λ(nm)** | **I (a.u)** | **Aki ($S^{-1}$)** | **$g_u$** | **Eu (eV)** |
|---|---|---|---|---|
| **700.41** | 4074.7 | 1.6E-03 | 4 | 2.0207 |
| **712.41** | 1867.99 | 5.00E+05 | 2 | 19.8010 |
| **726.75** | 590.83 | 1.10E+05 | 6 | 14.8592 |
| **763.5** | 2985.9 | 2.45E+07 | 4 | 13.1717 |
| **805.33** | 4086.1 | 8.60E+05 | 3 | 14.7108 |
| **820.5** | 4086.1 | 1.60E+05 | 3 | 14.8387 |
| **956.75** | 2614.17 | 5.40E+06 | 2 | 12.9069 |

The electron temperature of produced plasma with Aluminum electrode found smaller than others. This mean that the Te for the plasma jet with Al electrode is closer to the room temperature, and the worker on this plasma jet system has the advantage to use the system for a longer time without need for cooling system and lower thermal stress [96].

Table 4-2 Parameters of atomic Argon lines used the Boltzmann plot for Cu electrode

| λ(nm) | I (a.u) | Aki ($S^{-1}$) | $g_u$ | Eu (eV) |
|---|---|---|---|---|
| 714.25 | 596.77 | 6.30E+05 | 3 | 13.2816 |
| 728.25 | 250.42 | 1.02E+07 | 3 | 15.0035 |
| 786.29 | 1673.17 | 3.50E+05 | 1 | 14.8483 |
| 862.04 | 865.53 | 9.20E+05 | 1 | 14.7425 |
| 919.32 | 1673.17 | 1.67E+05 | 2 | 14.2550 |
| 956.75 | 2614.17 | 5.40E+06 | 2 | 12.9069 |

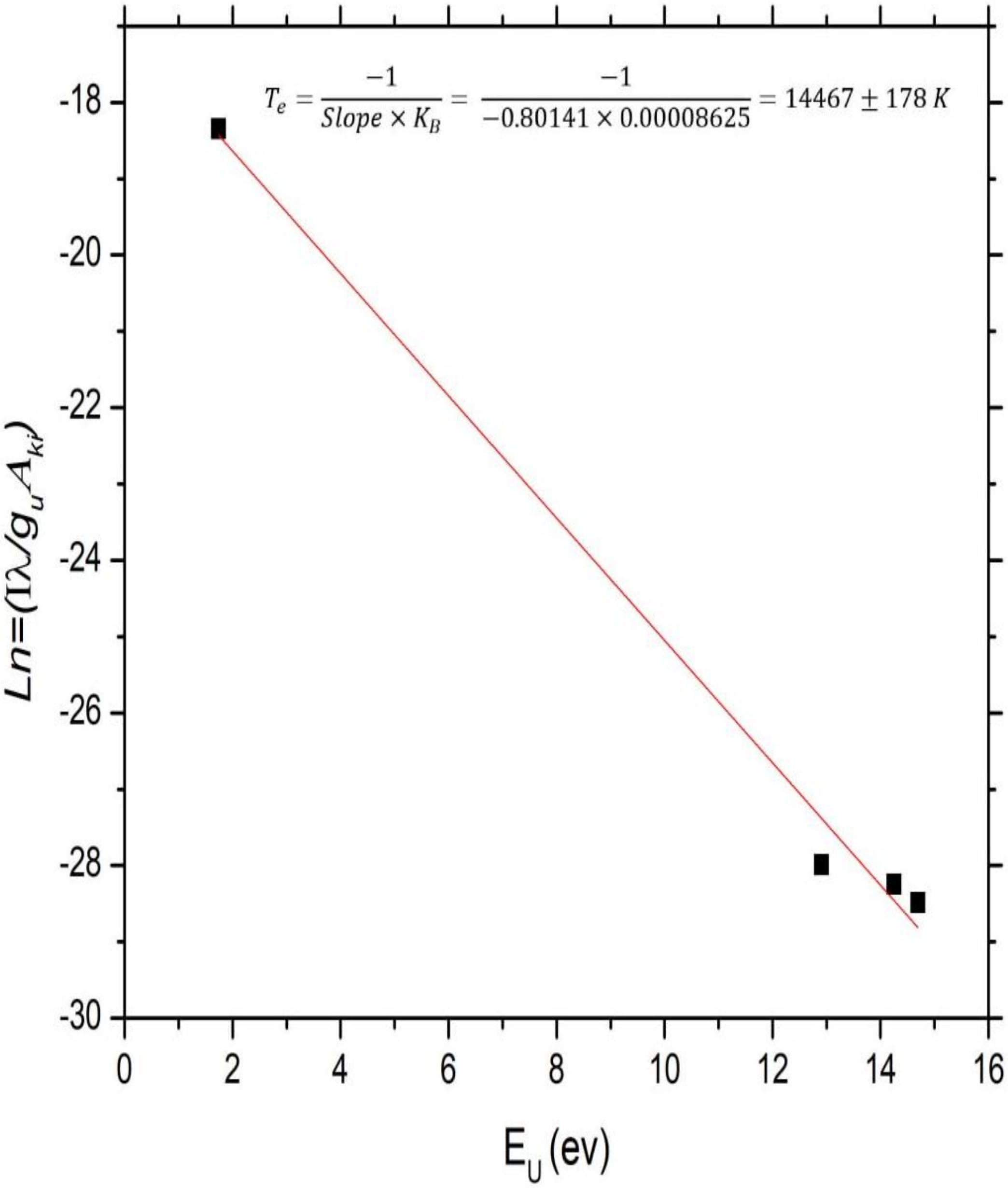



Figure 4-8 Boltzmann plot for calculating electron temperature of the silver electrode

Table 4-3 Parameters of atomic Argon lines used the Boltzmann plot for Ag electrode

| λ(nm) | I (a.u) | Aki ($S^{-1}$) | $g_u$ | Eu (eV) |
|---|---|---|---|---|
| 713.25 | 434.73 | 1.20E+03 | 4 | 1.7370 |
| 804.61 | 2604.85 | 1.12E+06 | 1 | 14.6936 |
| 919.46 | 2288.41 | 1.76E+06 | 2 | 14.2550 |
| 965.77 | 549.32 | 5.40E+06 | 2 | 12.9069 |

## 4.5 Effect of Electrode Types on the Plasma Parameters

The effect of increasing flow rate on both temperature, and jet length is investigated for produced plasma with (Al), (Ag), and (Cu). As figure 4-9 explains that when the flow rate increase, the plasma plume decrease for produced plasma jet with different electrode types. However, it can be indicated that the jet length with Al electrode is longer of those of (Ag), and (Cu)electrodes. Therefore, this can be counted as an advantage for using Al electrode over than (Cu), and (Ag) electrodes.

