The Effect of Electronic Disposition of Spherical Electrode on Plasma Behavior in Argon Gas Media

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Keywords: Plasma Reactor, Spherical Electrode, Argon Gas, Paschen Curve, Breakdown Voltage.

Abstract: Plasma is an ionized gas, a substance whose electrons leave the orbit of each atom and can be created by heating a gas or exposing a sufficiently strong electromagnetic field using a laser or microwave generator. This study examines how to design a high voltage plasma generator so that it can supply direct current (DC) voltage to generate plasma in the reactor chamber containing low-pressure argon gas. In this study, the breakdown voltage analysis was also carried out until a plot of the relationship between the breakdown voltage, gas pressure, and distance between the electrodes was found. It is expected that the plotting can be adjusted to the curve according to Paschen's Law and get results that are close to the ideal curve. This research also aims to see the condition, behavior, and discharge of plasma that results from the release of spherical electrode electrodes, so that the results of this research can carry out in an industry, agriculture, and electro-medical.

1 INTRODUCTION

Plasma is an ionized gas, a substance whose electrons come out of the orbit of each atom and can be created by heating the gas or by exposing a sufficiently strong electromagnetic field using a laser or microwave generator. The increase or decrease in the number of electrons present in the plasma results in particles with positive or negative charges called ions. This can usually be followed by the untying of the molecule. The appearance of a large electric charge makes the plasma conductive, so it reacts very strongly to electromagnetic fields. Like gas, plasma does not have a fixed shape or volume unless it is in a closed space. However, unlike gases under the influence of magnetic fields, plasma can form a variety of structures such as filaments, beams, and bilayers. Industrial and commercial applications of plasma technology include plasma cutting (a technology that emerged from plasma welding in the 1960s) and is a highly productive way to cut sheet metal and plate.

Plasma welding, in this application, uses high frequency and voltage. Plasma welding is much better than tungsten welding because the welding process can be faster. Besides, there is also the plasma nitriding method, which is a function of plasma in the hardening process of metal materials. In this application, a metal material is placed between the cathode and the anode electrode in a vacuum tube, releasing an electric current. Applications in other commercial and industrial fields, namely the manufacture of ozone, sterilization of pool water, removing various unwanted volatile organic matter, such as chemical pesticides, solvents or chemicals from the atmosphere, and as ionizing air which is good for health. Of the various applications of plasma technology, both in the industrial and commercial world that have begun to be developed, there are still obstacles in the application of plasma technology in the form of devices that are not yet available on the market or freely sold. One of the contributing factors is how to design a plasma reactor system that has low pressure (vacuum) and produces a high plasma discharge.

Based on the description above, this research will design a plasma generator that will generate from an HVT (high voltage transformer) that produce a voltage to activate the plasma on the electrodes installed in an airtight tube. HVT functions to convert an AC voltage of 220 V to an AC voltage of 2000 V, while the high voltage diode and capacitor function as a rectifier and filter circuit and then converts the 2000 V AC voltage to 2000 V DC voltage. From the plasma generator made, an optimization of the plasma

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formation process parameters will be carried out, namely knowing the Paschen curve of the gas used (argon gas). This research will use a ball electrode type. The choice of the shape of the spherical electrode is based on its function, which is to obtain a very high electric field so that it can produce a large enough plasma debit.

The research to be carried out is also in line with the 2017-2045 National Research Master Plan (RIRN) to support the direction of national development in the field of science and technology, as well as respond to the government's commitment to supporting the development of advanced materials.

2 BASIC THEORY

2.1 Plasma

Plasma is one of the four basics forms of matter, apart from solid, liquid, and gas. Plasma has different properties compared to the other. Plasma can be created by heating a gas or exposing it to a strong electromagnetic field, which can generate using a laser or a microwave generator. Basically, plasma is an ionized gas, which has atoms whose electrons bounce out of their orbits. This results in the plasma being able to conduct electricity because the atoms themselves no longer have a positive balance between the positive and negative charges, but the atoms are positively charged due to the presence of protons in the core, while the electron cloud that exists between the atoms is negatively charged. The concept of plasma was first described by Langmuir and Tonks in 1928. They defined plasma as a gas that is ionized in an electric discharge, so plasma can also be defined as a neutral-neutral mixture of electrons, radicals, positive and negative ions. The mixing of positively charged ions with negatively charged electrons has very different properties from that of the general gas and matter in this phase is called the plasma phase.

