The Effect Hollow Cathode Depth on Plasma Characteristics

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Abstract: ***Experimental study on the effect of hollow cathode depth on spatial glow distribution and the characteristics of plasma produced by dc discharge in Argon gas, were investigated bycurrent-voltage characteristic and image analyses for the glows within the plasma. It was found that the increasing the pressure leads to compress the cathode regions while increase the positive column, which appeared with periodic structure. increasing hollow depth from 19 to 40 mm reduce the positive column fluctuation and converted to continuous form at high pressure. The hollow cathode configurationalters the Paschen curves parameters, the emission intensity distribution and the current- pressure curve.***

Keywords: hollow cathode, DC discharge, cavity depth, Paschen curve

1. Introduction

The needed energy for excitation and radiations from numerous atoms, ions and molecules required in analytical emission spectroscopy, can be supplied in a variety of forms according to the used excitation source.The source used to product of free particles and their excitation results from the energy generated in electric fields, is done by the low pressure glow discharges, namely the planar and hollow cathode discharge[1].Hollow cathode discharges have numerous applications in manyfield processing and for gas lasers, and in dc discharge analysis[2].In inhomogeneous electric field configurations or in microscale gaps additional parameters alter the Paschen curve[3] also alter the plasma distribution [4]and plasma parameters[5].The geometry of a HCD enhance oscillations of hot electrons inside the cathode, thus enhancing ionization, ion bombardment of inner walls and other subsequent processes[6]. It is more effective ionization in the negative glow. Therefore, hollow cathodedischarges can yield more ions which make it useful for used as an ion source[7]sources of high intensity electron-beams, which can carry currents of several kA’s, as well as transmitters of X-rays [8].hollow cathodeshave beendeveloped and used for a wide variety of applications, including plasmaelectronsupply for ion and Hallthrusters, plasma contactors for electromagnetic tethers, and for spacecraft charging control.

2. Experimental Set Up

Figure (1) illustrates schematic for the hollow cathode electrodes (made of Aluminum) that were designed to be used in the DC discharge system. The cathodes have cylindrical external shape with outer diameter of 22 mm and a length of 45 mm whiles the inner diameter 10 mm and with two depth of 19 and 40 mm. On the other hand, the Anode electrode (made from Aluminum) has disk shape with thickness 2 cm and diameter of 10 mm covered with Teflon instead of circular aperture with 10 mm diameter. The inter- electrodes separation between the electrodes is 5.5cm.

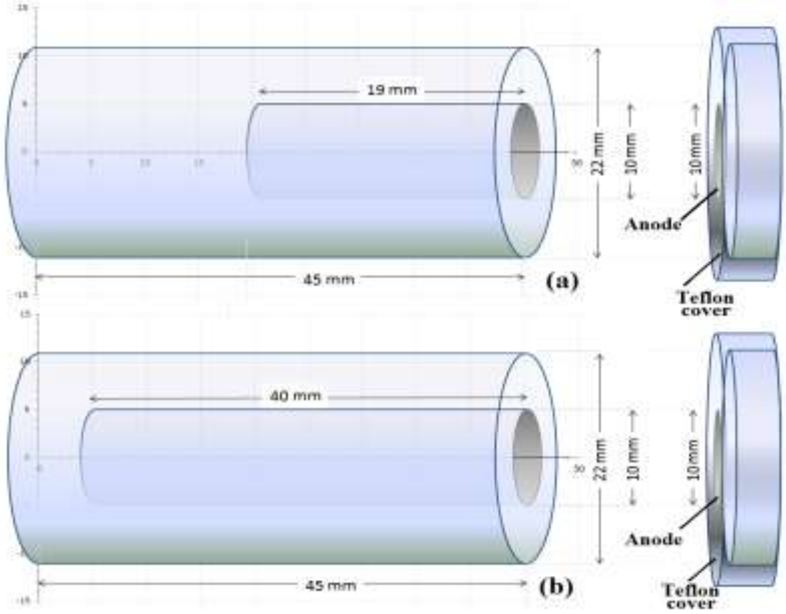

Figure 1: Schematic of hollow cathode electrode used in the DC discharge system with different depth (a) 19 mm and (b) 40 mm

The vacuum chamber was made of cylindrical stainless steel tube. The two ends of chamber were closed by two stainless steel flanges, and with small quartz window. The system connected with two stage rotary pump CIT-ALCATEL Annacy, (made in France), and with needle valve to deliver the Argon gas. The hollow cathode and anode electrodes are fixed by Teflon to prevent any connection with the chamber walls.The chamber was evacuate to a base pressure 2×10^{-2}Torr. Pirani gauge type Edward (made in England) was used to measure the pressure of the chamber. 4kV DC voltage was applied on the electrodes to generated the discharge in argon gas between two electrodes.