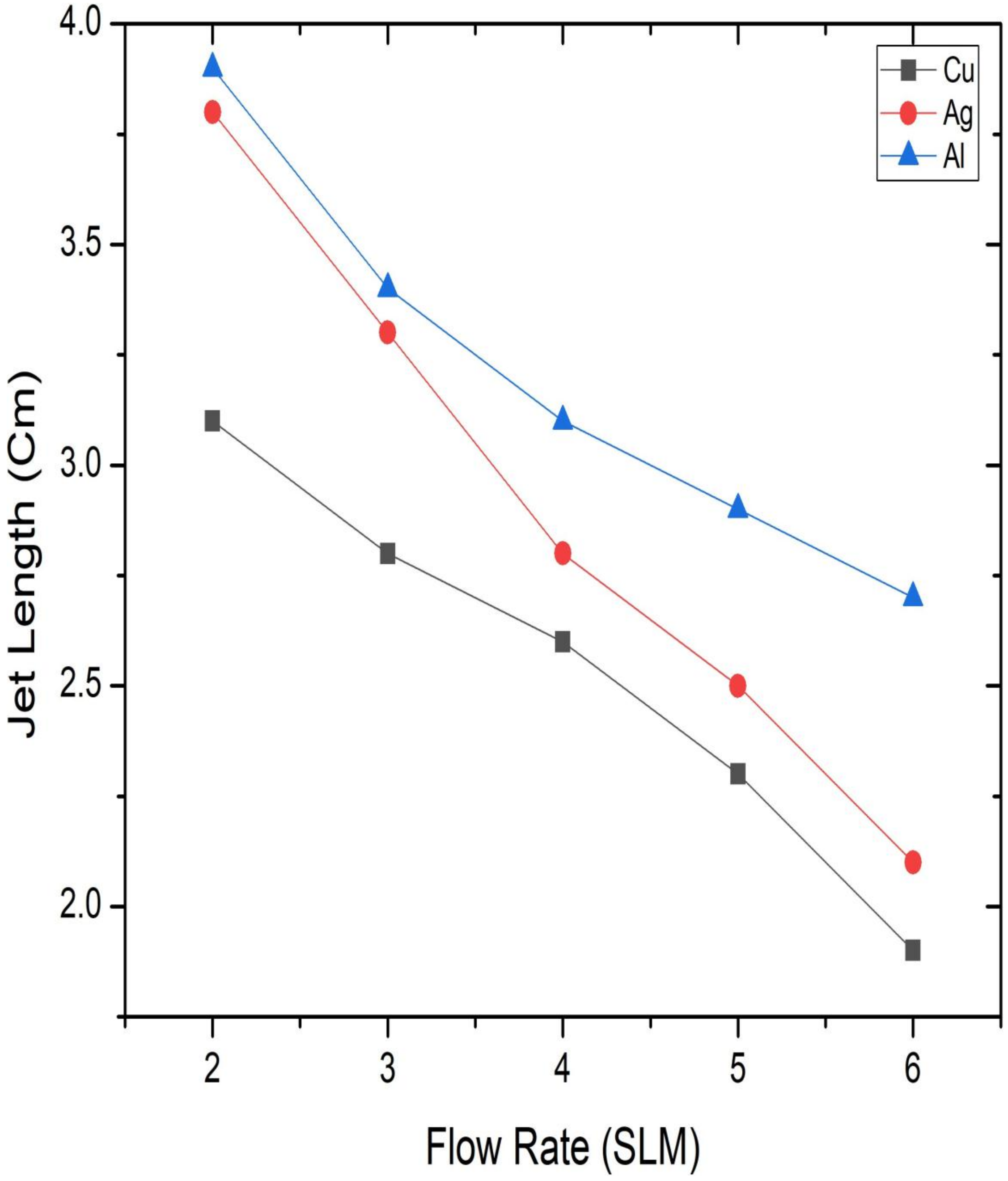



Figure 4-9 Effect of flow rate on jet length for Al, Ag, and Cu with Argon gas at 9 kV.

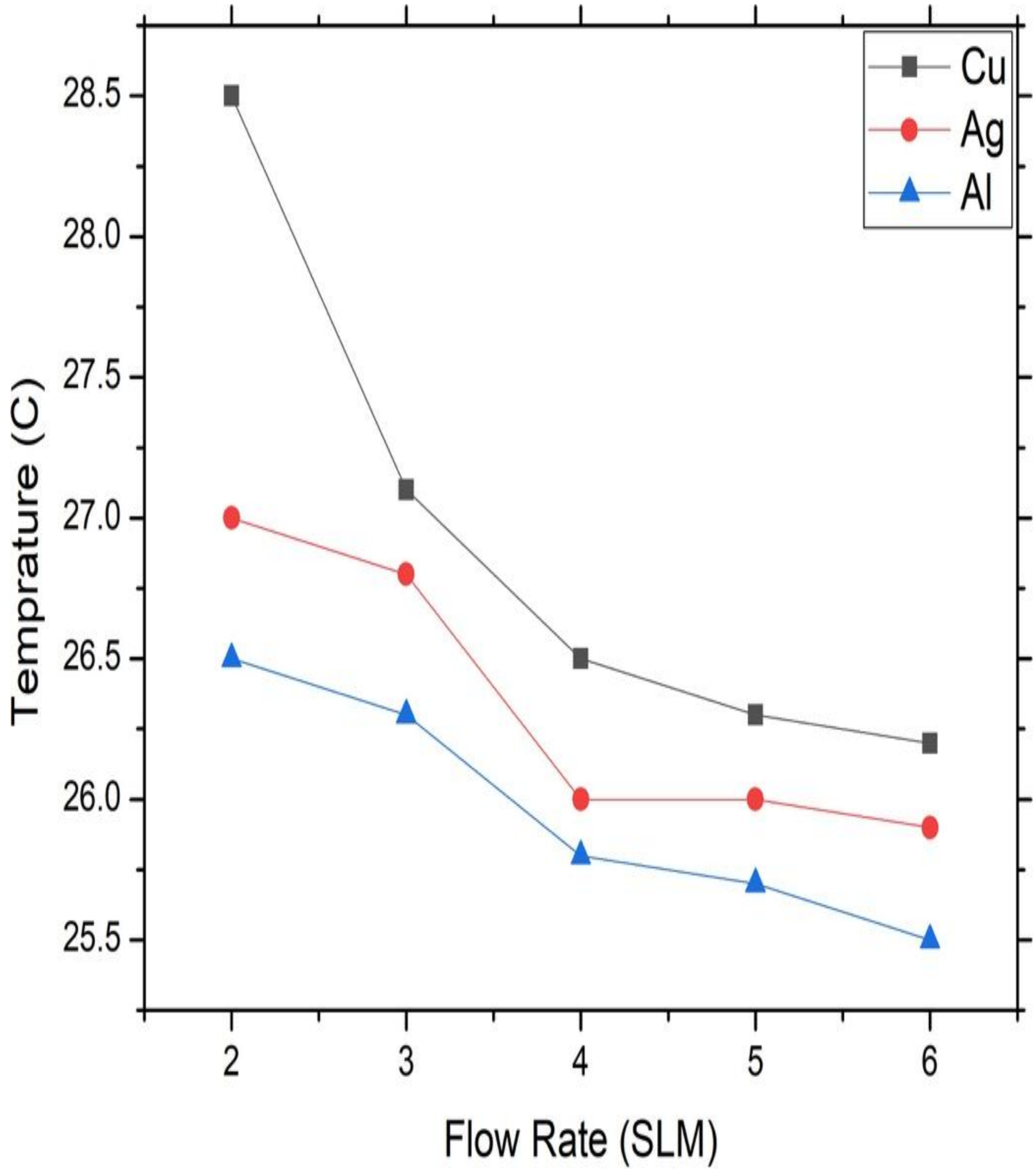



Figure 4-10 Effect of flow rate on jet temperature for Al, Ag, and Cu, with Argon gas at 9 kV at 21°C lab temprature

Figure 4-10 demonstrates the relation between the flow rate, and the plasma temperature, it is clear, that the flow rate increases, the produced atmospheric

plasma, but temperature decreases for different electrode types. However, it can be indicated that the temperature of the atmospheric plasma with (Al)

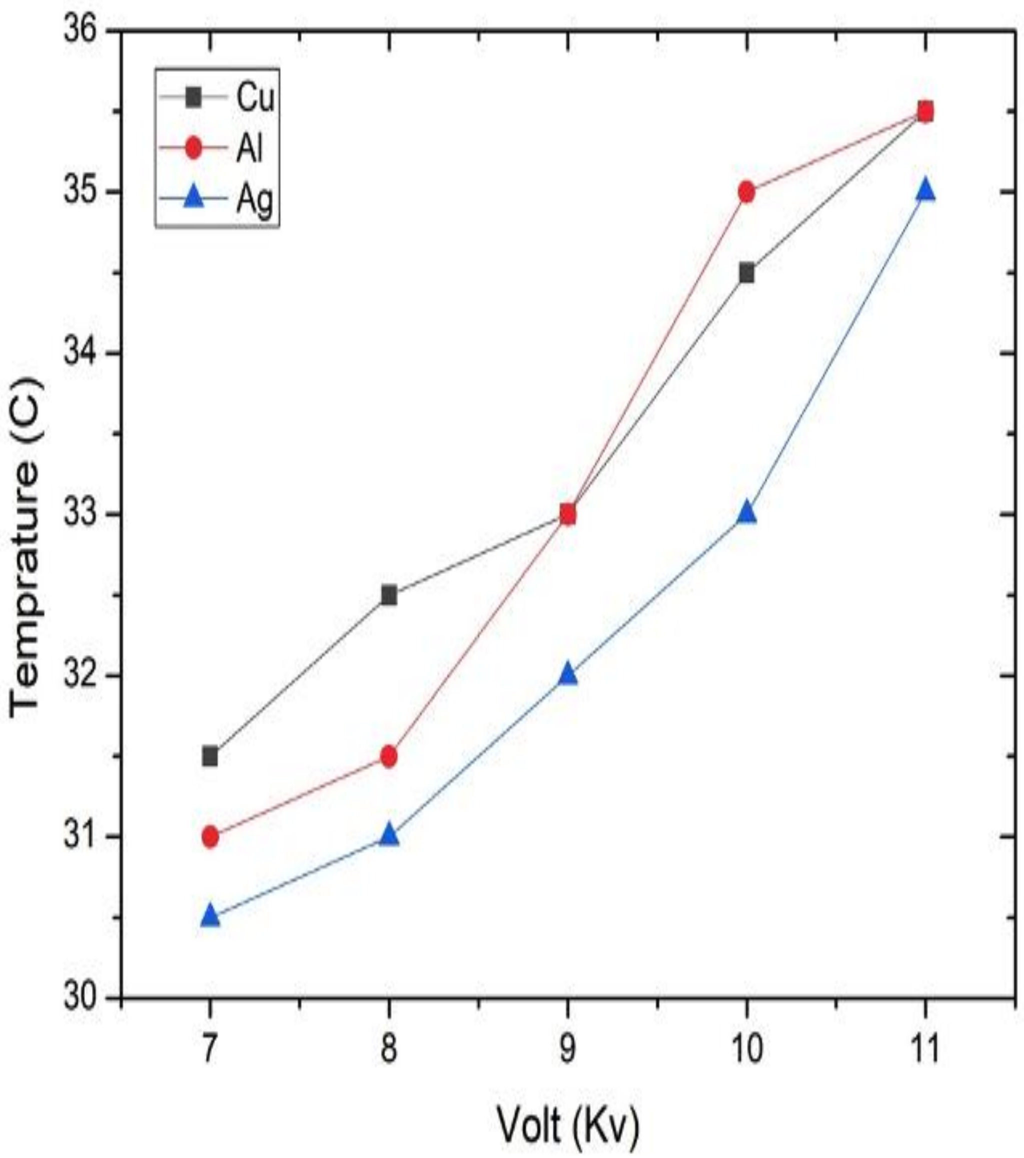



Figure 4-11 Effect of voltage on plasma temperature for Al, Ag, and Cu with Argon gas at 4 SLM flow rate at 29 °C lab temperature