2.2 Collecting the Data

Plasma is an ionized gas. Ionization events are always present in the process of plasma. Ionization is the process of releasing electrons from an atom or molecule from its bonds. The energy required to remove one or more electrons from its orbit in an atom is called the ionization energy E. The amount of ionization energy is expressed in electron-Volts (eV). In a stable state, ionization can occur if the energy of the colliding electron is greater than or equal to the ionization energy of the atom or molecule collided, which is shown in Equation (1).

$$\frac{1}{2^{m_e v_e}} 2 \geq eV^i \quad (1)$$

Where:
me = rest mass of the electron (9.109534 · 10- 31 kg)
ve = velocity of the electrons (m s-1)
e = elementary charge (1.6021892 · 10-19 C)
Vi = ionization potential of an atom or molecule (eV)

In the process of collisions between electrons and gas particles not only ionization occurs but also causes other events. The opposite of the ionization process is the recombination process. Recombination occurs by binding of electrons by ions and binding between atoms to become molecules so that they become neutral species or negative ions accompanied by photon emission (Nur, 2011).

2.3 Analyzing the Data

The discharge of electricity in gases has been a long-standing subject in physics. The release in the gas that is best known in nature is lightning. Gas, which is an insulator by nature, will turn into a conductor under certain conditions. The following is the mechanism of lightning. Clouds that are close to the earth's surface have a very high potential difference from the earth's surface. Due to cosmic radiation, there is the ionization of the gas between the cloud and the ground.

This ionized gas increases in volume and allows chain ionization to occur because the electrons produced in the ionization are accelerated towards the cloud and on their way collide with gas atoms and molecules.

This event continues and in a certain condition, there is an electronic avalanche. The air (gas) between the clouds and the earth becomes a conduit in the form of a canal and emits white light. Electrical discharge (electrical discharge) has occurred in nature, followed by the sound of lightning which is the sound of meeting between air separated in a short time by a channel of discharge between cloud and earth and between cloud and cloud.

In the laboratory, the discharge of electricity can be carried out in a gas-filled tube. If two electrodes in the form of parallel plates are placed in a tube containing gas with a certain pressure and the two electrodes are connected to a high voltage DC source, there will be a discharge of electricity between the electrodes. Gas discharge tube can be seen in Fig.1.

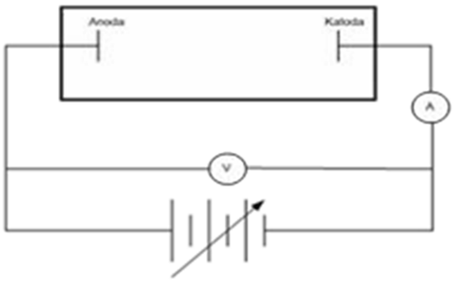

Figure 1: Gas Discharge Tube.

The electrons from the cathode will move towards the anode and during their travel, the electrons will hit the molecules or gas atoms between the two electrodes. For chain ionization to occur, the first step that must be passed is the ionization to produce free electrons. Scientists believe the first electrons came from the ionization of gases by cosmic ray radiation. This first electron is accelerated by the potential difference between the two plate electrodes in the discharge tube. In their journey, these electrons will collide and ionize other atoms or gas molecules in succession. The process of consecutive collisions will produce electronic avalanches and can lead to chain ionization.

2.4 Electric Field Generating Electrodes

The electric field distribution, which is greatly influenced by the shape and dimensions of the electrodes, the distance between the electrodes, and the number of electrodes arranged. In selecting the electrode material, it is emphasized on its function, which is to produce a very high electric field (Davidson, 2000). Fig. 2 shows the types of electrodes used to generate high electric fields.

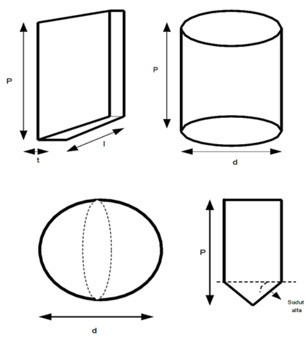

Figure 2: Types of High-Field Generating Electrodes.