3. Results and Discussions

Figures. (2 and 3) schematic the effect of increasing of argon pressure on the glow dischargeregions for Argon gas between two electrodes in hollow cathode system, using direct applied voltage about 4kV at different working pressuresfrom 0.2 to 1Torr for the two hollow cathodes depth (19 and 40) mm respectively.It'sclear from both figures that increasing the pressure leads to compress the cathode regions, wherethe negative glow becomes as a thin layer of intense luminosity, while the positive column and anode fall increase due to theinversely proportional of electrons mean free path to the gas pressure, which causeinversely proportional of the required distance for an electron to travel before it has produced adequate ionization to the pressure. The discharge appeared morestable, leas fluctuation, when increase the cathode depth to 40 mm.

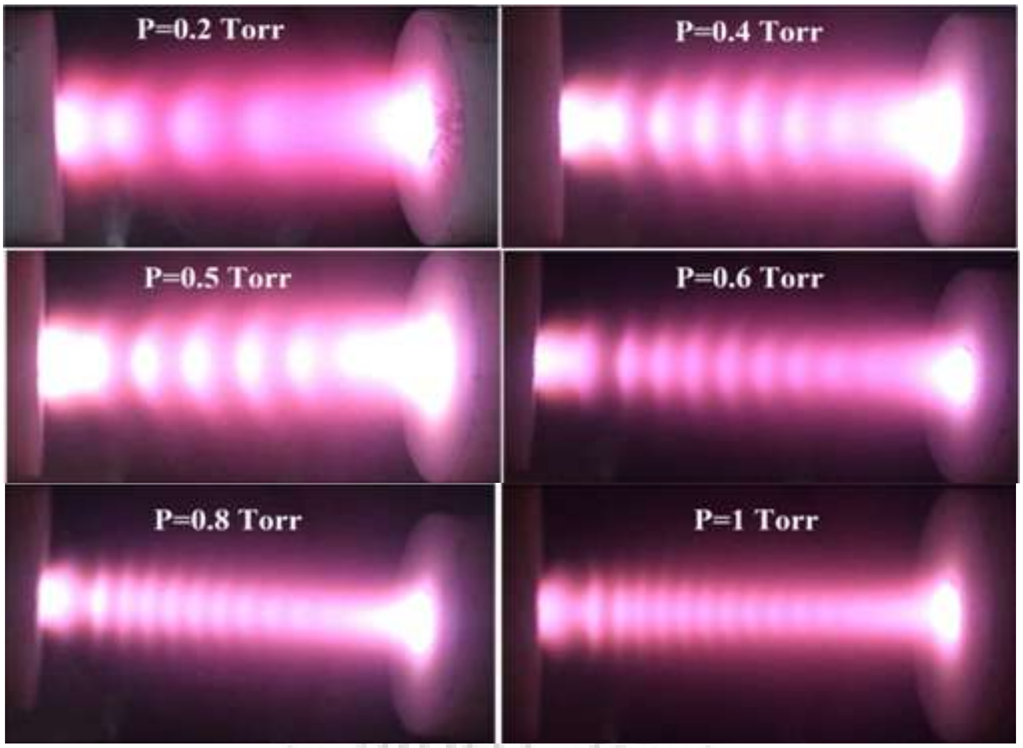

Figure 2: Effect of Ar gas pressure on the glow discharge structure of the hollow cathode system with 19 mm depth