electrode is still smaller than those of (Ag), and (Cu) electrodes during the entire procedure. It is obvious, that is another advantage for using (Al) as electrode instead of (Cu), and (Ag) electrodes.

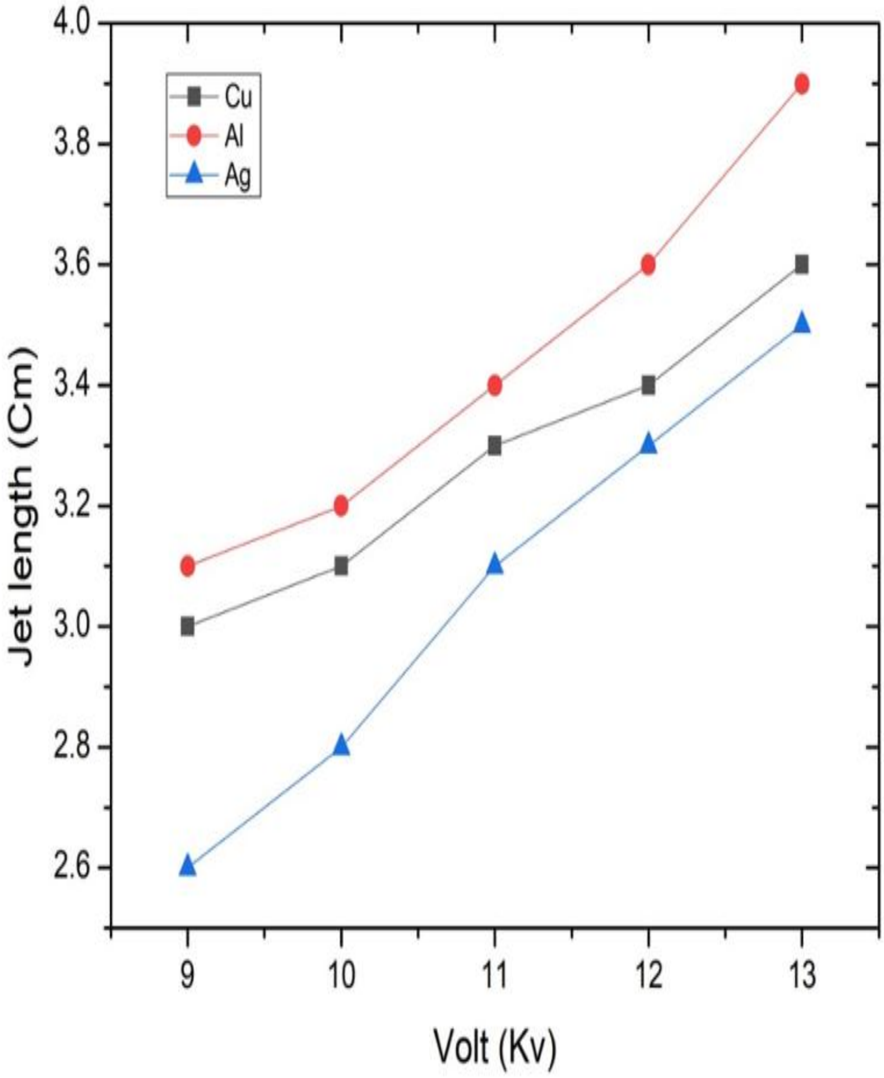



Figure 4-12 Effect of voltage on jet length for Al, Ag, and Cu with Argon gas at 4 SLM flow rate

The effect of rising voltage on both the atmospheric plasma temperature, and the plasma plume is evaluated for all produced plasmas, as pointing out in figures 4-11, and 4-12.

The behavior pattern of all the lines in figure 4-12 is approximately similar to each other. Also, the plasma plume with Al electrodes is still longer than that for those of Cu, and Ag electrodes in all conditions during the procedure of experiment. Therefore, this can be indicated as characteristic of produced plasma with Al electrodes over others. Figure 4-11 shows that the temperature of atmospheric plasma jet grows when the voltages is raised for the produced plasma of all electrode types. The atmospheric plasma jet temperature reaches 35.5 °C for both Al, and Cu electrodes at 11 kV, but it still with Ag electrodes at just 35 °C at the same voltage.

There is no huge difference between all produced plasmas in term of the temperature of the atmospheric plasma jet when the voltages grow. However, the temperature of plasma jet with Al electrode is still lower in comparison with those of Cu and Ag electrode plasma jet.

The main goal of the current comparison was to examine the different types of electrodes to enhance the produced plasma properties. The electrode types (Al, Cu, and Ag) are presented by using the homemade plasma jet system. A comparison method is used between all the produced plasma with different electrode types. Firstly, the produced atmospheric plasma jet with Al electrode is more efficient than those with Cu, and Ag electrodes, in term of the electron temperature, which was lower with Al electrodes than the others. Secondly, the reactive species intensities of produced plasma with Al electrodes are bigger than those of others, as well as the variety of reactive species. Finally, the plasma plume for Al electrodes was longer than those of Cu, and Ag electrodes. Whoever, the plasma jet temperature is approximately smaller with Al electrodes than others with Cu, and Ag electrodes.

These results can be explained by two reasons: firstly, the work function of Aluminum surface electrode is smaller than that of copper, and silver surface electrodes. It is 4·25 ± 0·05 eV for Al surface electrode and 4·61 ± 0·04, 4·35 ± 0·05 for Cu, and Ag surface electrodes respectively [105]. In other words, the breakdown voltage with Al electrode needs smaller energy to relase the photo electron, and whoever, needs more energy with Cu, and Ag electrodes to exceed the work function of electrodes metal and then reaches the gas breakdown voltage. Secondly, The material type of electrode is functions of electric field distribution in the plasma source, therefore, chemical kinetics of plasma is affected by the material type [101].

Furthermore, due to the different work functions of Al, Cu, and Ag, the space charge amount injected is bigger with the Al-electrodes [105]. The injecting a space charge will cause an electrical disturbance because it works to strengthen the electric field in the central region and weaken it in the region near the electrode. The difference in the electrode material works to distort the uniform electric field because each electrode material has a charge injection capacity that differs from the other, which distorts the electric field. In other words, the deformation of the electric field becomes more obvious with the increase of the injected space charge[106].

This true is agreed with the optical test (experimental test) for the Al electrode plasma jet Cu, and Ag electrodes plasma jet too. With Al electrode. The intensity of all reactive species is bigger than of that with Cu, and Ag electrode.

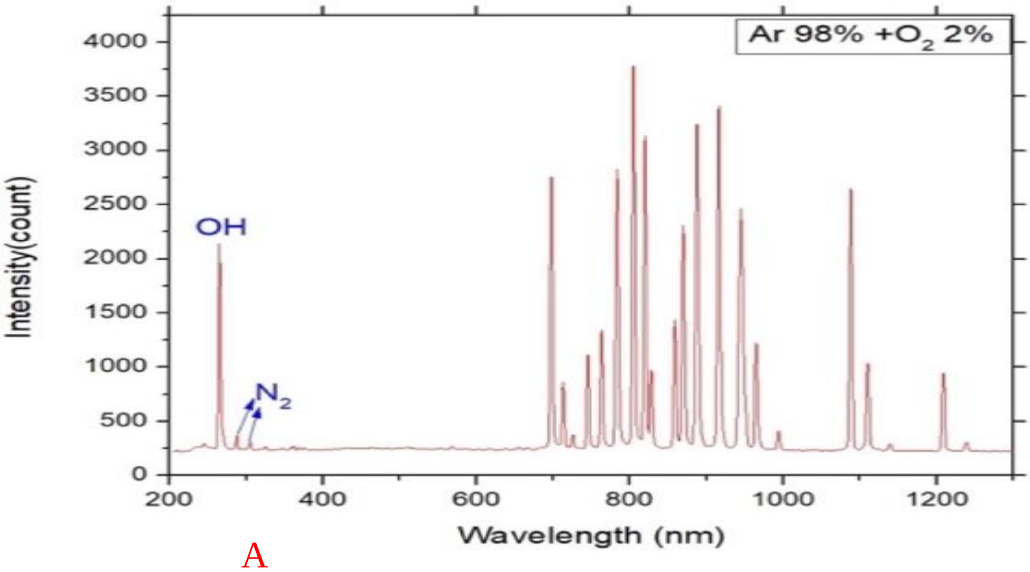
To sum up, the using of Al-electrode in our bulit plasma jet system is more efficient, and higher quality than others. There is no huge difference between all produced plasmas in term of the temperature of the atmospheric plasma jet when the voltages grow.