2.5 Electric Field Intensity

The electric field is an area around an electric charge which is affected by an electric force. Michael Faraday describes the electric field as a vector of electric field lines coming out of the positive charge into the negative one. The greater the intensity of the electric field is depicted by the denser of field lines. Each point in the electric field is a quantity that expresses the level of strength of it, which is called the electric field intensity. The intensity of the electric field is the electric force that rests on one unit of electric charge (Iskander, 1992). Electric field intensity is the electric force defined by Coulomb as the force that arises between two points of charges separated by a certain distance. This law states that if there are two points of charge there will be a force between them which is proportional to the multiplication of the values of the two charges and is inversely proportional to the square of the distance between them (Koefl and Saengl,2000), Fig. 3 shows vector electric field line generated by electric charges.

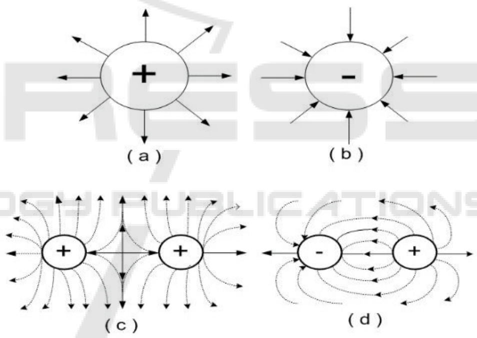

Figure 3: Vector electric field line generated by electric charges (a) one point of positive charge, (b) one point of negative charge, (c) two like charges, (d) two dissimilar charges.

3 RESEARCH METHODS

This research begins with the design of tools, manufacture, and testing of tools to determine the shape of the plasma which is produced from the release of spherical electrons in the argon gas medium and to determine the plasma debit generated in the plasma reactor. The results of this research will be used as initial data for further research on the application of plasma technology in industry, agriculture and medicine. The stages of this research can be seen in Fig. 4, which explains the procedures for implementing the research to be carried out.

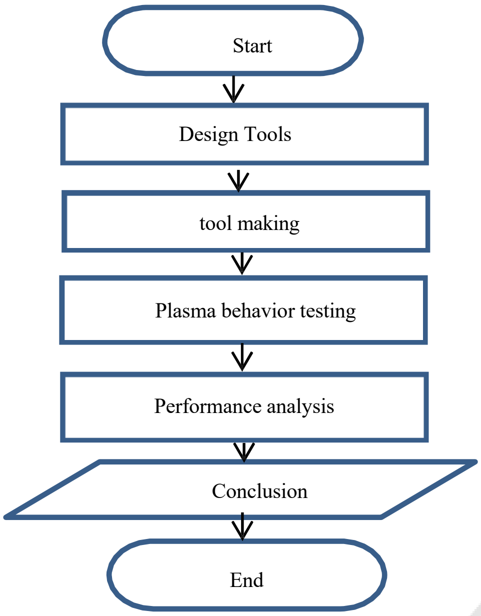

Figure 4: Research Flow Chart.

The stages in this research are:

1. Plasma generator system design.
2. Manufacture of a plasma generator system consisting of manufacturing a power supply, manufacturing a vacuum tube, installing a vacuum pump, installing pipes and valves, installing an argon gas reservoir, installing measuring instruments, and manufacturing an electrode system.
3. Plasma behavioral testing.
4. Data retrieval.
5. Analysis of the performance of the resulting plasma.

The airtight tube as a reactor filled with low-pressure argon gas is evacuated through the pipe using a vacuum pump and controlled by a valve, the cylinder containing high-pressure argon gas also acts as a supplier of argon gas and is controlled by a valve. The gas pressure in the reactor can be observed with a pressure gauge. The anode and cathode are made of spherical copper. The electrodes are arranged in parallel. The power supply used for the anode and cathode is a source with a maximum voltage of 2000 VDC. The Plasma generator system design is shown in Fig. 5.

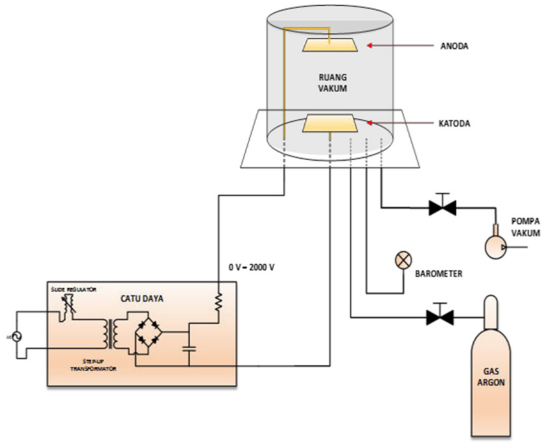

Figure 5: Plasma Generator System Design.