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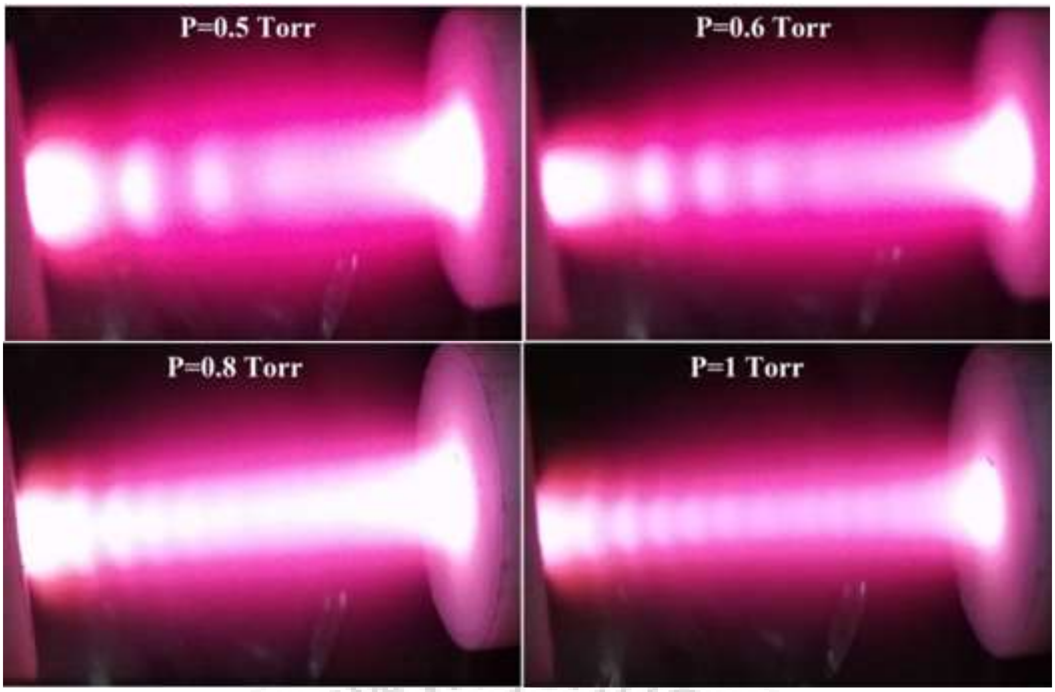

Figure 3: Effect of Ar gas pressure on the glow discharge structure of the hollow cathode system with 40 mm depth

The emission intensity of discharge regions in this system were analyzed using the image J software according toimage brightness to find the intensity behavior on the central line. Figures (4 and 5) show the glow distribution profile on central line for the two hollow cathode depth (19 and 40) mm respectively at different working pressure. Many features can be observed from these figures, the maximum intensity occur in the region near cathode surface (where the electric field is strong in this region). The plasma discharge regions are compression with increasing of gas pressure. The number of discharge regions that appear increasing with increasing of gas pressure finally converted to continuous form at high pressure especially at the 40 mm depth hollow cathode.

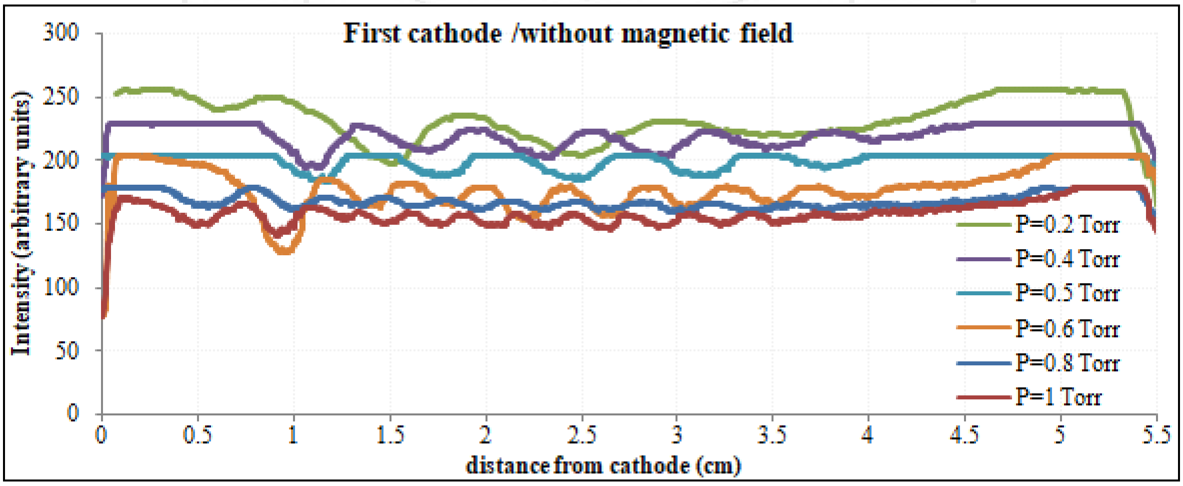

Figure 4: Glow distribution on central line using 19 mm depth hollow cathode system at different working pressure