## 4.6 Mixed Ar-$O_2$ Plasma

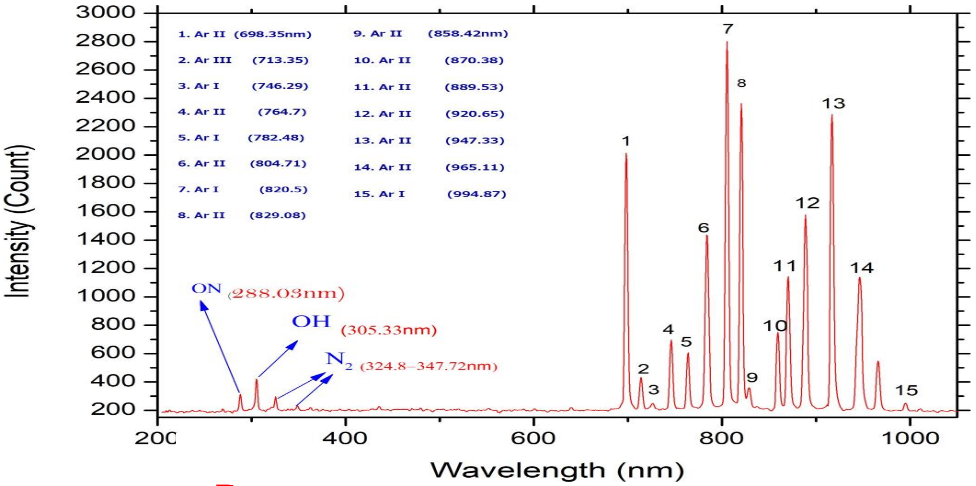
In order to examine and investigate the effectiveness of the cold plasma that was produced by using argon gas by 98% and oxygen by 2%, some comparisons were made between it and the produced argon plasma using the same manufactured system plasma jet, such as the comparison of the optical and electrical properties of the two types of plasma, and a comparison of the length of the produced jet and its temperature for the two kinds of produced plasma.

### 4.6.1 Optical Properties Comparison

An examination of the optical properties for the produced plasma by mixed gas method was conducted and compared with the results of the optical properties of the produced plasma using Argon gas, as shown in figure 4-13. It illustrates




A




B

Figure 4-13 comparison between the optical properties of A. mixed and Argon gas cold plasma that the intensity of reactive spices, which were produced by using mixed and argon gas plasma on y-axis virus the wavelength on x- axis. It is clear, that the intensity of all produced reactive spices of mixed gas plasma jet is higher than of those of Argon plasma jet, for instance the intensity of the OH compound with mixed plasma is higher than that of Argon one. In addition, the intensity of the ON compound, and $N_2$ of mixed plasma are higher also than other of Argon plasma. Finally, all the reactive species with mixed plasma have a higher magnitude than that of Argon plasma.

### 4.6.2 Plasma Jet Length

The length of the jet plasma is one of the important properties that determine the effectiveness and efficiency of the plasma produced. The figure 4-14 shows an important and simple comparison between the cold plasma (with Al electrode) in which mixed gas was used, and the cold plasma in which Argon gas was used. The lengths were compared based on the change in the breaking voltage that works to generate and produce the plasma.

The plasma jet length of mixed plasma is higher than that of argon plasma for all the used voltage, for example, at 9 kV the jet length of mixed plasma was 2.1 cm, whereas, it was 1.8 cm for argon plasma jet. The highest jet length was 3.1 cm for the mixed one at 13 kV, whoever, it recorded 2.4 cm as the highest magnitude for the length of argon plasma jet at the same breakdown voltage of the mixed plasma jet.

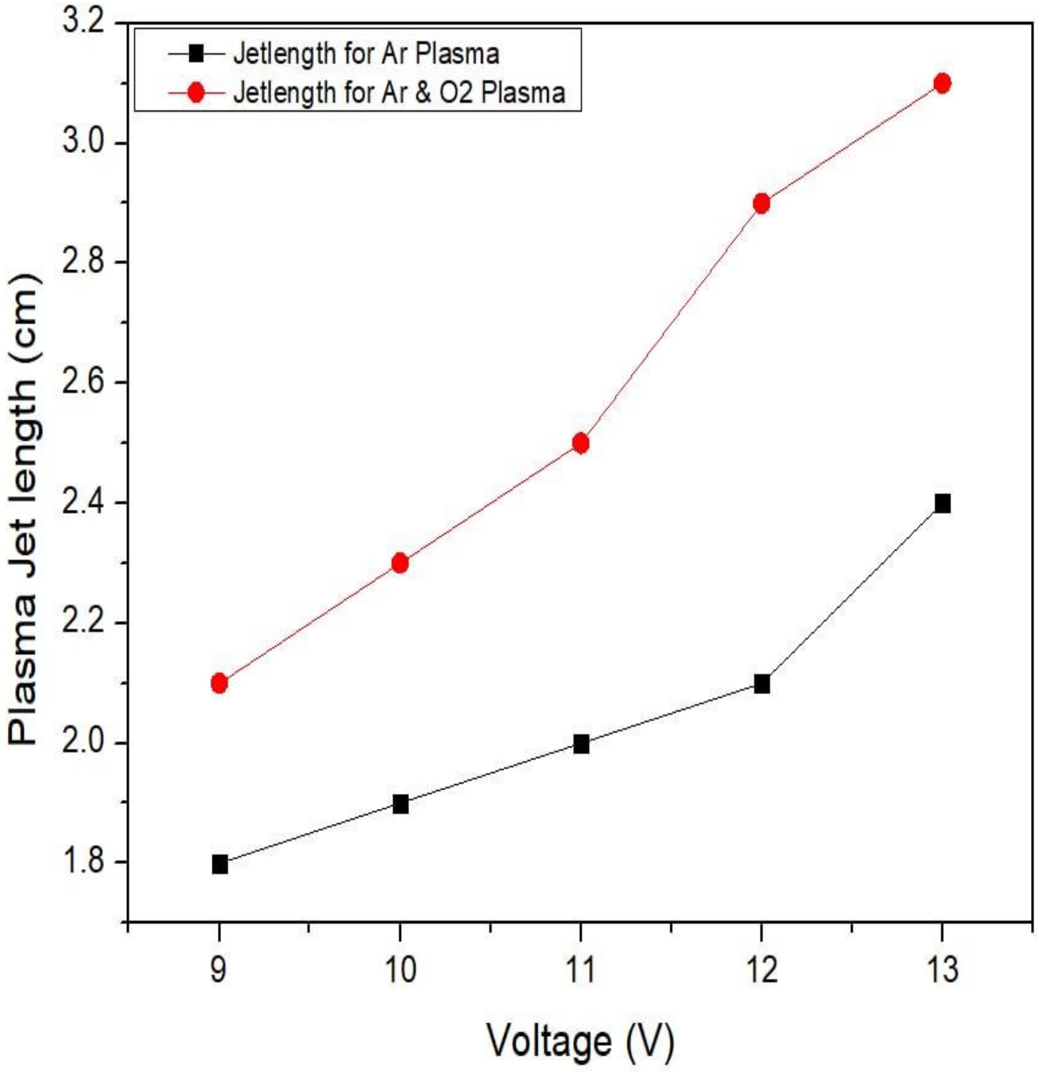



Figure 4-14 jet length for Ar and Ar + $O_2$ compared with voltage for Al-electrode

### 4.6.3 Plasma jet temperature

The other test was done, is the measurement of the plasma jet temperature for both Argon and mixed plasma.