4 RESEARCH RESULTS AND DISCUSSION

By the research method, the first step taken in designing the tools, then making the tools, and testing them, then analyzing the results and making conclusions.

4.1 Research Tools

The tools used to conduct research are divided into several parts. The first is the power supply, which functions to supply direct high voltage (DC). This section converts the input in the form of an alternating voltage of 220 V into a direct voltage that can be adjusted from 0 V to 2000 V. Fig. 6 shows parts of the power supply.

Figure 6: Parts of the Power Supply.

The second part is the plasma reactor, which must be a transparent, airtight space so that visual observations can be made. In the room, there is a ball electrode that can be changed the distance between the anode and cathode.

Figure 7: Plasma Reactors Used in Research.

Fig. 7. shows the plasma reactor used in this study. At the base there is a flat metal platform covered by a silicon glue seal to create a vacuum when the reactor glass is closed from above, thus preventing gas leakage from outside into the reactor. Fig. 7 also shows the ammeter at the bottom of the reactor platform, which is used to measure the amount of current when plasma occurs in the reactor. The plasma contours of the reactor are shown using special software, namely FEMM. The illustration in the software calculation results shows a slice of the electric field intensity and electric field flux in 2 dimensions using a vacuum.

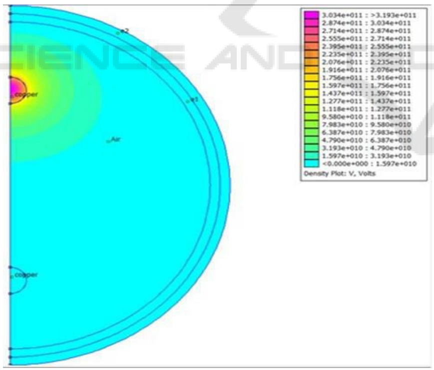

Figure 8: The Intensity of The Electric Field at The Spherical Electrode with a Distance of 1 cm and a Voltage of 200 V.

Fig. 8 shows the electric field intensity of a spherical electrode with a distance of 1cm and a voltage of 200 V. From Fig.8 it can be analyzed the behavior of the electric field that occurs at a spherical electrode in the form of a field that collects at the cathode and is spread along the spherical electrode surface as well. The distribution of the electric field is also visible at the anode, but very little. When viewed from Appendix 3, the higher the voltage used, the higher the intensity and the slightly more scattered the shape of the electric field is in the spherical geometry. In this simulation, voltage 200 V, 500 V, 1,000V, and 1,500 V. As for the greater distance between the electrodes, it can be seen that the shape of the electric field is constant. In this simulation, a distance of 1 cm, 5 cm, and 10 cm are used. The results of plotting the electric field intensity of the ball electrode with a distance of 1 cm and a voltage of 200 V are shown in Fig. 9.

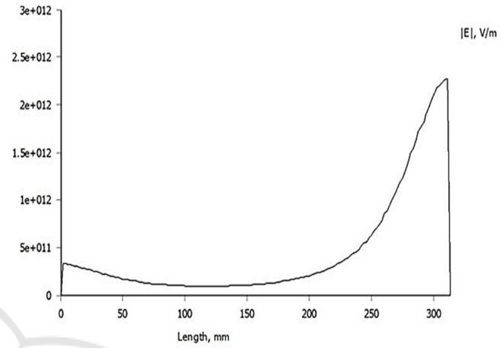

Figure 9: The results of plotting the electric field intensity of the ball electrode with a distance of 1cm and a voltage of 200 V. Source: Software Simulation FEMM.

4.2 Retrieval of Data

Data was collected by gradual iteration in accordance with the aim of obtaining a Paschen curve which shows the relationship between the breakdown voltage and the electrode distance and the argon gas pressure.

Retrieval of data starts from the electrode distance of 0.25 cm. First, the distance between the electrodes is adjusted until the tip of the anode needle with the tip of the cathode needle is 0.25 cm, then the adjustment bolt is locked and the reactor is closed. Table I shows an example of data collection carried out at a pressure of 0.8 Torr and an electrode distance of 0.25 cm.

In Table I, one of the observations of the breakdown voltage that occurs in argon gas with a pressure of 0.8 Torr and the distance between the electrodes (using a needle) is 0.25 cm. In Table I, the voltage data is skipped up to 265 V because the current values are both 0 mA. It can be seen that when the voltage reaches 268 V a sudden 120 mA of current is formed, and visually a plasma is formed in the reactor.

