International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 6 Issue 1 ǁ 1. 2018 ǁ PP. 01-12

The Effect of Argon Pressure on Plate-Shape Electrodes Plasma Forming Behavior

Koten, David S.[1],Badjowawo, Maria[2], Dana, Sumartini[3], Subiantoko, Arsono[4]
[1,2,3,4]*(Department of Electronic Engineering, State Polytechnic of Kupang, Kupang, Indonesia)*
Corresponding Author: Koten, David S.

ABSTRACT: To create plasma, it is needed to introduce some sort of energy into the electrons until reaching the ionization energy, and can be done by heating up the gas or by bombarding of high-energy electromagnetic field using laser or microwave generator. Plasma is ionized gas, i.e. a substance which the electrons excited completely out from the atomic orbit. The main challenge to create a plasma reactor is to develop low gas pressure whilst maintaining high current plasma. Common method used in plasma generating in the industrial world is CCP (capacitive coupled plasma). This method uses a pair of metal electrodes arranged in close distance inside a reactor. The gas pressure inside the reactor is then set to atmospheric pressure or lower. This research analyzes the technique for developing high voltage DC plasma generator in order to supply reactor chamber to generate plasma in low pressure argon environment. Furthermore, this research does the analyzing of breakdown voltage to plot it against gas pressure and distance between electrodes. Making a comparison between experimental plotting and the Paschen Law is the final objective of this research.
Keywords –Plasma, Reactors, Electrodes, Argon, Paschen, Breakdown Voltage.

I. INTRODUCTION

The word “plasma” was first introduced by Langmuir and Tonks in 1928, during the research of electrical discharge in ionized gas (Chang, 1991). Once the electric field exposed on gas, energetic electrons will transfer their energy to gas species by means of collisions, molecule excitation, electron capturing, dissociation, and ionization. Formation of plasma happens when electrons, positive ions, and negative ions mixing occurred (Tseng, 1999). Quasi-neutral state is an area range where ion density almost meet to the electron density, until it can be strained as plasma density (Francis, 1974). Currently, there are several non-thermal plasma systems founded. The main challenge in the plasma generator system development is to create low pressure vacuum chamber while generating high plasma output rate. Tomaz Czapka developed plasma reactor by using back corona phenomenon inside gas exhaust system. Such system generates more plasma output in specific pressure compared to other techniques.

The implementation of plasma in industrial, medical, and commercial world for example: plasma cutting, plasma welding, plasma nit riding, and plasma surgery. In cutting technology, plasma is often used for cutting sheets of metal, and likely a very productive way compared to conventional ones. Plasma welding is widely used mainly because of the rapid process against tungsten welding. Other implementation includes ozone gas production, water sterilization, and unwanted organic compounds eliminating. Common method to employ plasma in industrial world is CCP (capacitive coupled plasma), which is a method to generate plasma by using narrow gap between two electrodes inside a reactor. The gas inside the reactor set to be match or lower than the atmospheric pressure. Such system usually suppliedby about 13.56 MHz single radio frequency power supply. One electrode is connected with the power supply, while the other with the grounding. The basic configuration is similar to the capacitor in electronic circuit, hence the name (Nur, 2011).

Among the various applications of plasma technology both in the industrial and commercial world that has begun to be developed, the main problem is the application of plasma technology in the form of devices not yet available in the market or sold commercially. Based on the above description, this researchdesigns a plasma generator from HVT (high voltage transformer) that produces enoughDC voltage to activate the plasma between electrodes mounted in the reactor. HVT converts AC 220 V into AC 2000 V. High voltage capacitor and diode serves as rectifiers and filters which then convert AC 2000 V into DC of 2000 V. From plasma generator produced, it is expected for the parameters of the process of the plasma formation determined the Paschen Curve of the gas used (argon gas). Paschen Curve illustrates the gas breakdown voltage as a function of electrode gap and gas pressure. The minimum pressure and tension values obtained by the extraction are then analyzed to produce the Paschen Curve which is the semi-empirical curve of the gas pressure change to the gas duct voltage. With the semi-empirical Paschen curve, it will be attained a clearer picture related to voltage regulation, electrode gap, and gas pressure in the process of plasma formation.

The objectives of this research are to design, construct, and test plasma generators and to analyze their performance, especially the effect of gas pressure on plasma behavior to prove the Panschen Law.

II. THEORETICAL BASIS

A. Plasma

Put it in simple way, plasma can be defined as ionized gas, a state when the electrons ejected from orbits due to their kinetic energy. This situation makes plasma develop a conductive form, since the atoms have imbalance charge, which the atoms possess positive charges, while the cloud of electrons becomes negatively charged.The mixing between positively charged ions with negatively charged electrons has properties that are very different from the gases in general. The material in this phase is called the plasma phase. Hence plasma is defined as ionized gas and is known as the fourth phase of matter after the solid, liquid, and gas.