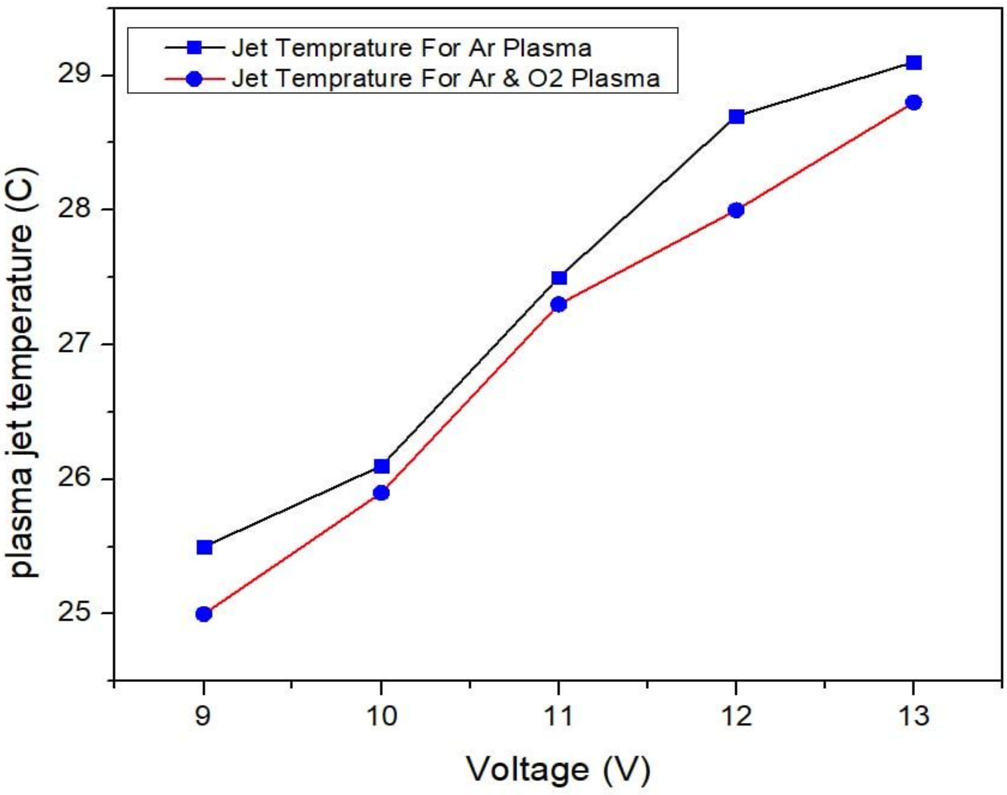



Figure 4-15 plasma jet temperature for Ar and Ar+$O_2$ compared with voltage

Figure (4-16) clarifies the relation between the plasma jet temperature as a function of the breakdown voltage.

It is obvious, that the plasma jet temperature for mixed gas is smaller than that of Argon gas plasma jet. The test was done at 21 °C temperature room. The red line represents the temperature of mixed gas plasma jet, the temperature was 24.5 °C at 9 kV. The temperature was grown up and reaches 28.5 °C at 13kV. Whoever, the highest temperature was 29 °C for the argon gas plasma jet as figure (4-15) demonstrated.

Table 4-4 Comparison between the Ar and Ar:$O_2$ gas APPJ parameters.

| Plasma type | OH intensity (counts) | Plasma jet plume at 9 &13 kV | | Plasma jet temperature at 9 &13 kV | |
|---|---|---|---|---|---|
| Argon APPJ | 417.7 | 1.8 cm | 2.4 cm | 25.5 °C | 29 °C |
| Mixed APPJ | 2301 | 2.1 cm | 3.1 cm | 24.5 °C | 28. 5 °C |

## 4.7 Treatment the Iraqi Wheat Seeds by the APPJ Technique

### 4.7.1 Wheat Surface Bactria Deactivation by Argon (APPJ)

The Bacteria present on the surface of wheat seeds can play a negative role, therefore reducing or killing them contributes greatly to the process of improving germination and growth [107]. Figure (4-16) shows the effect of the plasma jet on the Bactria deactivation. It illustrates five samples of Bactria culture based on the treated and untreated Iraqi wheat seeds samples. The figure 4-16 explains the growth of Bactria colonies in controlled sample, which is huge and the sample of plasma treated wheat seeds, the sample with 10 minutes treatment has smaller number of Bactria colonies, and they are in general have small number of Bactria colony than that of untreated sample.

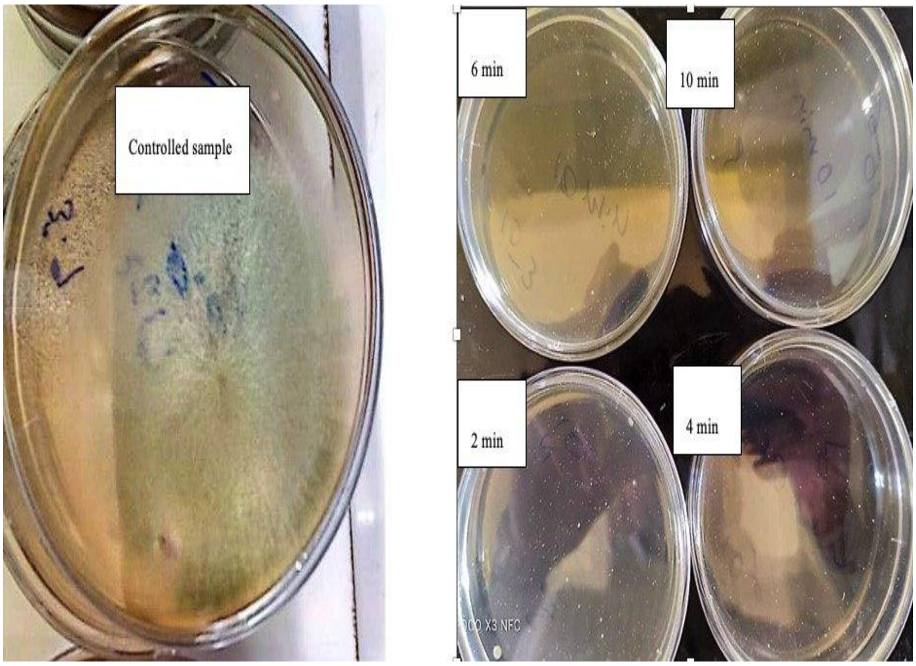



Figure 4-16 shows the effect of APPJ on Bactria deactivation on.

These results are agreed with that cold plasma jet works through charged particles an important role in the process of tearing the bacteria membrane through the electrostatic force that accumulates on the surface of the outer membrane of the cell and causes overcoming the tensile forces of the membrane and thus tearing it [107]. Therefore, the numbers of Bactria colonies were a huge number with untreated wheat seeds with plasma jet, whereas, they were a few numbers of colonies exist with treated samples

### 4.7.2 Calculate the Germination and Growth of treated Wheat Seeds by Argon (APPJ)

As shown in figure (4-17), Samples of treated Iraqi wheat with Argon cold plasma (0,2,4,6,8, & 10) min, which were cultivated and germinated for 15 days.

