RPE Radiation Physics & Engineering
An International Peer-Reviewed Journal
Published by K.N. Toosi University of Technology
http://rpe.kntu.ac.ir
Research Article

Radiation Physics and Engineering 2021; 2(3):17–23
https://doi.org/10.22034/rpe.2021.298764.1036

Investigation of the effect of insulator sleeves on the ion emission in a 4kJ Plasma focus device

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HIGHLIGHTS

- Ion emission in the Amirkabir plasma focus device.
- Effect of insulator length and material.
- Optimization of the performance of PFD.

ABSTRACT

For configuring plasma focus devise (PFD), the gap between electrodes is filled out with a gas at low pressure. When discharge is starting at the surface of the insulator, the gas breaks down, leading to the flow of the plasma current sheath toward the anode end. A homogeneous and symmetric current sheath which is essential for ion emission and a proper plasma pinching can be obtained when there is an electrical breakdown along the insulator. Therefore, one of the most important parts of the plasma focus is the insulator. In the present research, the effect of different insulator sleeves on the intensity of ions emitted from a 4 kJ PFD filled with Neon has been studied. Pyrex and Quartz are considered for the insulator materials and the length is varied from 3 to 6 cm for Pyrex and from 3.5 to 5.5 for Quartz. Numerous gas pressures were experimented with voltages of 11, 12 and 13 kV. The results show that both the length and the material of the insulator sleeve can affect the intensity of ions emitted from the device. The length of 4.5 cm seems optimal to yield maximum ion emission for Pyrex insulator. For the Quartz insulator, on the other hand, length of 3.5 cm results in higher ion emission. In addition, in some cases, utilizing Quartz insulator causes more ion emission compared to the Pyrex insulator.

KEYWORDS

Plasma Focus Devise
Insulator Sleeve
Ion Emission
Neon Gas

HISTORY

Received: 7 August 2021
Revised: 11 October 2021
Accepted: 13 October 2021
Published: Summer 2021

1 Introduction

Different experiments have been conducted to prove that insulator plays an essential role in radiations emitted by the PFD (Mather and Bottoms, 1968; Lee et al., 1988; Rosenman et al., 2000; Habibi and Amrollahi, 2010). Shyam and Rout, for instance, studied the effect of special anode materials on neutron yield and pinch current in a 2.2 kJ PFD (Shyam and Rout, 1997). According to their research, quartz or glass were better insulator compared to alumina for low energy plasma focus. Zakaullah et al. studied the effect of insulator contamination on neutron production with a 2.3 kJ PFD (Zakaullah et al., 1993). According to their findings, the neutron yield is decreased when using insulator with evaporated copper deposition. In other researches, impact of the insulator length on hard X-ray (HXR) and soft X-ray (SXR) intensity were reported (Koohestani et al., 2013, 2011). Habibi investigated the effect of electrode material on the emission of X-ray (Habibi, 2012). Zhang et al. also reported the influence of the insulator length on the time of discharge (Zhang et al., 2005). The influence of the insulator sleeve length on the emission of SXR also was investigated by Rawat et al. (Rawat et al., 2004).

The ion beam produced by the PFD is useful for the implantation of ion (Feugeas et al., 1988a, 1994), thermal surface treatment (Mozer et al., 1982), material processing (Rawat et al., 1993; Sagar and Srivastava, 1993; Srivastava et al., 1996; Agarwala et al., 1997; Rawat et al., 2000), semiconductor doping, deposition of thin film, and ion-assisted coating (Rawat et al., 2001; Feugeas et al., 1988b; Kelly et al., 1996; Nayak et al., 2001; Gribkov et al., 2003). In order to control these technological processes, obtaining various reliable information is required on ion