In terms of the temperature, plasma can be classified into three categories, namely: cold plasma, thermal plasma, and hot plasma. Cold plasma occurs in a state of thermal equilibrium (non-thermal equilibrium) between the temperature of electrons and gases. This type of plasma is called NTP (non-thermal plasma). In this type of plasma, the temperature of electrons is high but the temperature of the gas particles is relatively low because the collisions of electrons and gas particles are extremely rare. In cold plasma, ions and neutral atoms or molecules remain in the temperature of about 1000 K. These electrons in this type of plasma have a high enough temperature of about 50000 K. Cold plasmas are often used in the field of microelectronics, the formation of new materials, and the cleaning of pollutants. In NTP, electrons have very high energy, while heavy particles (such as ions and atoms) do not experience excitation. Therefore, there is a thermodynamic non-equilibrium condition. In this case, the gas stream is at ambient temperature, and the electrons can be around 10000 K or more (e.g. sparkling plasma). Electrical discharge in gas and electron beam irradiance should be used to generate plasma (Czapka, 2011). Thermal plasma pertained plasma in the state of thermal imbalance (non-thermal equilibrium). The heavy particles in the plasma have temperature higher than 3000 K. The electrons in this thermal plasma possess high temperature greater than 100000 K. This type of plasma is often used for welding, metal cutting, cleaning of pollutants, and others. The hot plasma occurs in a state of thermal equilibrium. In hot plasma generation the distribution of electron energy and gas molecules is approximately equal, since the collision frequency between the electrons and the gas molecules is greater. It is composed of high-temperature gas molecules. This type of plasma has temperatures above 1000000 K, and mostly used to produce electrical energy (nuclear fusion).

B. Plasma Generating Process

Ionization is defined as the electrons releasing process from atoms or molecules. The energy required to excite one or more electrons from their orbit on an atom is defined as an ionization energy E. The amount of ionization energy is expressed in electron-Volt (eV) unit.

C. Electrical Discharging in Gas

The phenomena of electrical discharging in gas is best known in nature as lightning. Gas, which is essentially an insulator, could turn into a conductor in certain conditions. Lightning are formed and followed by thunder sound. Clouds that are close to earth have a very high potential difference with the surface. Ionization occurs because of cosmic radiation hit the gas between the cloud and the earth surface.

This increasing in ionized gas leads to ionization chain reaction since the electrons generated in ionization accelerate toward the cloud and strike atoms and gas molecules on the way between.

This event continues and in one particular circumstance there is electronic avalanche. The air (gas) between clouds and the earth becomes a channel-shaped conductor and emits white light. Electrical discharges have occurred in nature, followed by a thunder sound,i.e. the sound of air tap separated in a short time by a channel releasing between clouds and the earth and within clouds.

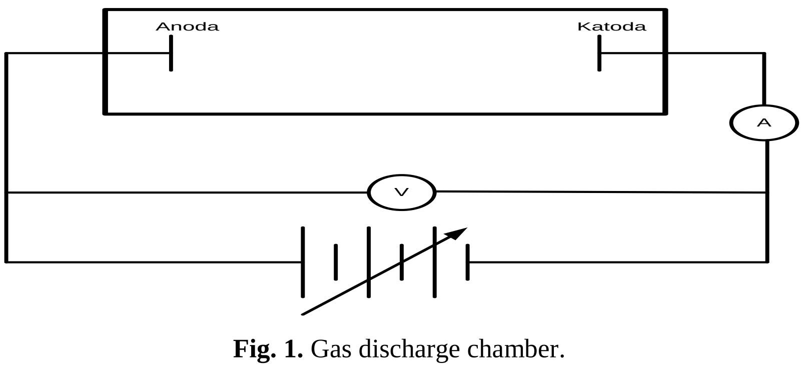

Fig. 1. Gas discharge chamber.

In the laboratory, the electrical discharging can be carried out in a gas-filled reactor. If two electrodes in the form of parallel plates are placed in a gas-filled tube with a certain pressure and the two electrodes connected to a high-voltage DC source, there will be electrical discharges between the electrodes. Example of the reactor can be seen in Figure 1. Electrons from the cathode will move toward the anode and during the course of these electrons will strike the molecules and gas atoms between the two electrodes. For the occurrence of chain ionization, the first step that must be passed is the ionization that produces electrons. At low voltage electrons have little effect on the gas atoms, because only a few ionization and the resulting electrons do not contributeenough current. By increasing the voltage, the gas particles, electrons, and ions that have been formed get additional energy, and multiply the ionization event, so that the electric current rises against the voltage.This area is called Townsend discharge. By continuously increasing the voltage, the electrons moving toward the anode have enough energy to ionize the gas particles they are pounding.