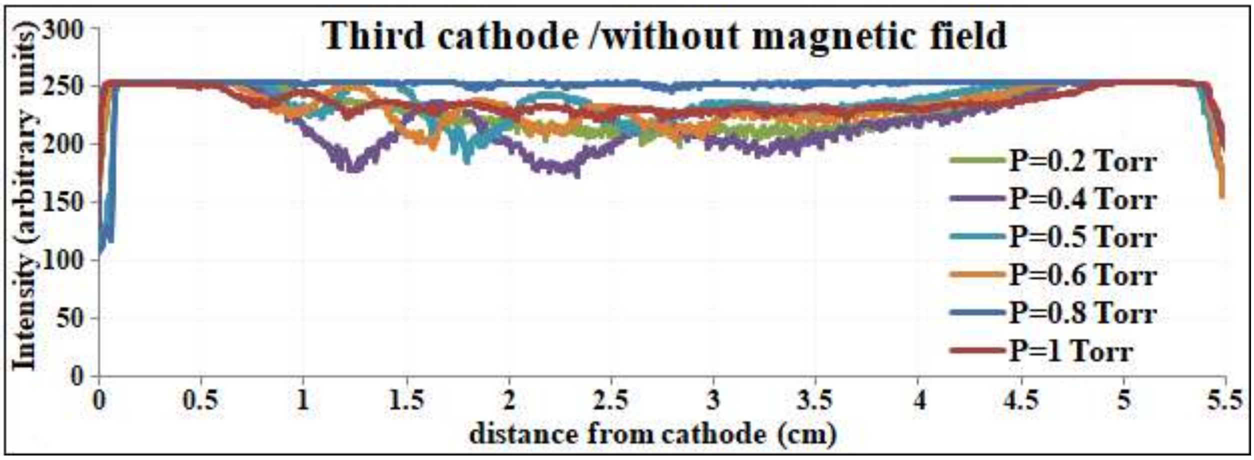

Figure 5: Glow distribution on central line using 40 mm depth hollow cathode system at different working pressure

Figure (6) illustrates a comparison between the glow distribution in the two cathode depths at P=0.2 Torr. Increasing the depth of hollow cathode from 19 to 40 mm, means the gap of electrodes, cause to the glow will go inside, which cause to decrease the fluctuation of emitted intensity. This result is agree with, David Alexander Staack (2008) [9].

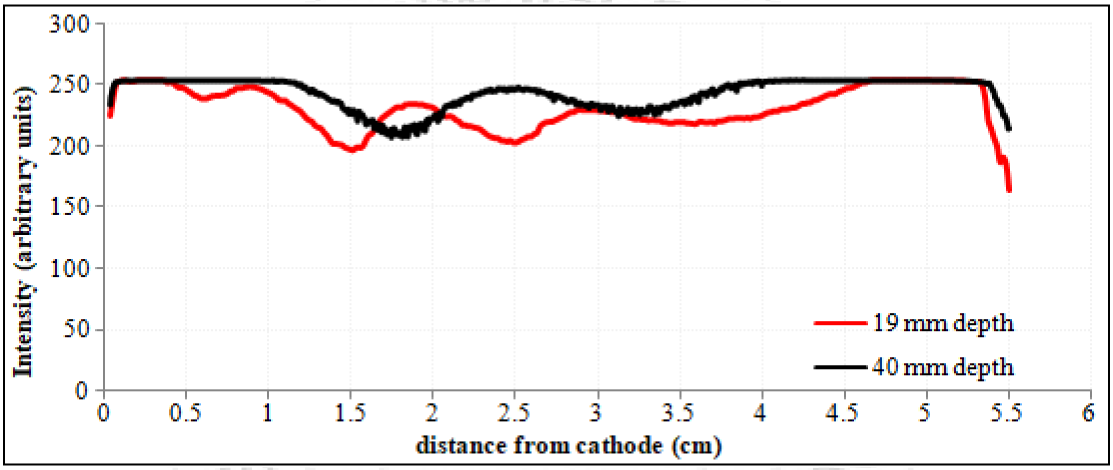

Figure 6: Comparison between the glow distribution at P=0.2 Torrin the two differ hollow cathode depth.

The breakdown voltages for different hollow cathode depth were measured at different operating pressures for each case four times by increasing the voltages until the flash occur and sudden increase in current. The rate was then taken to the breakdown voltage for each case.