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kinetic energy spectrum,the ion flux, and angular distribution. Various researches have been carried out for this purpose (Sadowski et al., 1985; Rhee, 1984; Kelly et al., 1997; Bhuyan et al., 2001a). Sadowski et al. (Sadowski et al., 2000) studied the characterizations of ion beam in the energy range of 5 to 50 kJ. Theyfound that the ion beam intensity relies on operating pressure, capacitor bank-energy electrode geometry, and working gas. The asymmetric condition of fast ions angular distribution was investigated by Mohanty (Mohanty et al., 2005).According to this paper,various micro sources might be the cause of this asymmetry, produced in the dense plasma column. Etaati et al. (Etaati et al., 2011) investigated angular distribution of ion beam emission from a 4 kJ PFD filled with argon gas. They reported that the intensity of argon ions reduced significantly at angles higher than ±11°. The anisotropy of hydrogen and carbon ions was studied by Bhuyan et al. (Bhuyan et al., 2001b) in methane plasma. They found that the maximum flux of hydrogen ions was at 0°, while the carbon flux happens at around 15°.

Based on the literature, it can be observed that insulator sleeve effect on the ion emission in the PFD has not received enough attention. Although useful informationis provided by theoretical analyses and numerical simulations foroptimizing the PFD parameters,insulator geometry could be mainly optimized through experiments. The present paper aims mainly to enhance performance of the Neon filled 4 kJ PFDin term of ion beam emission through varying theinsulator sleeves length and material, which is utilized at the coaxial electrode assemblyclosed end.

2 Experimental set-up

The Amirkabir Plasma Focus (APF) device, located at the Amirkabir University of Technology, was used for the experiments (Habibi et al., 2009). A 40 μF capacitor is used for energizing the device that was charged up to 15 kV. The length of the anode is 148 mm, and its diameter is 27.8 mm. The cathode length is 145 mm and its diameter is 44.7 mm and it has the form of a squirrel cage that consists of 6 rods arranged coaxially around the anode. In this research, the effective lengths of Pyrex insulators were considered 3 cm, 3.5, 4, 4.5, 5, 5.5, and 6 cm and the effective lengths of Quartz insulators was considered 3.5 cm, 4, 4.5 and 5 cm. The thickness of insulators is considered to be constant and 3 mm. Before injection of the Neon gas, the chamber is evacuated down to 10 to 5 Torr by the vacuum system that contains a rotary backed diffusion pump. The old gas is cleaned up after about five shots for decreasing the impurities impact that are gathered in the working gas and machine is filled with fresh gas again. For all electrical transmission,identical RG 58 Al shielded cables with 8 m long were utilized. Aluminum foil diagnostic system was used for wrapping all cables in the experimentin order to decrease electromagnetic noise effects on data signals. Rogowski Coil was employed for determining plasmapinch signal andfast plastic scintillator (NE-102) for evaluating the intensity of HXR signal. In this system, digital storage oscilloscopes with three-four-channel 200 MHz TDS 2024 recorded all electrical signals of Rogowski coil, Faraday Cup (FC) detectors and plastic scintillator. An array of five FCs was used as the apparatus for investigating the ion emission from the APF device.