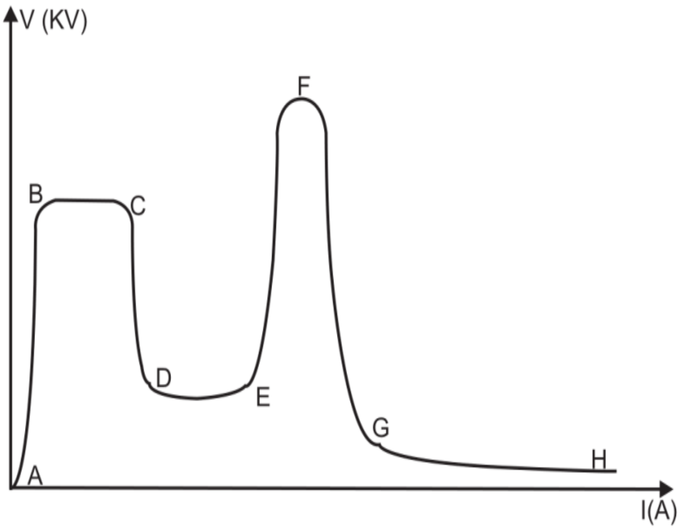

Fig. 2. Characteristic of discharge gas V-I relation.

The ionization process is more frequent, resulting in electronic folding. The resulting ions will then be accelerated by the electric field and eventually strike the cathode. The collision of ions produces electrons emitted by the cathode through a photoelectric effect, such collision are called secondary electrons collision. The cause of the emergence of electrons differs from the ionized electrons called primary electrons. The emission occurs at the cathode due to recombinant between gaseous ions and secondary electrons and due to the heat of the bremstrahlung ion at the cathode. In the gas itself there is a change that causes the gas gradually become the conductor, this condition is called breakdown. After the circumstances of cathode incandescent caused by ion collisions and secondary electron emissions will cause a rise in current, this condition is called normal discharge. In this state the ionization process will occur in chains and no longer requires the addition of external stresses for ionization.

Once the entire cathode surface is glowing, the voltage and electric current will rise simultaneously and this is called abnormal discharge. The characteristic of relation between voltage and current in gas discharging is shown in Figure 2. If the voltage continues to be increased then the cathode will get heated due to high energy ion collision and this process becomes dominant to produce electrons. In this case the discharge voltage becomes decreased and the electric current increases, this condition is called arc discharge.

D. Breakdown Voltage in Gas

The process of electron excitation from gas molecules with positive ion production is called ionization. In the ionization process by collision, the free electrons collide with neutral gas molecules and give rise to new electrons and positive ions. If there is a pair of separate electrodes at distance d and connected to the E = V / D electric field (as in Figure 3) then the primary electrons located near the cathode will carry an initial current of i0.

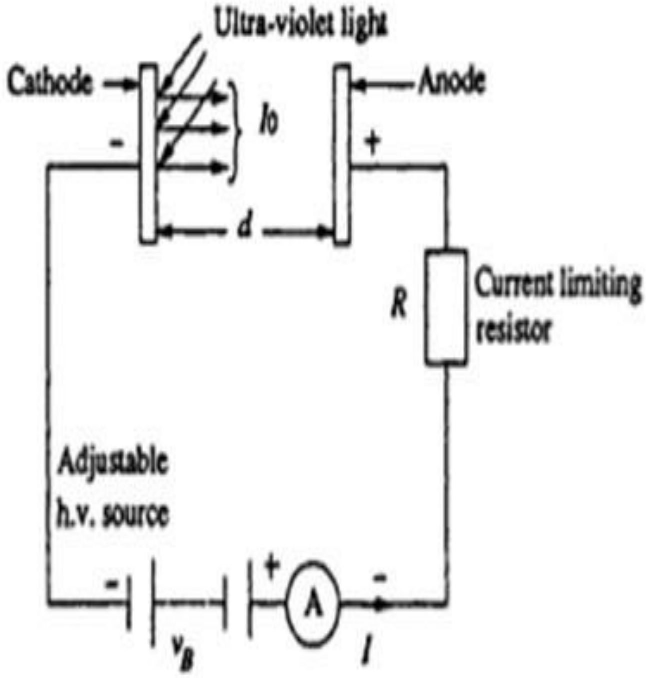

Fig. 3. Townsend discharge electrodes arrangement.

According to Figure 3, if it is assumed that n0 electrons are emitted from the cathode and when one electron collides with a neutral particle, then a positive ion and electrons, called ionization of the collision with α (Townsend ionization coefficient), is the average number of first collision ionization performed by Electrons per cm (α depends on gas pressure p and E / p).

E. Paschen Law

Paschen's law is the breakdown voltage equation between two electrodes with the pressure function and the gap between the electrodes. Paschen studied breakdown voltages of various types of gases between parallel metal plates as a function of gas pressure and gap variation. In the Paschen Law approach, we assigned the A and B from random values, and then change the value while observing the direction of the curve shift. Paschen's law can be seen in Equation (1).