An example of plasma display is shown in Figure 10. In taking this data, it can be concluded that the breakdown voltage for a pressure of 0.8 Torr and a needle electrode distance of 0.25 cm is 268 V. Observations by increasing the voltage are no longer needed because the breakdown voltage has been obtained. Figure 15 shows the relationship between current and voltage.

Data collection was carried out continuously for different pressures with a pressure gap of 0.1 Torr. At the next level, data collection is carried out for different electrode distances (made further).

Figure 10: One of the Experiments when there was Plasma in The Reactor.

Table 1: Combined Average Breakdown Voltage Data from Each Electrode Distance and Type of Ball Electrode.

Pressure * Distance (Torr cm)	Data Retrieval (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	277	270	271	272	274	277	280	275	274.5
0.4	237	229	227	236	237	241	241	234	235.3
0.6	218	215	225	226	219	229	227	219	222.3
0.8	218	214	212	227	227	220	228	218	220.5
1.0	220	220	223	226	223	218	229	219	222.3
1.2	225	223	230	228	237	235	232	225	229.4
1.4	236	227	231	242	236	231	234	235	234.0
1.6	237	253	242	244	246	239	252	243	244.5
1.8	246	240	236	249	254	247	247	249	246.0
2.0	256	247	252	252	256	259	257	256	254.4
2.2	264	255	262	266	266	264	261	268	263.3
2.4	265	236	261	273	265	267	270	258	261.9
2.6	258	258	256	269	266	270	269	268	264.3
2.8	267	260	266	267	273	265	269	261	266.0
3.0	264	259	252	273	274	262	266	272	265.3
3.2	270	265	260	279	283	271	267	273	271.0
3.4	270	264	266	277	280	269	271	267	270.5
3.6	271	261	269	269	267	274	280	270	270.1
3.8	275	264	272	277	283	269	279	267	273.3
4.0	273	267	267	282	272	273	273	268	271.9

Table 1, shows the average breakdown voltage of the spherical and plate electrodes. Fig. 11 shows a data comparison graph of all electrode distances for the spherical electrode.

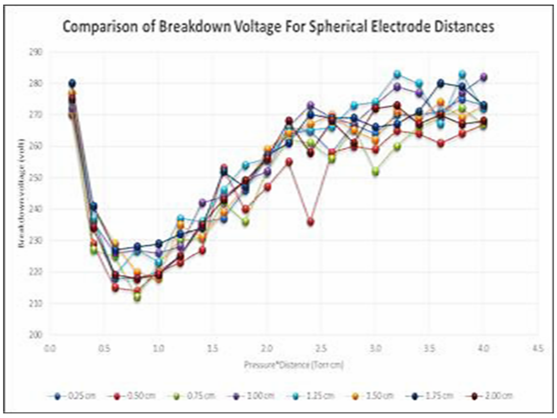

Figure 11: Retrieval of Argon Gas Breakdown Voltage Data for All Spherical Electrode Data at a Distance of 0.25cm to 2.00cm.

4.3 Searching the Ideal Paschen Curve

From the results, the actual Paschen Curve is obtained in accordance with the results of the ball electrode data collection. From this data, several values can be taken, including values A, B, and γSE. Because there are difficulties in getting the Ideal Paschen Curve using the equation in Paschen's Law, the strategy for finding the Ideal Paschen Curve is divided into two, the first uses the Paschen's Law equation approach, and the second uses the polynomial approach.

Fig. 12 shows the results of plotting the average breakdown voltage from all distances in the experiment, where the Ideal Paschen Curve will be searched based on the results of this plotting. In both approaches, MSE (mean squared error) is used as an indicator of the similarity of the observed data with the ideal curve data sought. The search for the MSE value is based on the error or difference between the observed data and the ideal curve data which is squared to avoid negative values (called SE or squared error) and from all SE values the average is sought so that the MSE value appears. The lower the MSE value, the more similar the observation results will be to the ideal curve.

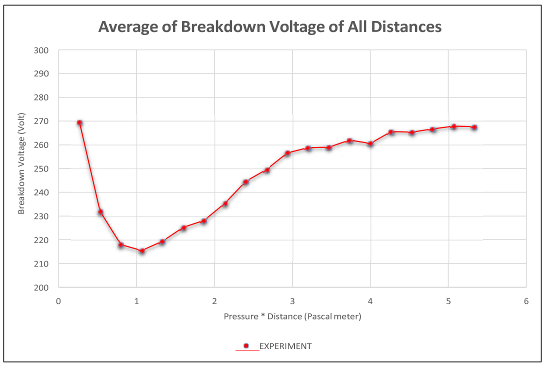

Figure 12: The result of plotting the mean breakdown voltage over all experimental distances.