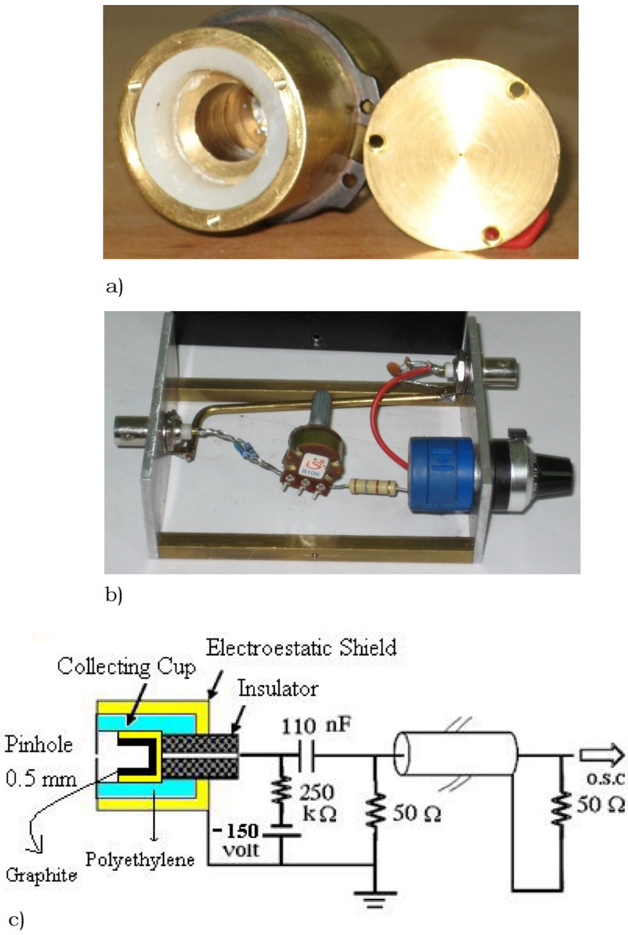

Figure 1: Configuration of a) Faraday Cup, b) biasing circuit, c) Schematic of biasing circuit.

The FC generally contains a deep collector and asmall aperture. All electrons that accompany the incidentbeam are removed by the negative potential of FCs. The negative bias voltage can also remove the secondary electrons that are generated through the incoming beam collision to the collector surface. The FC dimension should be selected in a way that leads to the ultimate collision of the scattered ions and secondary electrons with the cup. Figure 1 demonstrates the configuration of FC and schematic biasing circuit. The cups' internal and external shells are made up of brassand the cup is also covered with a layer of graphite. The FC consists of acap with 500 μm aperture and is insulated with polyethylene. Each FC reversed voltage was selected as -150 V. An apparent with the resistance of 51 Ω should be provided by the FC for matching RG58 data transmission cables. Therefore, the outer cups inner diameter is chosen to be 34 mm and the inner cup's outer diameter to be 9.5 mm. In order to measure the ion beam anisotropy, the five FCs are placed at the angels of

0°, ±11° and ±33° (0 refers to the axis of anode), 14 cm away from the tip of anode as depicted in Fig. 2. The data collected by the oscillator were averaged for five shots at any pressure-voltage limit, and the analysis was performed through ORIGIN software and a MATLAB-based signal acquisition program, developed by AmirKabir Fusion Lab.

3 Results and discussion

Neon gas was fed into the device chamber to generate the dense plasma, and data was collected at 11, 12, and 13 kV with pressures of 6, 7, and 8 Torr. For each working condition (voltage, pressure, insulator type and length), five shots have been conducted and the results were averaged for the five discharges to decrease experimental errors after attaining the plasma pinch conditions. To reduce the impact of impurities collected in the working gas, the previous gas is cleaned and the new gas is injected after approximately five shots. In Fig. 3, typical ion emission signals observed by the central FC detector array for 5 cm Pyrex and Quartz insulator length is presented.