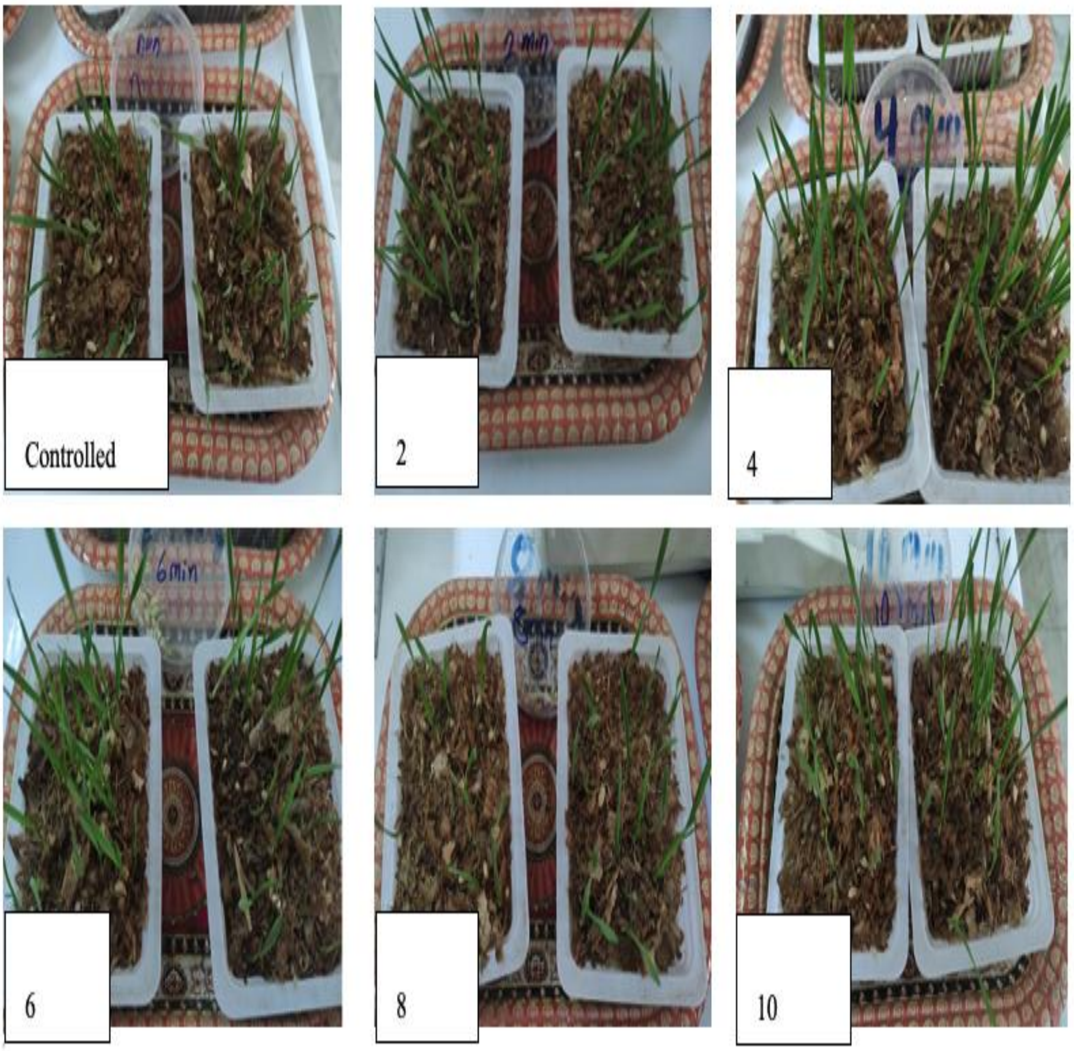



Figure 4-17 Samples of treated Iraqi wheat with Argon cold plasma (0,2,4,6,8, & 10) min, which were cultivated and germinated for 15 days

Starting from the fourth day, the germination percentage data were recorded for each day by calculating the number of germinated seeds until fifteen days to calculate the speed of germination by using equation (3- 1). To calculate the percentage of germination, the overall germinated seeds were divided by the total number of seeds for each replicate, as explained in the equations: (3-2),(3-3).


Figure 4-18 Samples of A. untreated (left side of picture ) and treated B. (right side of picture) seed by Argon cold plasma after 4 days of germination

Figure (4-18) illustrates the effect of the APPJ on the size and the weight of the Iraqi wheat seeds. The results of seed vigour index are calculated as illustrated in table (4-5). It explains the details for all the recorded parameters for the treated seeds with argon plasma jet. Figure (4-19) illustrates the relationship between the treatment time in x-axis, and the number of seeded plants, germination percentage, speed of germination, and seedling vigour index in y-axis. It is clear, that the all-parameters (the number of seeded plants, germination percentage, speed of

Table 4-5 Treatment time of argon plasma jet with No. of seeds plant, germination percentage, speed of germination, and seedling vigour index

| Treatment time (minute) | Av. Number of seeded plants | Leg weight (g) | Root weight (g) | Leg length (cm) | Seedling dry weight | Germination % | speed of germination seed/ day | Seedling vigour index |
|---|---|---|---|---|---|---|---|---|
| 0 | 26 | 0.04476 | 0.0303 | 8.75 | 0.0751 | 74.285 | 4.03 | 5.578 |
| 2 | 28.5 | 0.06694 | 0.0429 | 9.75 | 0.1075 | 81.428 | 4.87 | 8.754 |
| 4 | 31.5 | 0.08843 | 0.0621 | 12.6333 | 0.1505 | 90 | 10.26 | 13.551 |
| 6 | 24 | 0.06403 | 0.0456 | 10.3667 | 0.10961 | 68.571 | 8.71 | 8.320 |
| 8 | 16.5 | 0.06005 | 0.0436 | 8.4 | 0.1036 | 47.142 | 7.89 | 4.883 |
| 10 | 23 | 0.06206 | 0.0495 | 9.5166 | 0.1116 | 65.714 | 6.25 | 7.333 |

germination, and seedling vigour index) reach the highest value with four minutes treatment by Argon cold plasma jet. The seeds hydrophilicity is improved as a result of the plasmas effect on the seed coating. Consequently, the germination will be enhanced [88]. The values of all parameters are increased gradually from (0) minutes of treatment to reach the summit at 4 minutes. They decrease progressively with 6, 8, and 10 minutes. These results

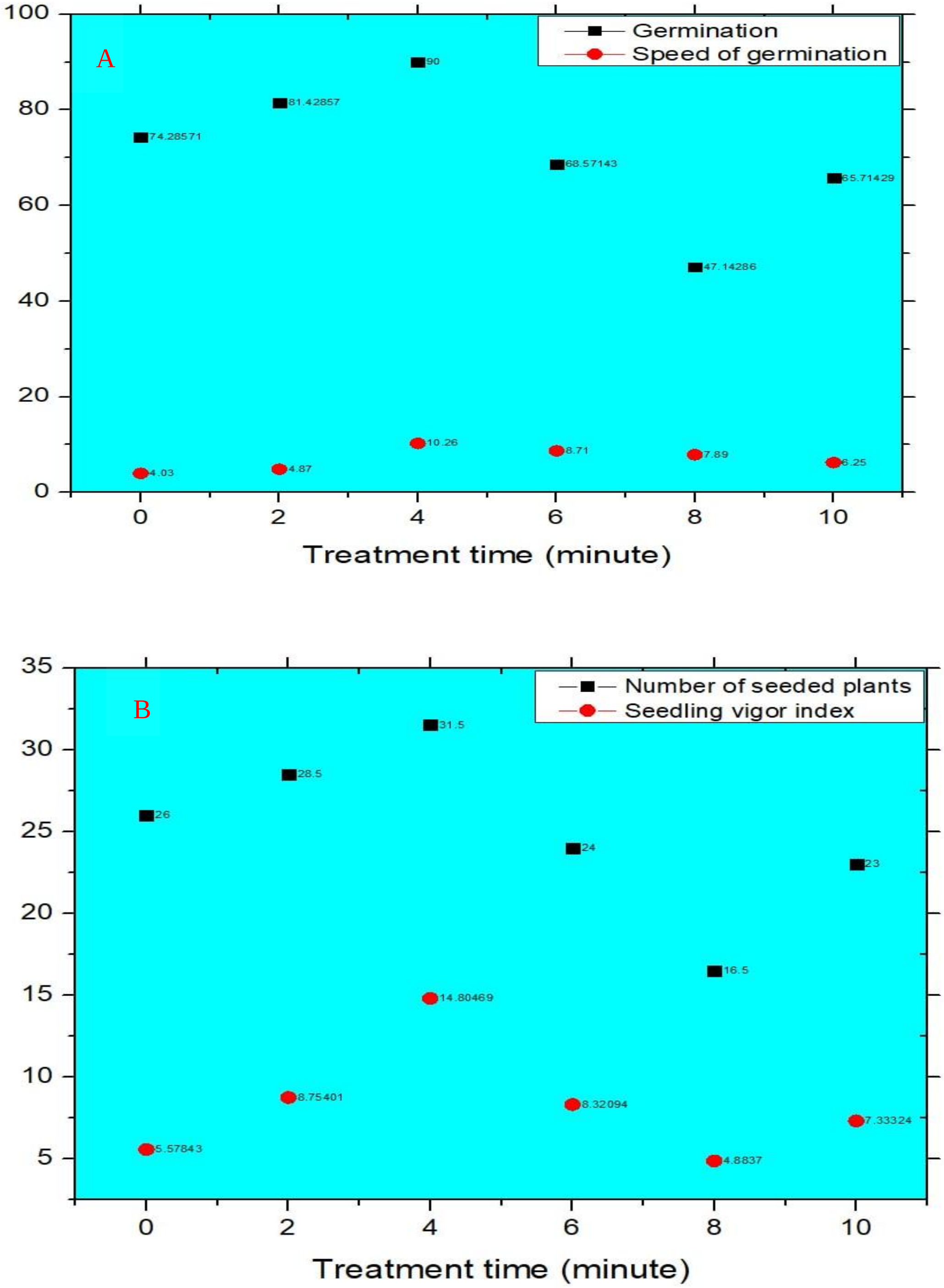



Figure 4-19 A. Percentage germination, and speed germination, B. The number of seedlings, and seedling vigour index, of treated wheat with treatment time

are in agreement with a study that indicated the effect of medium density plasma (DBD) on wheat seeds indicated that. It has an effects on the germination and growth process, as the growth potential increased by 24, 28 and 35.5% after four minutes of air, nitrogen and argon plasma treatments, respectively, compared to the non-treated seeds[108].

The decrease of germination and seedling growth with 6 to 10 minutes treated could be understanding by the high-intensity of plasma jet etching the shield of seeds, which can have negative effectiveness on permeability and hygroscopicity of the Iraqi wheat seeds[109]. In addition, germination and seedling growth is going to be promoted if the wheat seeds treatment with moderate intensity whereas, they are decreasing if they treated with high intensity plasma jet [110].