III. METHOD OF RESEARCH

Method used in this research is the designing, manufacturing and testing. As shown in Figure 4, this study goes through several stages:

1. Plasma generator system design.
2. Manufacture of plasma generator system consisting of making of power supply, making of vacuum tube, and making of electrode system.
3. Testing of plasma behavior.
4. Data retrieval.
5. Plasma performance analysis.
6. Conclusion.

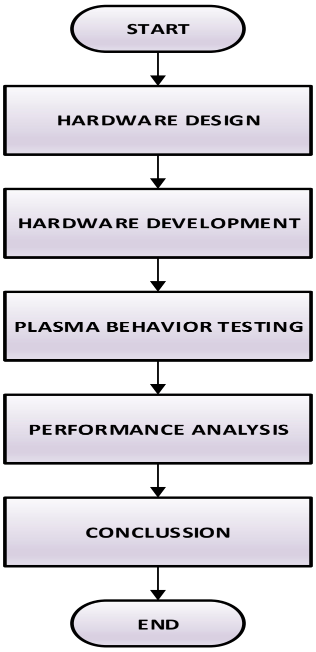

Fig. 4. Diagram of Research Method.

Based on Figure 4, the problem formulation model can be explained in several stages as follows:

A. Hardware Design

At design stage, a high voltage DC power supply will be designed. For the plasma generator power supply circuit can be seen in Figure 5.

The power supply circuit has a high voltage DC output. The input voltage of 220 VAC is raised by a transformer applying some coil ratio,where the winding ratio of a transformer affects the resulting voltage ratios. The voltage generated by the transformer is still in the form of an AC wave and rectified by using a rectifier. The rectifier circuit used utilizes four diodes that have been designed to pass both the AC wave cycles into DC.

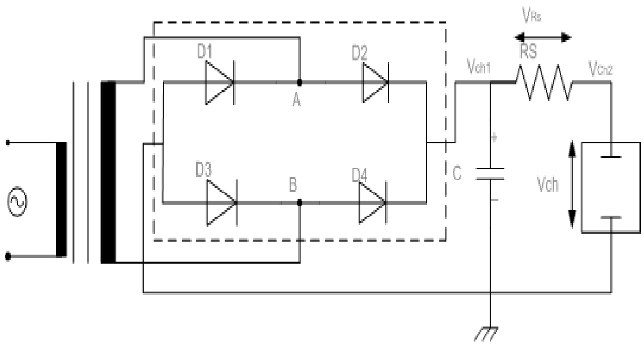

Fig. 5. Plasma generator power supply circuit diagram.

The delivered sine wave that has been converted into DC output from the bridge diode still has a ripple or still has an uneven voltage amplitude. This is because the bridge diode only eliminates the negative cycle and makes it a positive cycle but does not change the waveform at all where it still has valleys and hills. For that purpose, capacitors that have a capacitance large enough to make the average wave. This is due to the length of the discharge process by the capacitor so that the amplitude of the wave is flat.

The DC wave form output of power supply after flatten by capacitor is shown in Figure 6.

B. Block Diagram of Plasma System Generator

At the hardware building stage, the first step is to manufacture or assemble the components of high voltage power supply circuit consisting of:

1. Step-Up Transformer 220VAC to 2000VAC.

2. Rectifier diodes with a capacity of 8 kV, 380 mA.
3. Capacitors with 1 μF capacitance and 2100 V maximum voltage.
4. 300 kΩ resistors.

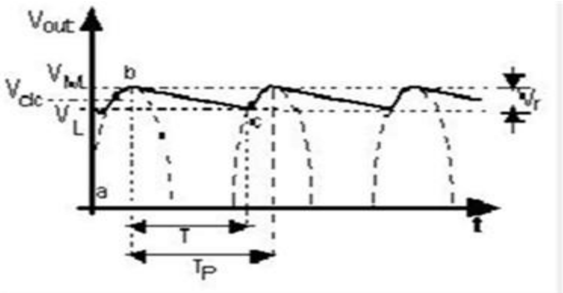

Fig. 6. Flatten output voltage from power supply.

The components in the power supply circuit areconsisted of components from a microwave oven circuit. After assembling the components of the power supply circuit, further measurements are made to ensure accuracy of the circuit output voltage.

Then the second process is to develop plasma reactor, using glass chamber for vacuum tubes and aluminum plates for vacuum tube holder (platform). Three holes are made in the platform, one for air pressure evacuation path, the second as argon gas supply line, and the last as the input voltage at plasma reactor electrode. This process needs high precision work to ensure vacuum tube has no leakage.