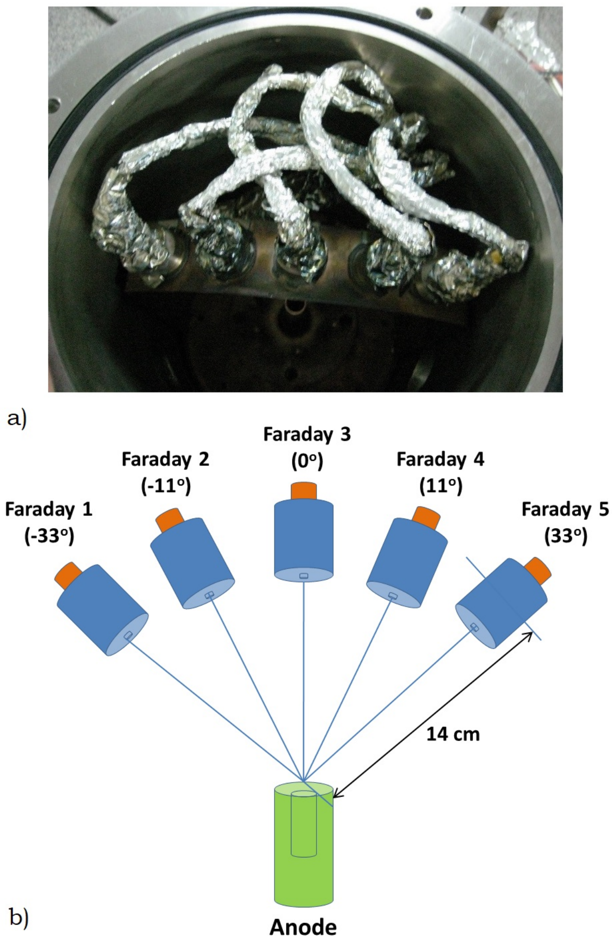

Figure 2: a) Experimental setup and b)schematic arrangement of FCs for measuring ion beam anisotropy.

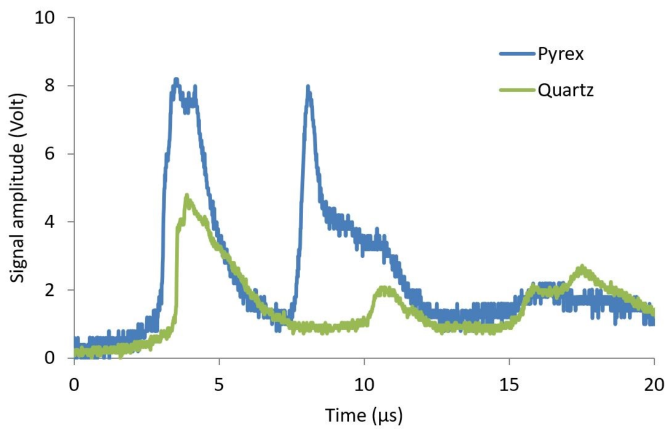

Figure 3: Typical ion emission signal obtained from central FC at pressure of 8torr and Voltage of 11 kV for 5 cm Pyrex Quartz insulator.

As it can be observed in Fig. 3, there is usually more than one peak in each signal obtained by Friday cups. The first peak which is mostly the highest one is related to the current discharge and is associated with plasma pinching. In case of proper working condition (pressure and voltage), there would be a second current discharge in RLC form and hence another ion beam envelope would move up toward FC and they are recorded as the second peak.

To get empirical results, 500 shots were applied in various circumstances. For the Pyrex and Quartz insulators, the Neon ion measured angular distribution at different lengths is depicted in Figs. 4 and 5, respectively. Each data point is generated by taking the average of five successful discharges.

The angular distribution of fast ions displays highly anisotropic features, considerable irregularity with regard to the PF axis, and a noticeable decrease at a specific angle, as seen in Figs. 4 and 5. This anisotropic ion emission can be due to a rapid shift in plasma inductance that began during the compression stage of focused plasma. The rise in induced electric field caused by the $m = 0$ instability speeds the ions and electrons to extremely high energies. It has also been discovered that the intensity of ion emission between 0 to -11° is greater than the corresponding value between 0° to 11°, implying that the density of Neon ions is higher on one side of the PF chamber.However, the intensity of ion emission reduces when moving from the center line to the chamber flanks on both sides and the highest value of ion emission belongs to the central FC. The reason why ion emission behavior is asymmetric can be due the fact that fast ions are produced in several hot areas that develop inside a dense plasma column. These hot spots are not always symmetrical with regard to the plasma focus axis. As a result, they are distinguished by distinct local characteristics.