Figure7 shows the relationship between the pressure and the breakdown voltage of the two cathodes. This figure shows that the two curves have the same behavior, decrease with increasing pressure, reaching the minimum valuethen increase, as described by Paschen's law (The breakdown voltage of a gas discharge is a function of the product of gas pressure and electrode separation) [10]. The difference among the curves is the breakdown voltages minima and Pd_{min}.

However, in inhomogeneous electric field configurations additional parameters alter the Paschen curve, Therefore, we observe that the Pd_{min} values are larger than the values of the flat electrodes calculated in the previous researches (Pd_{min}≈1 Toor.cm) [11], ie, the breakdown can be obtained at higher pressures due to the increasing the concentration of electrons within the cavity. The assumption of forward scattering in cavity causes an overestimate of the breakdown voltage [12]. This result is agree with Niedrist *et al.*[3]. The comparison between Paschen curves between the two hollow cathodes shows that increasing the hollow cavity depth cause to reduce minimum breakdown voltageand the values of Pd_{min}. The hollow cathode discharge promote oscillation of hot electrons inside the cathode. There by enhancing ionization, ion bombardment of inner wall and other subsequent processes, therefore electrons loss more energy during these ionizing collisions to the atoms - molecules of gas [13].

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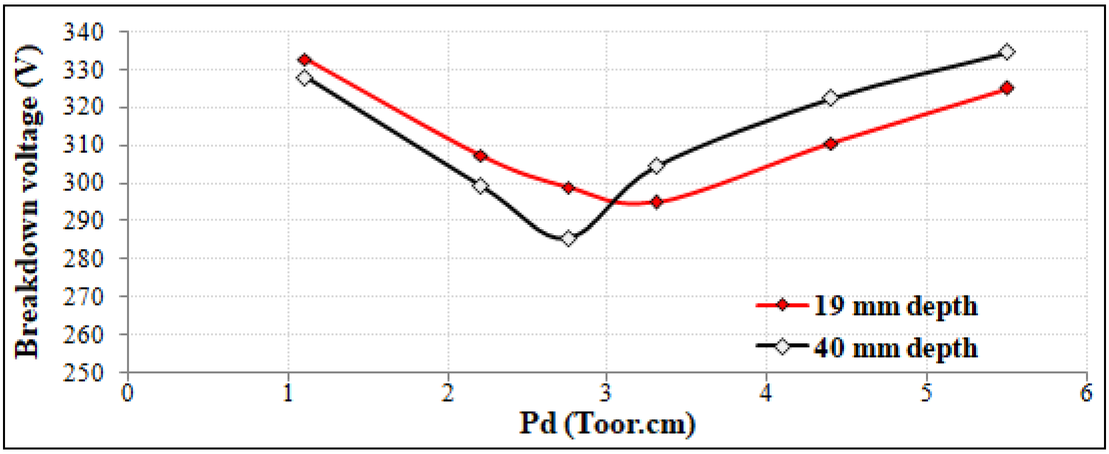

Figure 7: Comparison between the Paschen curves with varying cathode cavity depth

Figure (8) illustrate a comparison between the characteristics of current-pressure curves (I-P) for the two hollow cathodes, with different cavity depth, of the hollow cathode dc discharge at constant inter-electrode spacing (d =5.5 cm) for argon gas. The current was measured withchanging the pressure at a fixed controller resistance and dc power supply voltage. This figureshows that the two curves have increase with increasing pressure reaching maximum values at specific point then decrease with more pressure. The increment in current with pressure due to increasing the atoms density which cause more ionization collisions, hence, increase the current which essentially depend on electron density. While more pressure cause to reduce the electron free path which prevent electrons to access the sufficient energies for ionization between successive collisions. These maxima shifted toward lower pressure with increase the cavity depth due to increase the separation distance. In addition, the hollow electrode current increase with increasing cavity depth of HC which refer to increasing the hollow effect which cause to enhancing the ionization.

