DETERMINATION OF MAGNETIC PRESSURE IN A D.C ELECTRIC ARC IN THE SCHOTTKY THEORY

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ABSTRACT:

The magnetic pressure, plasma pressure and the ratio between them which represent the beta (β) have been determined in a D.C electric arc discharge for current values (3.5-24A) under argon gas pressure ranged from (0.1-50torr). The obtained electron density and temperature from the double probes characteristic were used to calculate the magnetic and plasma pressure as well as the beta. The electron temperature explicit relation of product of gas pressure and radius of discharge arc that holds in schottky limit is used to determine the later parameter. The results show that the magnetic pressure varies nearly exponentially with gas pressure while it increases as a function of square value of arc current in agreement with the theoretical magnetic pressure. Plasma pressure and the beta plasma decreases exponentially with both arc current and gas pressure due to decreasing electron temperature.

KEY WORD: Plasma Pressure, Magnetic Pressure, Plasma Confinement and Electric Arc

1. INTRODUCTION:

The magnetic pressure is an energy density associated with the magnetic field. This pressure is identical to any physical pressure except that it is carried by the magnetic field rather than kinetic energy of gas molecules (Garren and Chen, 1994).

Magnetic pressure play an important role in the dynamic of geophysical system, from deep inside the earth to the tenuous of deep space .In solar system plasma magnetic pressure play critical role in the transfer of mass momentum of energy from one region to another (C .T. Russell,1999).The main problem in controlled thermonuclear reactions is the confining of high temperature plasma i.e. the obtaining of a stable plasma configuration isolated from the walls (B.B. Kadomtsev and S.I Braginesky,1958) .One of the most direct methods for creating a plasma separated from the walls consists in the application of the well-known pinch effect stabilized by longitudinal magnetic and metal casing .when the current run through the plasma , the particle in plasma are pulled toward each other by the Lorentz force thus the plasma contracted .The contraction is counteracted by increasing the gas pressure of the plasma, Editor (Alan Chodos**,** 2013) .To see how the plasma can contain a vacuum we start with Ampere's law which state that:-

$$\nabla X B = \mu_0 J \qquad (1)$$

If we rearrange this and take the curl with $\vec{B}$, we get the:-

$$J X \overline{B} = \frac{1}{\mu_0} (\vec{\nabla} X \vec{B})\, X \vec{B}$$

$$J X \overline{B} = \frac{1}{\mu_0} (\vec{B}.\vec{\nabla})\, \vec{B} - \vec{\nabla}(\frac{B^2}{2\mu_0}) \qquad (2)$$

But we have $\nabla P = \vec{J} x \overline{B}$ is the force on a plasma.

$$\nabla P + \nabla(\frac{B^2}{2\mu_0}) = \frac{1}{\mu_0} (\vec{B}.\vec{\nabla})\, \vec{B}$$

$$\nabla (P_g + P_{mag}) = \frac{1}{\mu_0} (\vec{B}.\vec{\nabla})\, \vec{B} \qquad (3)$$

Where B is the magnetic flux density , P is the pressure, J is the current density, μ_o is the magnetic permeability and ∇ is the deferential del operator equal to (i ∂ / ∂x) + (j ∂ /∂ y) + (k∂ /∂z.).We obtain a pressure balance contain the gas pressure P_g and a new magnetic pressure (Tilley; Davis and Hague, 2011):

$$P_{mag.} = \frac{B^2}{2\mu_0} \qquad (4)$$

Note that the magnetic field increase the plasma pressure by an amount $(\frac{B^2}{2\mu_0})$, in direction perpendicular to the field and decrease the plasma pressure by the same amount in the parallel direction(Fitzpatrick, 2008) .