As seen in Figs. 4 and 5, changing the insulator length affects ion intensity. Despite the similarity of the overall ion angular distribution for various insulators, it is clear that insulator type and length have a significant impact on ion intensity. Based on the curves in Fig. 5, the ion emission intensity for the quartz insulator with length of 3.5 cm was more than 10 times bigger than the correspond-

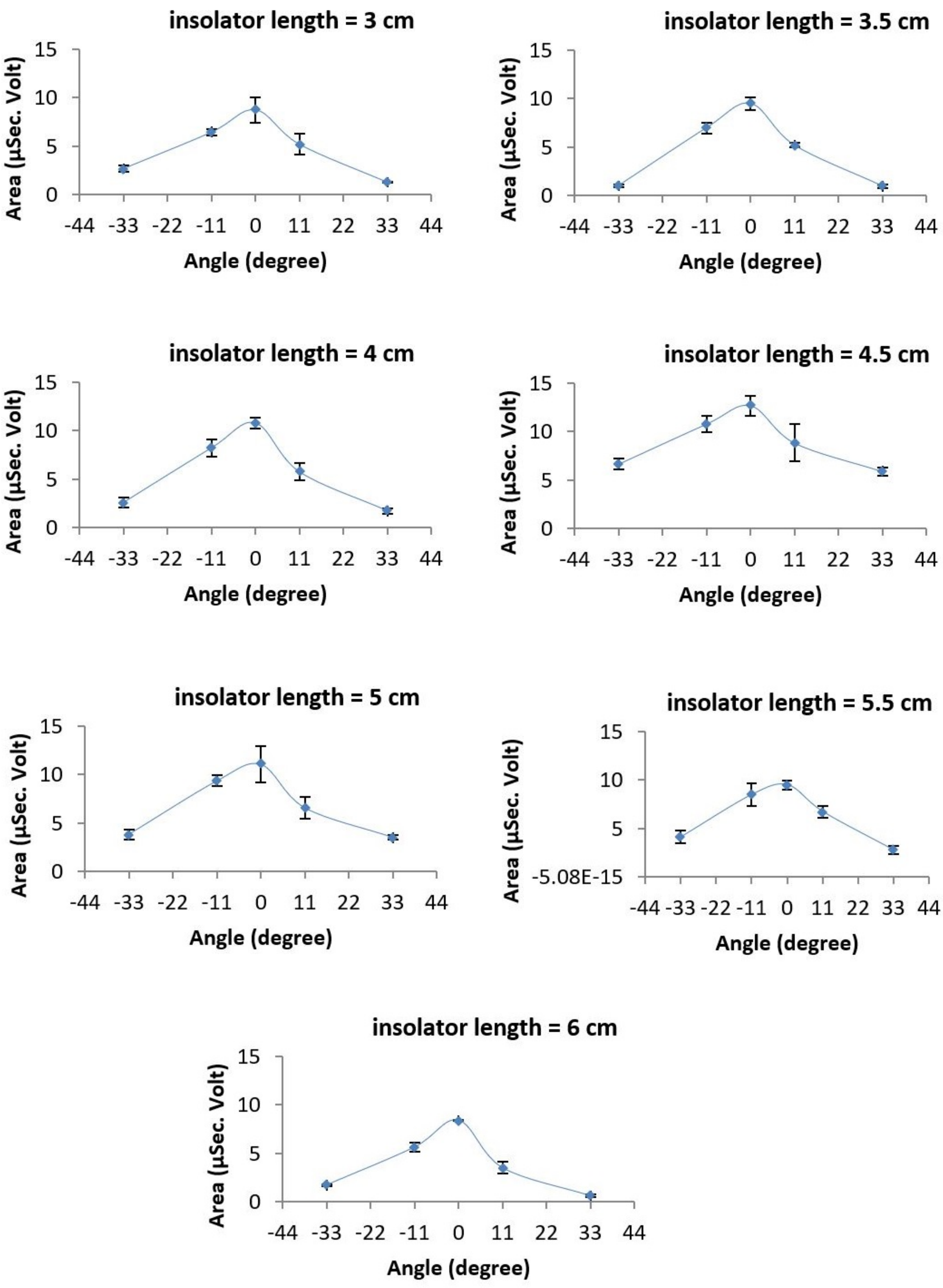

Figure 4: Angular distribution for the emission of Neon Ion for various Pyrex Insulator lengths at a voltage of 12 kV and pressure of 7 Torr.