Consequently, the ability of wheat to imbibe water could be prohibited by its shells, therefore, the seed germination processing could be affected dramatically. However, scientists reported that the treatment of wheat with cold plasma led to the promotion of seed ability to absorb water consequently this triggered new developments in seed germination[111] [112].

### 4.7.3 Calculate the Germination and Growth of Wheat Treated Seeds by Mixed Gas (APPJ)

The germination and speed of germination results of the treated Iraqi wheat seeds by argon and mixed plasma, show an improvement in the ratio of

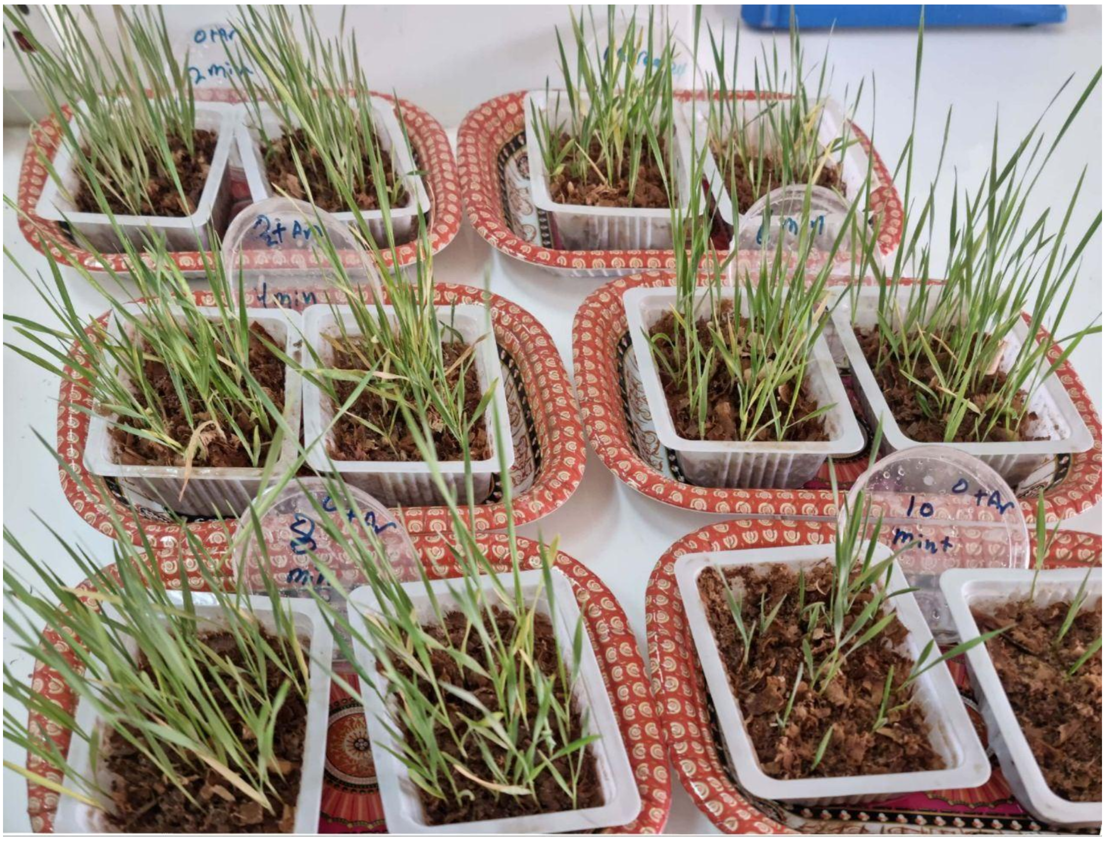


Figure 4-20 Samples of treated Iraqi wheat with mixrd gas cold plasma (0,2,4,6,8, & 10) min, which were cultivated and germinated for 15 days

germination, which was 90% with Argon (APPJ), whereas it was 91.4% with mixed gas (APPJ), at 4 minutes treated as figures (4-20), (4-21) shown. The speed of germination, number of seeded plants, and seedling vigour index were improved with mixed gas (APPJ) treated. This enhancement could be explained as a result of the increased intensity of hydroxyl radical (OH), ON, $H_2O_2$, and $N_2$ with mixed gas (APPJ) [113].

Table 4-6 illustrated the treatment time of mixed gas (APPJ) for Iraqi wheat seeds with No. of seeds plant, germination percentage, speed of germination, and seedling vigour index

| Treatment time (minute) | Av. Number of seeded plants | Leg length (cm) | Leg weight (g) | Root weight (g) | Seedling dry weight | Germ-ination % | Speed of germina-tion seed/day | Seedling vigour index |
|---|---|---|---|---|---|---|---|---|
| 0 | 23.5 | 8.5833 | 0.0865 | 0.06208 | 0.1485 | 67.142 | 4.66 | 9.976 |
| 2 | 29 | 12.0833 | 0.1051 | 0.10956 | 0.1813 | 82.857 | 8.08 | 15.02 |
| 4 | 32 | 17 | 0.148 | 0.13253 | 0.2805 | 91.428 | 12.85 | 25.64 |
| 6 | 25 | 13.0833 | 0.1134 | 0.086583 | 0.20001 | 71.428 | 7.12 | 14.28 |
| 8 | 24 | 14.5 | 0.2655 | 0.081883 | 0.2646 | 68.571 | 5.03 | 18.14 |
| 10 | 14 | 9.3333 | 0.07568 | 0.0528 | 0.1284 | 40 | 2.73 | 5.139 |

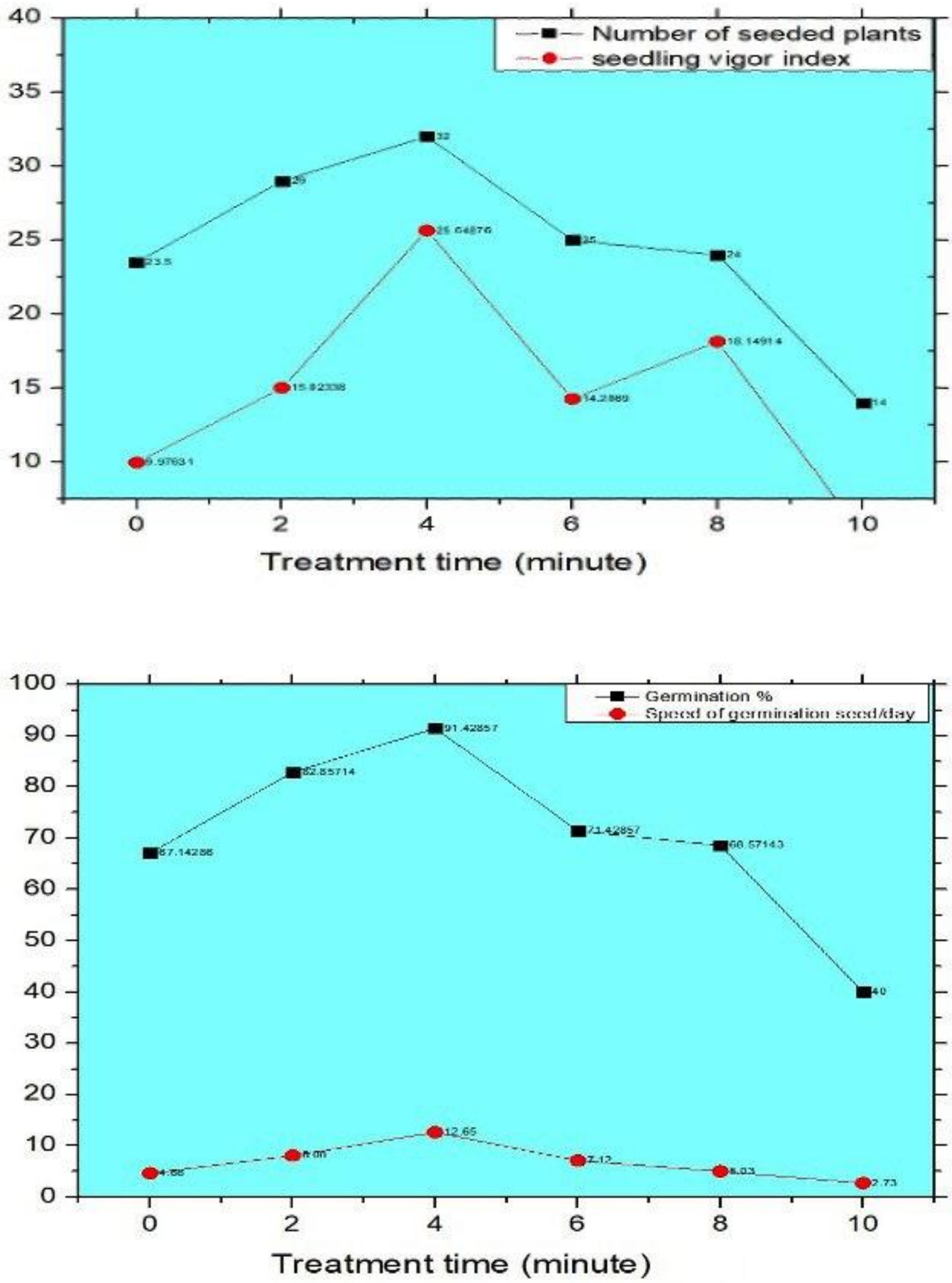



Figure 4-21 The effect of mixed gas of (APPJ) on the number of seedlings, seedling vigour index, percentage germination, and speed germination, of treated wheat with treatment time in min

The early germination stage culminates in the tearing of the outer shell surrounding the seed and then the tearing off the endosperm stage as a late germination stage. The germination process is regulated through Abscisic acid (ABA) and Gibberellins acids (GAs), which are two widely examined plant hormones, the germination process ABA maintains dormancy, while GA promotes germination [37].