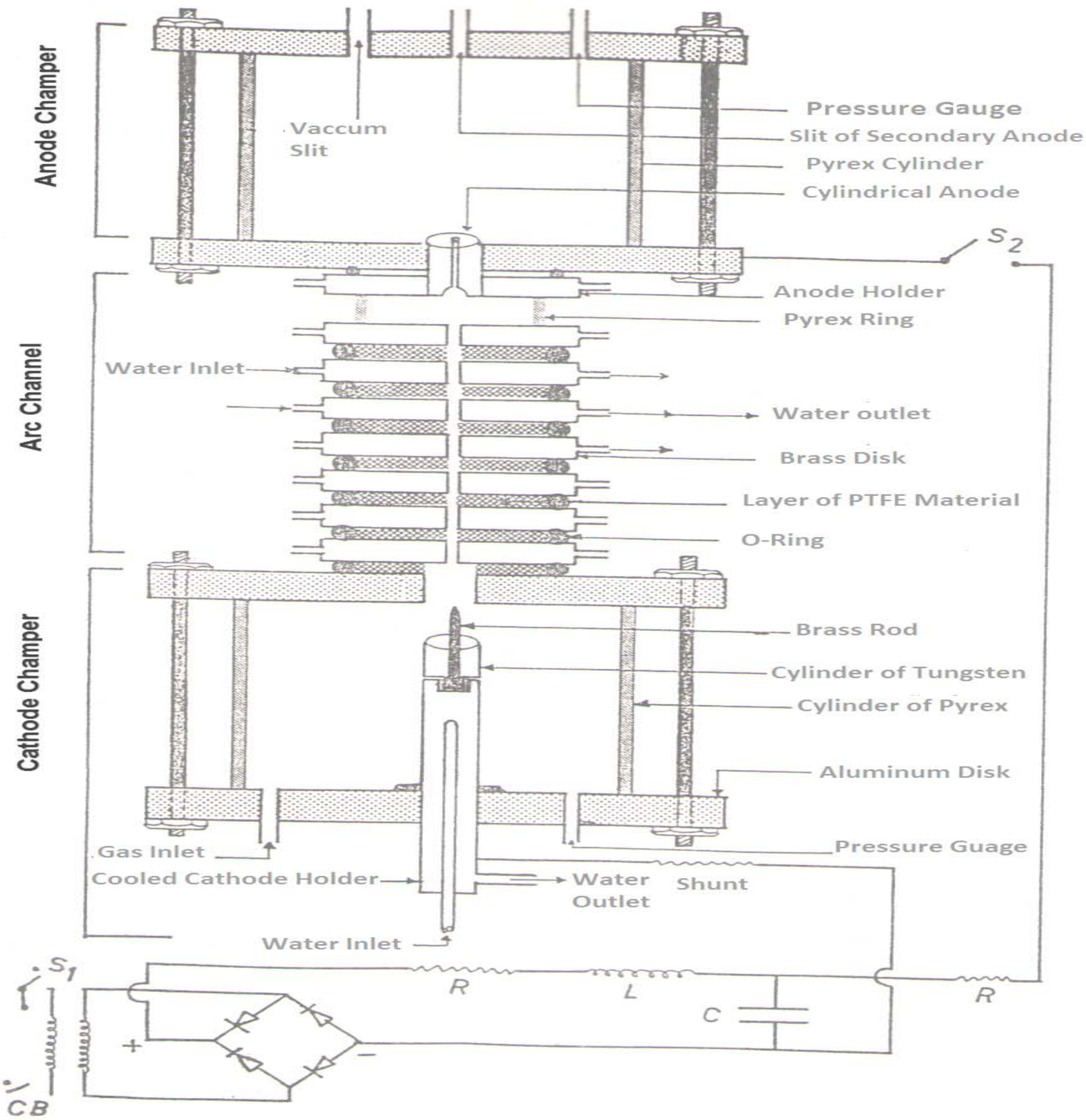
In the present work the magnetic pressure has been determined using the relationship that the electron temperature can be written as an explicit function of pressure – radius product (PR) in schottky theory i.e.:-

$$\frac{eV_i}{KT_e} = a + b\,Ln(PR) \qquad (5)$$

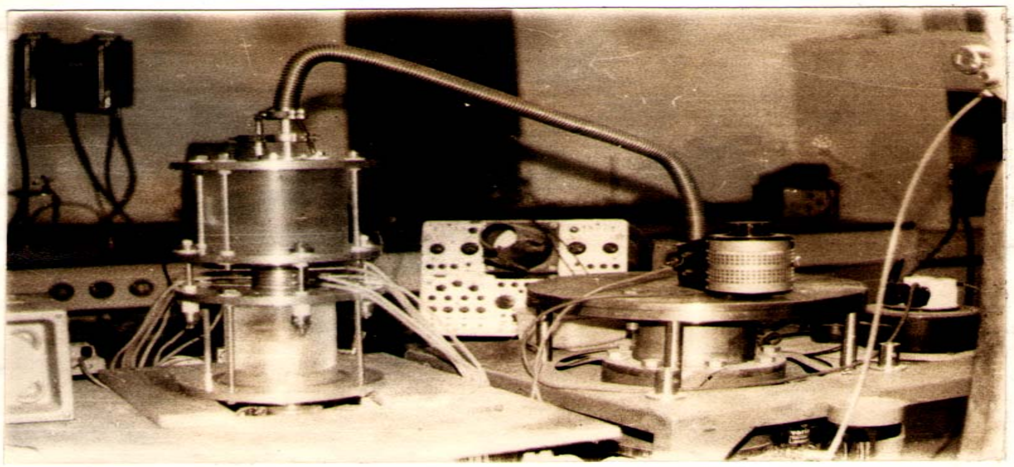
Where V_i is the ionization potential of the gas, a is the constant that depend on the type of the gas, note that a represent the value of $(\frac{eV_i}{KT_e})$ at (PR=1torr.cm).and b is a universal numerical constant (Masumi Sato, 1989).