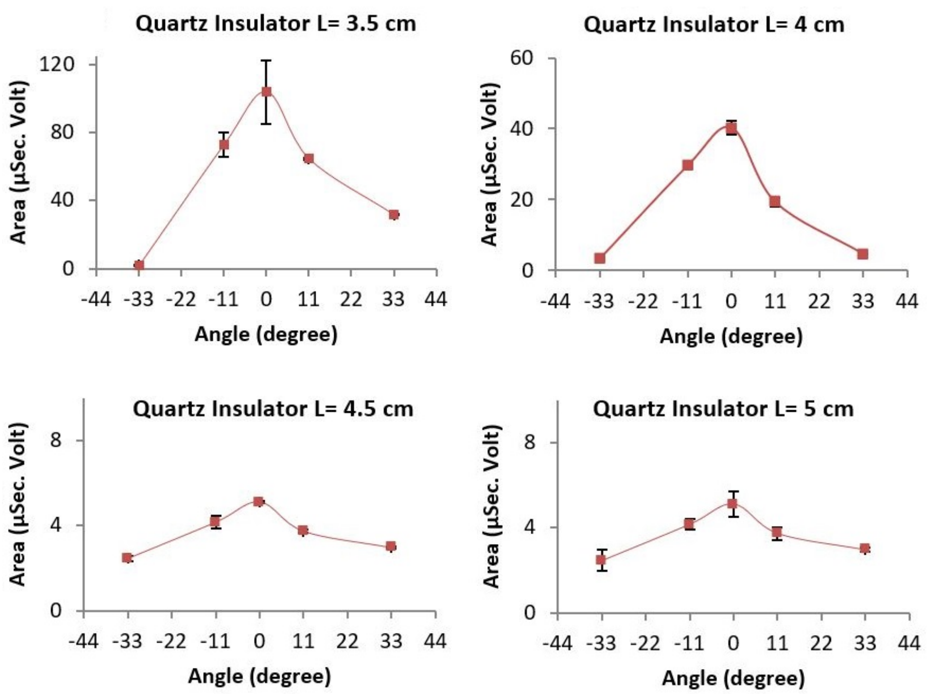

Figure 5: Angular distribution for the emission of Neon Ion for various Pyrex Insulator lengths at a voltage of 12 kV and pressure of 7 Torr.

ing values for the lengths of 4.5 or 5 cm. To explore the impact of the insulator more closely, the central FC total ion flux for various insulator lengths at different operation settings is presented in Figs. 6 for Pyrex and in Fig. 7 for Quartz.

Ion emission for Pyrex insulator increases with length up to 4.5 cm and subsequently decreases for all operating conditions, as illustrated in Fig. 6. This indicates that a Pyrex insulator with a length of 45 mm produced more ion emission than other lengths of Pyrex insulator. The average ion intensity of the Quartz insulator, on the other hand, has been observed to reduce with increasing the length of insulator from 35 to 45 mm for 11 and 12 kV voltages, as illustrated in Fig. 6. An increase in insulator length to 50 mm has not any considerable effect on ion intensity. When dealing with 13 kV, the Quartz insulators have a different performance. In this case, ion intensity was considerably enhanced when the 40 mm Quartz insulator was utilized instead of the 35 mm. The signal intensity was observed to drop significantly when the length of the insulator was increased to 45 and 50 mm. Therefore, at 11 and 12 kV, a quartz insulator with a length of 35 mm appears to be the best for maximal ion emission generation, but a 40 mm insulator length appears to be the best for operating at 13 kV.