Generally, the tool used in this research was designed as in theory, i.e. the need for DC high-voltage outputs (in this case, 2000 VDC is used) for plasma formation and low gas pressure in the reactor.Two electrode plates facing each other in parallel and a high DC voltage will produce an Avalanche effect. This effect occurs when the initial ionization event frees one electron, then the collision that occurs frees the other electrons, so that two electrons arise from every collision: ionized electrons and released electrons. The plasma reactor chamber diagram using two electrode plates can be illustrated as in Figure 7.

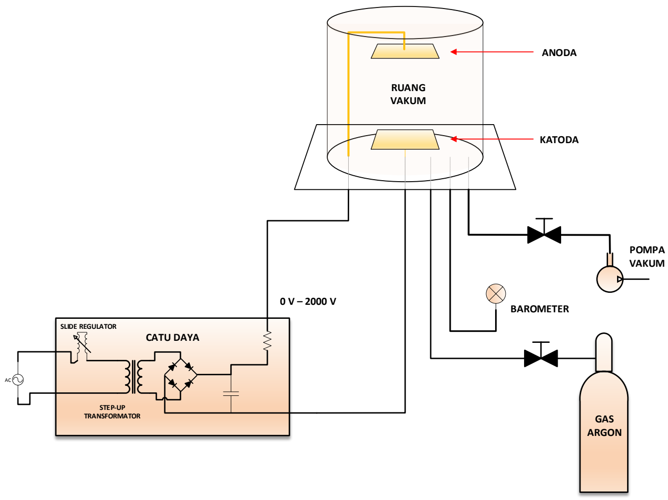

Fig. 7. Design of plasma system generator.

The reactor filled with low pressure argon gas is discharged through the pipe by means of a vacuum evacuation pump and controlled by the valve, while on the other side the high pressure argon gas reservoir acts as an argon gas supplier and is controlled by the valve. The gas pressure inside the reactor can be observed through a pressure gauge. Anodes and cathodes are made of copper plates in such a way that they are arranged parallel. The power supply used for the anode and cathode is a DC source of 2000 V voltage.

C. Plasma Generator System Testing Method

Figure 8 shows steps of the plasma behavior test. Initially the gas in the reactor is evacuated to almost empty, then the argon gas is added until the pressure reaches a certain pressure. After that the supply voltage to the electrode is gently raised until the plasma formed. Plasma behavior was observed at this stage and data plotting was performed on the Paschen curve function. This step is repeated again while increasing the pressure of argon gas in the reactor as much as 0.1 Torr, until the pressure shows 4 Torrs. The resulting curve of the plotting process is the final goal of this research.

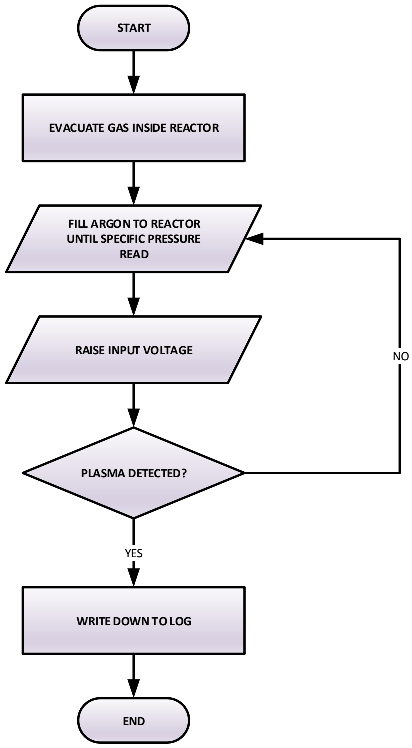

Fig. 8. Flowchart of plasma behavior testing method.

D. Phases of Testing

The final stage of the research is to conduct a series of testing to observe the behavior of plasma when the input voltage and the gas pressure of the argon inside the reactor are continuously but slightly altered.

As in Figure 8, the test is first performed by filling the reactor chamber with a 0.1 Torr pressure argon gas. After that the test continues by turning on the reactor and observing the plasma behavior that is formed.

The next stage is to plot the Paschen curve according to the plasma behavior at the gas pressure present in the reactor. The two stages are repeated, with at each adds argon gas pressure to the reactor with 0.1 Torr increment, up to 4 Torrs. The results of the Paschen curve are analyzed and then formulated the function that forms the curve, i.e. the plasma behavior against the gas pressure.

III. RESULTS AND DISCUSSIONS

In accordance with research methods, the initial step is designing the hardware, then followed the making of the hardware, testing phase, and the results analyzing and conclusions defining.

A. The Research Hardware

The hardware used to conduct the research are divided into several sections. First is the power supply which serves to supply DC high voltage. This section converts inputs into AC voltage of 220 V into DC voltage that can be adjusted from 0 V to 2000 V. Figure 9 shows the power supply section equipped with an output voltage adjustment knob, input voltmeter, and output voltmeter.