2. EXPERIMENTAL ARRANGEMENT:

The cascaded arc used in this work consist of three main parts (Al – Hakary,1991) , namely cathode section, cascade water –cooled hollow discs section (arc channel) and anode section as shown in figure (1) . Figure (2) represent the picture of electric arc discharge system .The anode section consist of two identical aluminum discs .Three slits exists through the upper disc one to evacuate the system from the gas and the second for connecting to the secondary anode and the later is used for vacuum gauge .One grove is also made through disc for O- ring of inter diameter (0.17m) .The anode is a cylindrical copper of outer diameter (0.03m) with a hole at the axis of diameter ($6.3x10^{-3}$m).



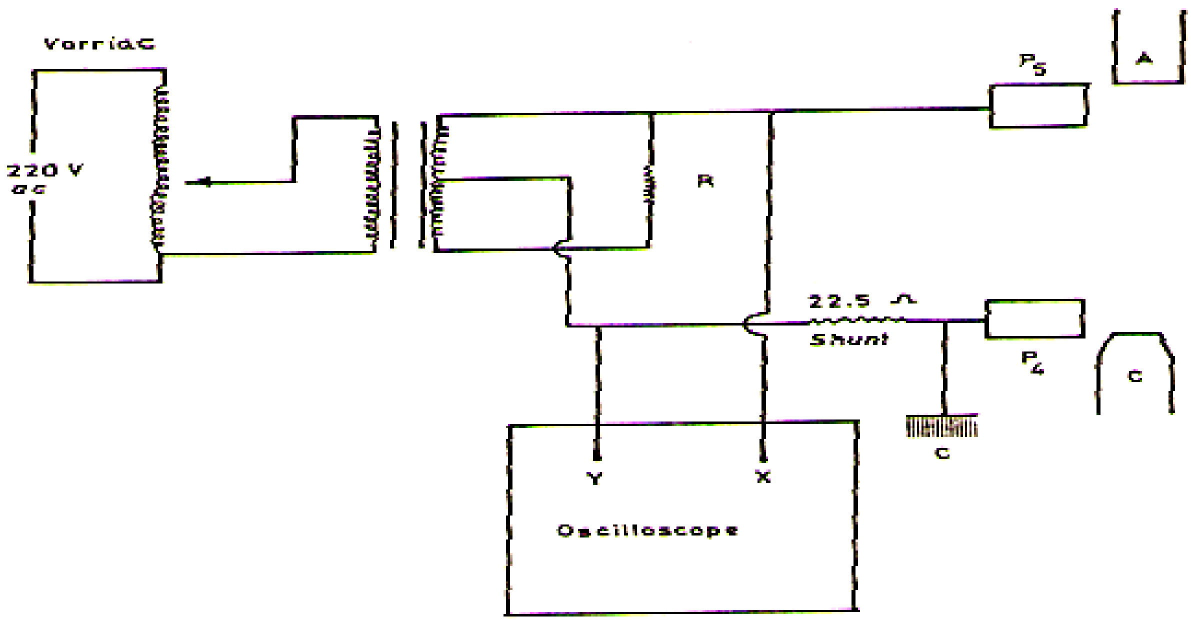
Figure(1) Electric Arc Discharge System



Figure(2) Picture of electrical arc chamber

The cathode chamber consists of two identical aluminum discs of same diameter and thickness. Cathode is a brass rod of length ($5x10^{-2}$m) and outer diameter ($4x10^{-3}$m). The brass rod interred in to the tungsten cylinder of length ($2.5x10^{-2}$m) and outer diameter ($1.7x10^{-2}$m).The later compound cathode stand through a hollow copper cooled cathode of length ($12x10^{2}$m) and diameter ($1.3x10^{-3}$m).The gas is fed through the lower cathode disc while the evacuation is from anode chamber .Both two aluminum discs of anode and cathode are separated from each other using a cylindrical Pyrex tube of length ($10x10^{-2}$m) and inter diameter ($17x10^{-2}$m).