Reactive oxygen species (ROS) play a fundamental function in seed dormancy regulation, germination, and spoil in plants. The (ROS) low level as signaling particles improves dormancy cast and enhances seed germination. Excessive ROS accumulation causes seed deterioration during seed storage [114]. whereas, the ROS high level led to the orthodox seed spoil under natural and artificial aging circumstance by affecting peroxidation of lipid, permeability of membrane, faulty proteins, system of antioxidant, mitochondrial degradation, and damages of DNA and RNA [115]. Therefore, keeping a balance in the ROS levels in seeds plays an important role in the regulation of seed dormancy, germination, and deterioration.

# Chapter Five

# Conclusions and Future Works

# Chapter Five
# Conclution and Future Works

## 5.1 Conclusions

1. The design and construction of atmospheric pressure plasma jet system and describe its characterization is presented in this theseis.
2. As this research has shown, the electrode types (Al, Cu, and Ag) are presented by using the built plasma jet system, the produced atmospheric plasma jet with Al electrode is more efficient than those with Cu, and Ag electrodes, in term of the electron temperature, which was lower with Al electrodes than others. The reactive species intensities of produced plasma with Al electrodes are obviously bigger than of others.
3. Investigate the different types of APPJ feed gas to enhance the produced plasma characterization. As present in thesis have shown, the argon and mixed gas (2% Oxygen and 98% Argon) are presented by using the built plasma jet system. A comparison method is used between Ar, and mixed APPJ plasma. It is clear that, firstly, the produced atmospheric plasma jet with mixed gas is more efficient than of those with Argon gas, in term of, firstly, the reactive spices intensities of produced plasma with mixed gas are obviously bigger than of others, as well as the various of reactive spices. Secondly, the plasma plume for mixed gas was more than those of Argon gas. Finally, the mixed gas plasma jet temperature is smaller than that of Argon plasma jet.
4. The protentional of the generated plasma jet is a test and applied on Iraqi wheat seeds. The results show that the using of Argon plasma jet enhanced the germination rate and speed of germination.

## 5.2 Future works

1. Design and constriction a nonthermal plasma jet array (APPJs) and investigate the characteristics of the proposed system.
2. Using the Argon and Nitrogen gas as a feed gas, in addition investigate and study the optical and electrical properties of the generated plasma jet.
3. Utilizing the cold atmospheric plasma in treat the barley and corn seeds and check the germination ratio and growth rate.
4. Using DNA sequence for treated wheat seeds might be lead to show the changing of the treated seeds.

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## الخلاصة

تعتبر تقنية البلازما الباردة تقنية واعدة وآمنة نجحت في العديد من التطبيقات مثل الطب والطب الحيوي والصناعة والزراعة ، في هذا العمل تم معالجة بذور القمح العراقي بواسطة نظام بلازما الضغط الجوي الاعتيادي (APPJ) ، تم تصميم وبناء المنظومة في مختبر البلازما المتقدم في جامعة كربلاء ، كلية العلوم ، قسم الفيزياء. وقد تم فحص أنواع مختلفة من الأقطاب الكهربائية ( Al ،Cu ، و Ag) من أجل تشخيص خصائص البلازما للوصول إلى البلازما المتكونه المثلى. وقد استخدم الأركون كغاز تغذية، تم دراسة الطيف البصري وجبهة الموجة الكهربائية ، وقياس درجة حرارة الإلكترون وكثافة الإلكترون باستخدام طريقة بولتزمان، وكذلك طول نفث عمود البلازما و قياس درجة حرارته.

بلغ طول نفث البلازما لقطب الالمنيوم (Al) ٣،٨ سم أطول من تلك المتكونه مع أقطاب الفضة (Ag) ٣،٦ سم و النحاس (Cu) ٣،٣ سم. درجة حرارة البلازما الناتجة باستخدام قطب الالمنيوم (Al) هو ٢٦،٥ درجة مئوية أقل من الناتجة مع قطب الفضة (Ag) ٢٧ درجة مئوية و مع قطب النحاس 28.5(Cu) درجة مئوية. بلغت درجة حرارة الإلكترون في البلازما المتكونه عند استخدام قطب الالمنيوم (Al) ٠،٨٣٤٩(الكترون فولت) ، في حين أن درجة حرارة الإلكترون لكل من قطب (Cu) و قطب (Ag) كانت تعادل ٠،٨٦٢٢(الكترون فولت) و ١،٢٤٦٦ (الكترون فولت) على التوالي. إن شدة الأيونات التفاعلية للبلازما المنتجة بأقطاب (Al) أكبر من الأنواع الأخرى. أظهرت النتائج أن جودة البلازما النفاثة مع القطب الكهربي Al هي الأفضل.

اختبار البلازما الباردة التي تم إنتاجها باستخدام غاز الأركون بنسبة ٩٨٪ والأوكسجين بنسبة ٢٪. وقد حددت الخواص البصرية والكهربائية. تتمت مقارنه درجة حرارة تدفق البلازما وطول عمود البلازما للبلازما المختلطة مع تلك الخاصة بنفث الأركون البلازمي. كثافة جميع الايونات التفاعلية المنتجة لنفث البلازما المختلطة أعلى من تلك الخاصة بنفث البلازما بالأركون ، وطول تدفق البلازما المختلطة أعلى من تلك الخاصة ببلازما الأركون ، حيث بلغ طول تدفق البلازما المختلطة ٢،٥ سم ، في حين أنه كان ١،٨ سم لبلازما الأركون عند جهد ٩ كيلو فولت. كانت درجة حرارة نفث البلازما للغاز المختلط أصغر من درجة حرارة نفث غاز الأركون وبلغت ٢٤،٥ درجة مئوية و ٢٥،٥ درجة مئوية على التوالي عند الجهد المحدد.

تمت دراسة تاثير البلازما المتولدة على تحسين إنبات ونمو القمح العراقي. تمت معالجة خمس عينات من بذور القمح العراقي باستخدام بلازما الاركون وبلازما المزيج (الاوكسيجن والاركون) ولفترات زمنية مختلفة (٢، ١٠،٨،٦،٤) دقائق لكل من العينات بالترتيب. ثم زُرعت البذور المعالجة والعينة غير

المعالجة في حاضنة نمو عند( ٢٥ ± ١ )درجة مئوية ، وإضاءة (١٥٠٠-١٨٠٠ لوكس) ورطوبة ٦٠-٧٠٪.

أوضحت النتائج أن هناك تحسنا جيدا في نسبة النمو والإنبات للقمح العراقي. علاوة على ذلك ، كانت نسبة الإنبات والنمو لبذور القمح المعالجة بالبلازما المنتجة بالخليط ( الاوكسجين والاركون) افضل مقارنة بالبذور المعالجة بغاز الأركون . كانت نسبة الإنبات ٩٠٪ وسرعة الإنبات ١٠،٢٦ بذرة / يوم في حالة غاز الأركون (APPJ). بالإضافة إلى ذلك ، تم تحسين نسبة الإنبات وسرعة الإنبات مقارنةً بالغاز المختلط (APPJ) ، فأصبحت ٩٢٪ لنسبة الإنبات و ١٢،٨ بذرة / يوم لسرعة الإنبات. علاوة على ذلك ، كان معامل قوة الشتلات ٢٥،٥ للبذور المعالجة بالبلازما المختلطة و ١٣،٥ للبذور المعالجة بغاز الأركون APPJ.

جامعة كربلاء
كلية العلوم
قسم الفيزياء

# بناء منظومة بلازما نفث الضغط الجوي الباردة لمعالجة إنبات بذور الحنطة العراقية ونموها.

أطروحة
مقدمة الى مجلس كلية العلوم- جامعة كربلاء كجزء من متطلبات
نيل شهادة الدكتوراه في علوم الفيزياء

من قبل
**سجاد حسين معن**

إشراف
**أ.د فاضل خدام فليفل**
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