The second part is a plasma reactor which must be a translucent chamber to conduct visual observation. Inside the chamber there are electrodes with replaceable ends and adjustable distance.

Figure 10 shows the plasma reactor used. At the bottom there is a flat metal platform surrounded by a seal in the form of a silicon glue to create a vacuum when the reactor glass is sealed from above, thus preventing gas leakage from outside into the reactor. Also in Figure 10 there is also anampere meterbelow the platform, which is used to measure the current of the plasma in the reactor.

Fig. 9. The power supply unit.

The third part is the support of connecting pipes, evacuation pumps, and argon gas reservoirs. The support device shall be capable of evacuate air from the reactor until it reaches a pressure of less than 0.01 Torr, and no single leak allowed so that after evacuation the gas pressure will be unchanged.

Fig. 10. The plasma reactor.

In addition to the power supply and plasma reactors, the following are the miscellaneous equipment to be prepared:

1. Conductor electrode passing through hole in reactor wall.
2. Power supply voltage regulator, in a form of rotary button.
3. Voltmeter that measures the voltage of the power supply, with a precision of 1 volt.
4. Amperemeter that measures the current that flows through the electrode, with a precision of 1 mA.
5. The 1 mm ruler in the reactor is positioned behind the electrode and mounted parallel to the electrode axis, which serves to determine the distance between the electrodes.
6. An electrode holder that can be loosened and fastened to adjust the distance between electrodes.
7. Pipe passing through gas evacuation hole.
8. Barometer on the main pipe, which measures the air pressure inside the reactor, with accuracy of 0.1 Torr (1 desiTorr).
9. Valve for gas evacuation.
10. Vacuum pump to evacuate gas.
11. Valve to supply argon gas.
12. Argon gas reservoir tube.

13. Oscilloscope for DC voltage confirmation of supply to plasma reactor.

B. Data Retrieval

The data retrieval is done using a loop repetition in accordance with the objective of obtaining Paschen curve which is a breakdown voltage function against the distance of the electrode and the pressure of argon gas.

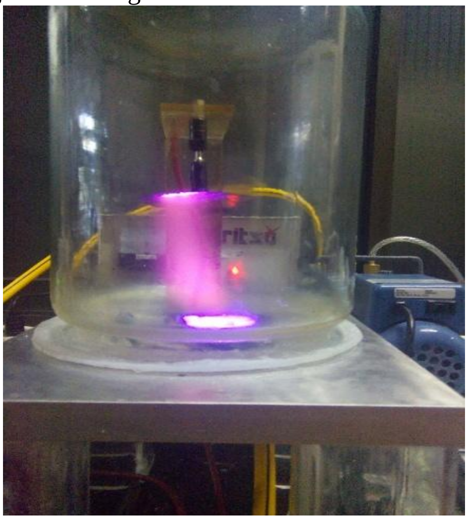

Fig. 11. The plasma forming inside the reactor.

Data collection is done starting from 0.25 cm parallel plate electrodes distance. The first distance between the electrodes is set to the end of the anode plate with the cathode plate spaced on 0.25 cm, then the controller bolt is locked and the reactor is closed. Table I shows an example of data retrieval carried out at a pressure of 0.8 Torr and all various electrode distance.

Table I indicates one observation of breakdown voltage occurring in an argon gas with a pressure of 0.8 Torr and the distance between parallel plate electrodes varies between 0.25 cm and 2.00 cm. In Table I, the voltage data is skipped up to 265 V because the current value is equally 0 mA. It can be seen that when the voltage reaches 268 V it suddenly forms 120 mA current, and visually forms the plasma in the reactor.

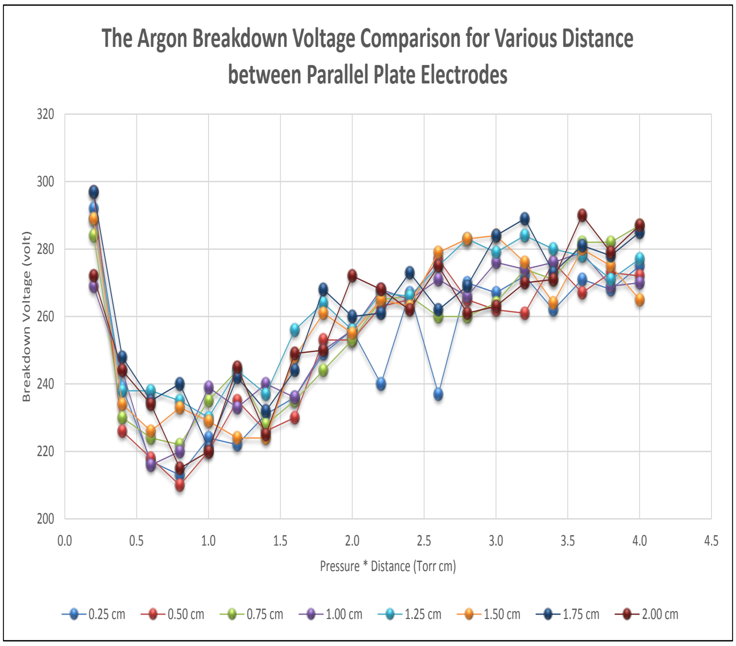

Fig. 12. The plotting result for all various gap between parallel plate electrodes.