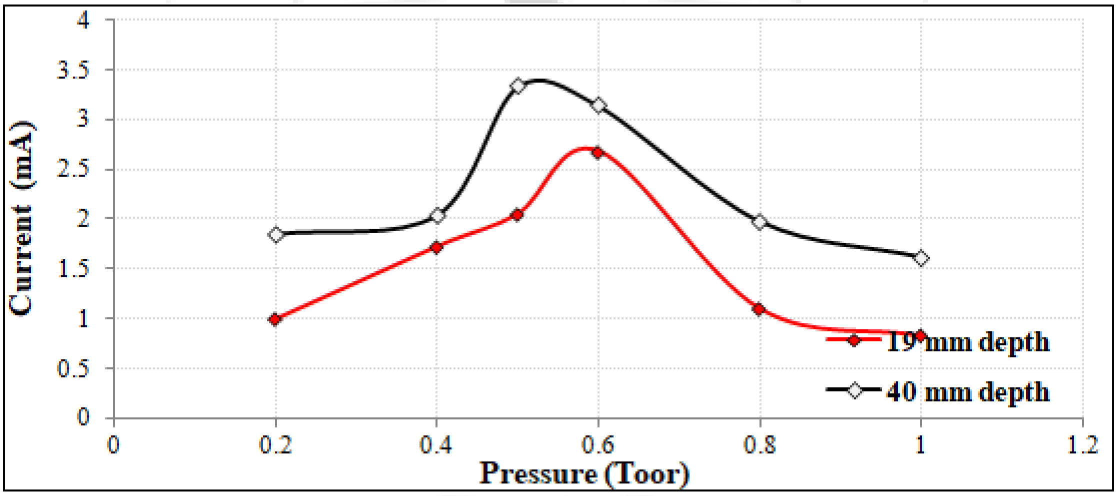

Figure 8: Current –Pressure curves the two hollow cathode depth

Figure (9) shows the variation of emission intensity of plasma as a function of working pressure for the two depth. It seems that the emission intensity have a maximum value at 0.8 torr for both curves. Increasing the cavity depth cause to reduce the plasma emission intensity due to the glow going inside the hollow.

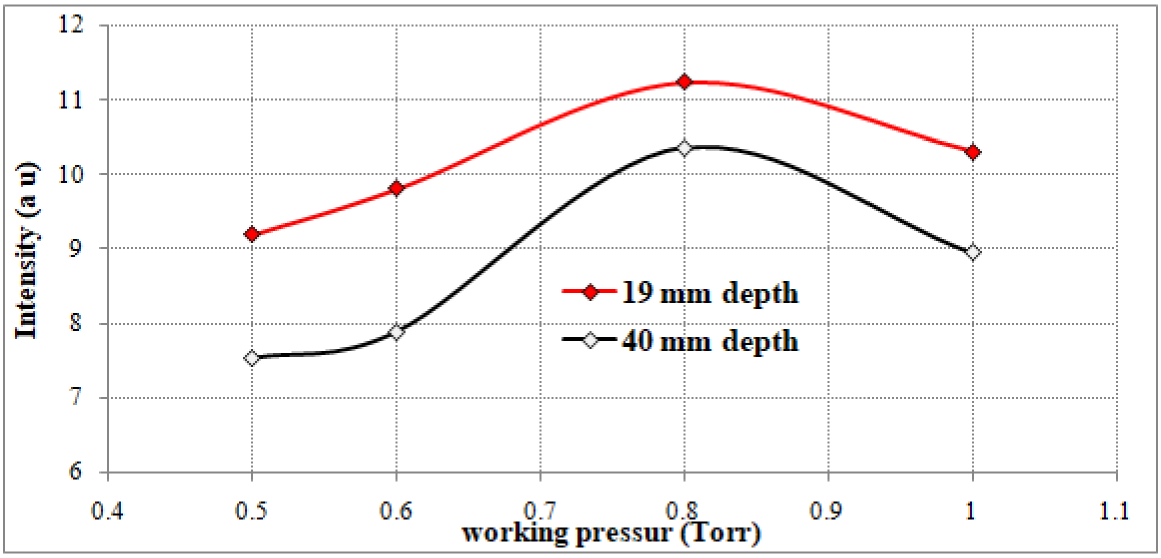

Figure 9: Variation of emission intensity with pressure for ArDC discharge using different hollow cathode depth

4. Conclusions

The glow distribution and plasma characteristics in hollow cathode dc discharge plasma effected by working pressure and the cavity depth. It was found that glow be more stable with increasing hollow depth from 19 to 40 mm and positive column converted to continuous form at high pressure. The hollow cathode configuration alter the Paschen curves parameters, where the Pd_{min} values are larger than the values of the flat electrodes. Increasing the hollow cavity depth cause to reduce minimum breakdown voltage and the Pd_{min}. The emission intensity have a maximum values at 0.8 Torr while the maximum current at 0.6 Torr and decrease to 0.5 with increasing hollow depth to 40 mm .

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