4.4 Polynomial Approach

In the polynomial approach, the Microsoft Excel tool is used after plotting the average breakdown stress over all distances. The tool in Microsoft Excel is able to display trend lines as well as their equations. The trend line that is formed can use one of several types, namely exponential, linear, logarithmic, polynomial, quadratic, and moving average. The only curve that is able to form a pattern close to the result of plotting the average breakdown stress is the polynomial.

The 6th order polynomial approximation is shown as in Fig. 13, which produces a line equation as in Equation (2).

$$V_B = 0.1168(pd)^6 - 2.5984(pd)^5 + 23.461(p) \quad (2)$$

$$= - 108.67(pd)^3 + 264.42(pd)^2$$

Where,

$$- 291.36(pd) + 329.26$$

V_B = breakdown voltage (V)
p = gas pressure (Pa)
d = distance between electrodes (m)

Visually, it can be seen that the polynomial approach of the sixth order has been very detailed in describing the Paschen Curve as shown in Fig.13 below.

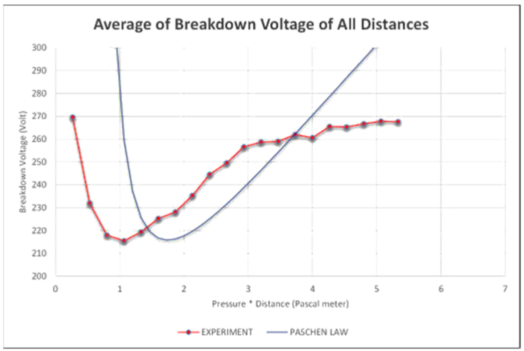

Figure 13: Results of the order 6 polynomial approximation.

4.5 Paschen's Legal Approach

In the Paschen Law approach, the values A, B, and γSE are taken according to the results of previous research. The γSE value is determined to be 1.32 according to the results of research on secondary electron emission constants for copper metal (as the electrode material used in this study) at a voltage of 240 V.

Meanwhile, the value of A as the gas ionization constant was determined to be 16 Pa · m-1 and B as the excitation constant and the ionization energy was 240 V · Pa · m-1, according to the experimental results for argon gas. The next step is to fill in the three values while observing the shape of the curve that occurs. The following is the equation of Paschen's Law as in Equation (3).

$$V_B = \frac{Bpd}{Apd} \quad (3)$$

Where:

VB = breakdown voltage (V)
A = gas ionization constant (Pa m-1)
B = excitation constant and ionization energy (V Pa m-1)
γSE = secondary electron emission coefficient
p = gas pressure (Pa)
d = distance between electrodes (m)

In Fig. 14, the results of the Paschen's Law curve approach are shown using a value of A of 16 Pa · m -1, B of 240 V · Pa · m-1, and γSE of 1.32.

Fig. 14. shows the curve of the results of the approach from Paschen's Law using an A value of 16 Pa · m-1, B of 240 V · Pa · m-1, and γSE of 1.32, which results in an MSE value of 12,654.49. Some of Paschen's Law theoretical curves fall below the graph boundary line on the y-axis.

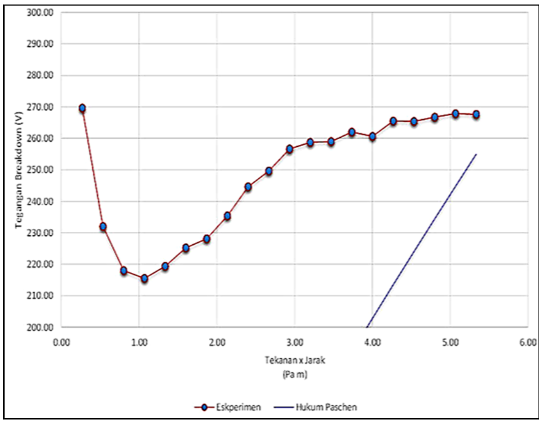

Figure 14: Paschen's Law Approach with A = 16 Pa m-1, B = 125 V Pa m-1, and γSE = 1.32, with a minimum breakdown voltage limit of 200 V.

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