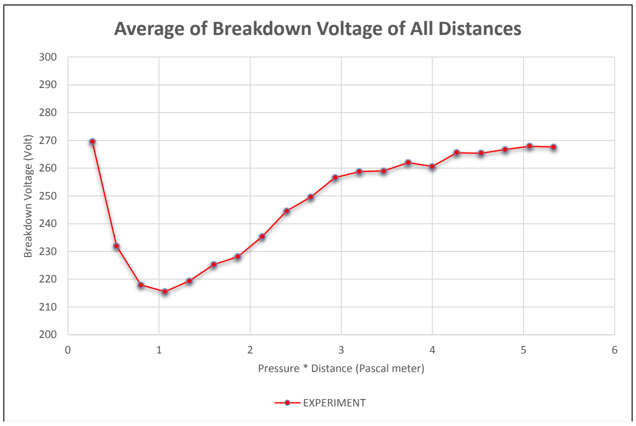

Fig. 13. The average plotting result for all various gap.

An example of a plasma display is shown in Figure 11. In this data collection, it can be concluded that the breakdown voltage for 0.8 Torr pressure and 0.25 cm plate-shape electrode distance is worth 268 V, and so on. The observation by increasing the voltage is no longer necessary because the breakdown voltage has been obtained. Figure 15 shows the relationship of current to voltage.

C. Result of Data Retrieval

Data retrieval is carried out for different pressures with 0.1 Torr pressure increment. At the next level, data retrieval is done for different electrode distances.

TABLE I. TESTING FOR VARIOUS PARALLEL PLATE ELECTRODES DISTANCE.

Pressure * Distance (Torr	Data Acquired (V)								Average (V)
	0.25 cm	0.50 cm	0.75 cm	1.00 cm	1.25 cm	1.50 cm	1.75 cm	2.00 cm	
0.2	292	297	284	269	289	289	297	272	286.1
0.4	239	226	230	244	238	234	248	244	237.9
0.6	217	218	224	216	238	226	235	234	226.0
0.8	213	210	222	220	235	233	240	215	223.5
1.0	224	220	235	239	230	229	221	220	227.3
1.2	222	235	244	233	244	224	242	245	236.1
1.4	231	226	228	240	237	224	232	225	230.4
1.6	236	230	235	236	256	248	244	249	241.8
1.8	249	253	244	250	264	261	268	250	254.9
2.0	256	253	253	256	256	255	260	272	257.6
2.2	240	263	265	268	267	265	261	268	262.1
2.4	267	265	266	265	266	263	273	262	265.9
2.6	237	277	260	271	275	279	262	275	267.0
2.8	270	265	260	266	283	283	269	261	269.6
3.0	267	262	264	276	279	284	284	263	272.4
3.2	272	261	274	274	284	276	289	270	275.0
3.4	262	276	271	276	280	264	273	271	271.6
3.6	271	267	282	279	278	280	281	290	278.5
3.8	268	273	282	269	271	275	278	279	274.4
4.0	275	272	287	270	277	265	285	287	277.3

From the data retrieval, the breakdown voltage data obtained for various gap between electrodes. Table I shows the breakdown voltage list for the various gap and various pressure. Of all the data retrievals, Figure 12 shows the complete results, while Figure 13 shows the average plotting results.

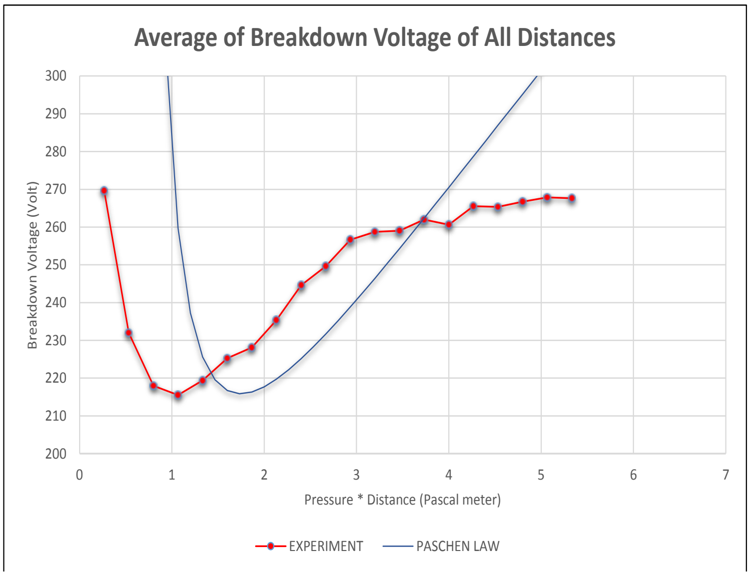

Fig. 13. Average plotting result versus ideal Paschen Curve.