When the performances of Quartz and Pyrex insulators are compared, it is possible to deduce that the Quartz insulators would produce greater ion intensity in some circumstances than the Pyrex insulators. It was also discovered that the ion emission is greater while operating at a pressure of 8 Torr for the majority of Pyrex insulator lengths. Nevertheless, there was no discernible pattern for the ion emission intensity against working pressure when Quartz was used.

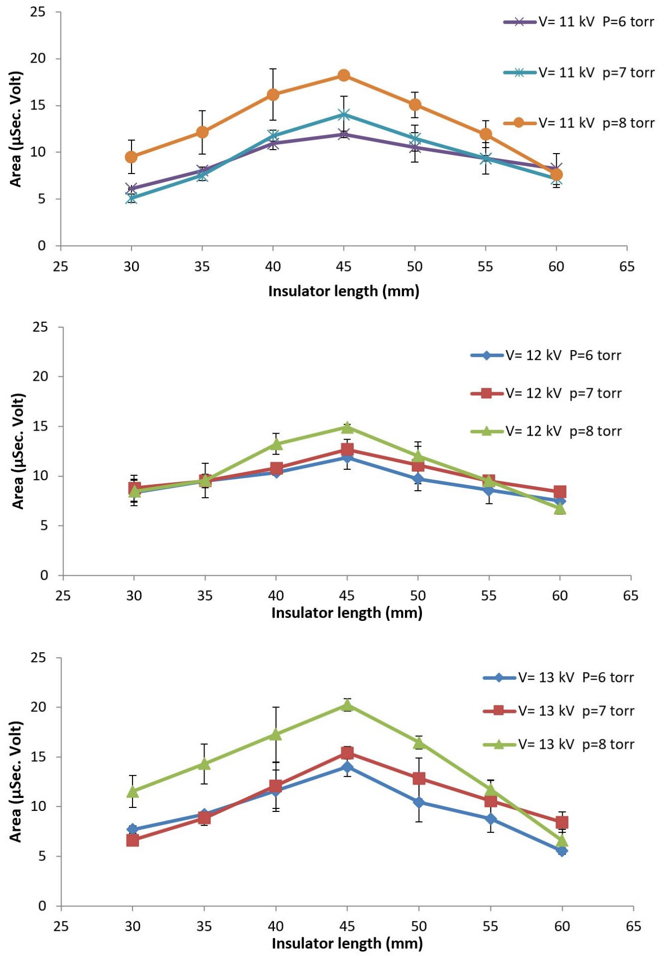

Figure 6: Variation of the emission of Neon ion obtained through central FC versus Pyrex insulator length at at different working conditions.