D. Ideal Paschen Curve

In the data retrieval result, the actual Paschen curve obtained according to the results of data collection using the plate-shape electrode as in Figure 18. From the data obtained, it can be taken several values including the value of A, B, and γSE. Table III shows the best results of Paschen's Law approach, and shows MSE of 27392.32. Paschen's Law Approach has an A = 0.55, B = 165, and the value of SE = 3.3. Figure 13 shows the graph formed from this Paschen Law approach.

V. CONCLUSION

Based on the test results it can be concluded as follows:

1. The plasma generator designs include power supply (voltage converter 220 V to DC 2000 V), supply voltage regulator, reactor chamber, electrodes, vacuum pump, argon reservoir, plumbing installation and vacuum valve, have succeeded in generating plasma accordingly with the rules of the existing theory.
2. The search for equation using Paschen's Law produces a curve model approaching the data with MSE reaching 12,888.61.

While the suggestions that can be given are:

1. The next research is expected to obtain several types of electrodes.
2. It is expected that subsequent research can produce data for gas pressure below 0.1 Torr to determine the behavior of breakdown voltage values at near-zero pressure.

REFERENCES

[1] Alonso, M. dan Edward, J.F. 1967. Fundamental University Physics.Vol.II Fields and Wave. Addison-Wesley Publishing.
[2] Bueche, F.J. dan David, A.J. 1995. Prinsiples of Physics. New York: McGraw-Hill Inc.
[3] Czapka, Tomasz. 2011. Back-Corona Discharge Phenomenon in the Nonthermal Plasma System. IEEE Transactions on Plasma Science. New York.
[4] Chen, J. dan Davidson, J.H. 2002. Electron Density and Energy Distributions in the Positive DC Corona: Interpretation for Corona-Enhanced Chemical Reactions. Plasma Chemistry and Plasma Processing. Vol. 22.
[5] Davidson, J.H. 2000. Recent Trends In Electrostatic Precipitation. New York: McGraw-Hill Inc.
[6] Duffy, A. 1999. Electric Charge and Coulomb's Law, Physics Lecture Demonstration. Massachusetts: Boston University.
[7] Francis, F.C. 1974. Introduction to Plasma Physics. Plenum Press. New York.
[8] Hayt, W.G. 1982. Teknologi Elektromagnetik. Edisi keempat alih Bahasa Houw Liong. Jakarta: Erlangga.
[9] Iskander, M.F. 1992. Electromagnetic Fields and Waves. New Jersey: Prentice Hall Inc.
[10] Kind, D. 1993. Pengantar Teknik Ekspremental Tegangan Tinggi. Bandung: ITB.
[11] Kim, H.H. Prieto, G., Takashima, K., Katsura, S., Mizuno, A. 2002. Performance Evaluation of Discharge Plasma for Gaseous Pollutant Removal. Journal of Electrostatic Elsevier Vol. 55.
[12] E., Kuffel, W.S., Saengl, J., Kuffel. 2000. High Voltage Enggineering Fundamental. Published by Butterworth-Heinemann. Typeset by Laser Words, Madras, India.
[13] M.S., Naidu. 1995. High Voltage Enggineering. Second Edition. New York: McGraw-Hill Inc.
[14] Nur, Muhammad. 2011. Fisika Plasma dan Aplikasinya. Universitas Diponegoro. Semarang.

[15] Shimizu, K., Kinoshita, K., Yanagihara, K., Rajanikanth, B.S., Katsura, S., and Mizuno A. 1997. Pulsed-Plasma Treathment of Polluted Gas Using Wet/Low-Temperature Corona Reactors. IEEE Transaction on Industry Applications. Vol 33.
[16] Sumanto. 1979. Transformator. Jogjakarta: Andi Offset.
[17] Teske, Christian James, and Jacoby, Joachim. 2008. Pulsed Low Frequency Inductively Coupled Plasma Generator and Applications. IEEE Transactions on Plasma Science. New York.
[18] Trujillo, Sánchez, Brian, Ángel, Méndez, Martínez, Rigoberto, Rodríguez, Portillo, and Otniel. 2016. Prototype of a Plasma Generator for Electrosurgery. 13th International Conference on Power Electronics. Toluca, Mexico.

Koten, David S. “The Effect of Argon Pressure on Plate-Shape Electrodes Plasma Forming Behavior.” International Journal of Research in Engineering and Science (IJRES), vol. 05, no. 01, 2018, pp. 01–12.