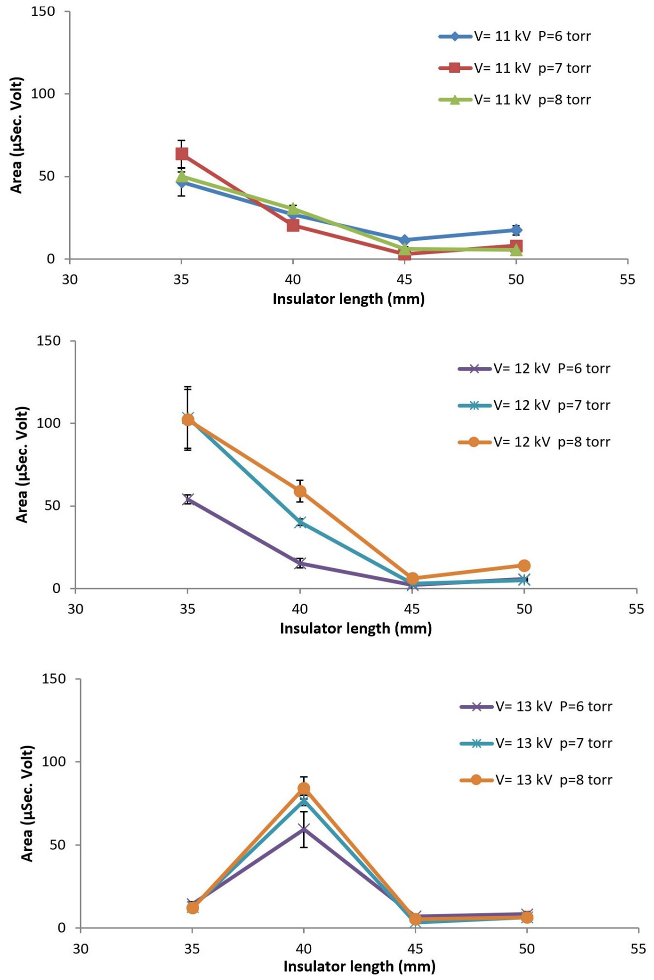

Figure 7: Variation of the emission of Neon ion obtained through central FC versus Quartz insulator length at different working conditions.

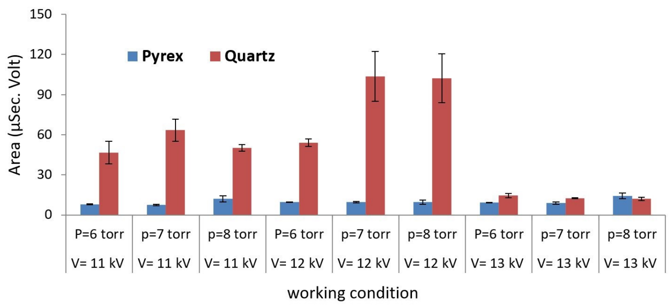

Figure 8: VComparison between Neon ion emission obtained through central FC for two different insulator material with 3.5 cm length at different working conditions.

In order to show how insulator material solely can affect ion emission in the APF, the average ion emission intensity for 3.5 cm insulators with different materials have been compared in the chart of Fig. 8.

As it can be observe in Fig. 8, Quartz insulator with 3.5 cm length led to higher ion emission in comparison to the Pyrex material. In other word, Quartz insulator with the length of 3.5 cm optimizes performance of APF in terms of ion emission. The findings shown in Figs. 6, 7, and 8 indicate that the intensity of ion emission is significantly dependent on the length and material of the insulator sleeve. If the insulator length is less than the optimum length, the electrical failure along the insulator surface occurs quicker, and the current sheath reaches the anode end before the peak period of discharge current. On the other hand, if the length of insulator is more than optimum value, the plasma pinching also will not happen at the time of discharge current peak. In addition, inappropriate insulator material results in more heating of the surface before lifting off the sheath, which may cause increased contamination of the sheath through the material of insulator (Zakaullah et al., 1989) which results in poor signal intensity as observed in Figs. 6 and 7. Hence, to construct a plasma focus device as an ion emission source, an adequate insulator length and material must be obtained experimentally.

4 Conclusion

The angular distribution of Neon ions under different pressures is measured using an array of five Faraday Cups placed individually inside the device chamber at angles 0, 11, and 33 degrees. The ion distribution exhibited anisotropic behavior, while the majority of ion emission observed within a range of 0° to -11° degrees. The findings indicate that the ions flow grows as the length of the Pyrex insulator increases from 3 to 4.5 cm, and then decreases as the length increases to 6 cm. Unlike Pyrex, the intensity of ions decreased substantially as the length of the Quartz insulator grows from 3.5 to 4.5 cm. This observation was different when the PF was run at 13 kV and Quartz lengths of 4 cm resulted in greater ion flow. The greatest ion flux is released at 8 Torr, 12 kV, and 35 mm quartz insulator, according to the graphs illustrated in Figs. 6 and 7.

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