The arc chamber used was that of Mackerel's type (Meacker, 1964) .Arc channel consist of seven discs stack. Each disc was made of brass ($6x10^{-3}$ m) bore diameter. They were insulated from each other by (PTFE) washers and cooled individually, the inter disc resistance was approximately (2.6MΩ). Arc current values being investigated ranged from (3.5- 24A), the pressure varied from (50torr) down to (0.1torr) and the gas used was commercial argon of quoted purity (99.99%).The fourth and the fifth disc were used as probes, the probe voltage was obtained from an isolated transformer (50 volt and 50Hz), the voltage recorded across the two discs (V_p) and that a cross a series resistor (R_S =50Ω), the probe current (I_P) were displayed using Tektronix oscilloscope as (X-y) plotter as shown in figure 3.



Figure(3) A.C. Circuit of applied voltage between two probes

3. RESULTS AND DISCUSSION:

For determination of plasma parameters of D.C electric arc discharge, Langmuir double probes technique has been used, the plasma parameters have been obtained from double probes characteristic (Al – Hakary,1991).Figure (4) represent (I_p–V_p) characteristics of double probes at (I_d = 19.5A,P= 1torr and T_e 2400K^0. The obtained electron density and the temperature in plasma as initial parameters(Al – Hakary, 1991) , were used in calculation of the plasma and magnetic pressures as well as in determination of the beta of a plasma symbolized by (β) . As an additional experimentally obtained parameters we used the equation that hold in schottky limit (Alfred,1994) , to determine the magnetic pressure ,because in this case the pressure in equation represent gas pressure and additional magnetic pressure associated with magnetic field due to discharge current itself (Alexander, 2010).

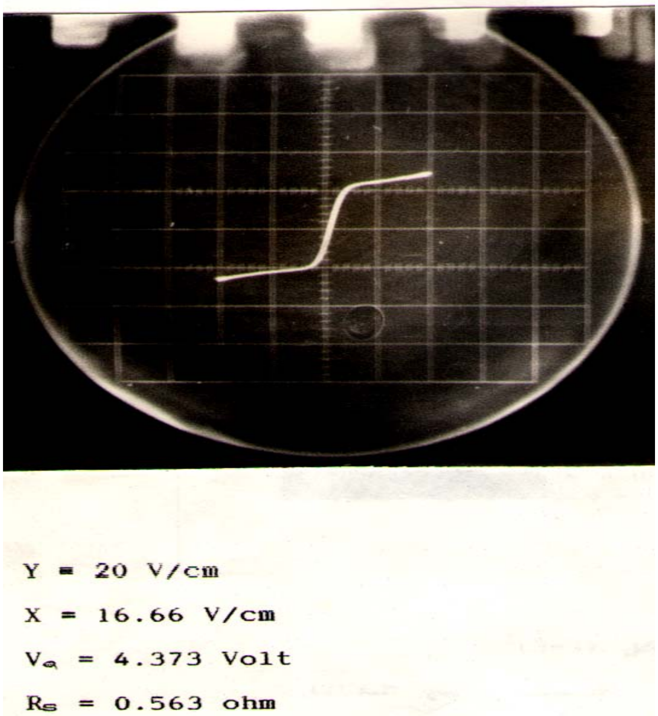


Figure (5) show the magnetic pressure versus the gas pressure at constant discharge current (24A).

The relation close to the increasing exponential function because enhancing gas pressure leads to increase in a magnetic pressure. On the other hand, magnetic pressure obtained experimentally varies as a function of the square of the current discharge satisfying the theoretical equation (4).This is shown in figure (6). When a current run through the plasma, the particle in plasma are pulled toward each other by the Lorentz force, thus the plasma contracted. The contraction is counteracted by increasing gas pressure of plasma (Editor, Alan Chodos, 2013). Furthermore the obtained theoretical magnetic pressure from equation (4) is plotted as a function of arc current as shown in figure (7).

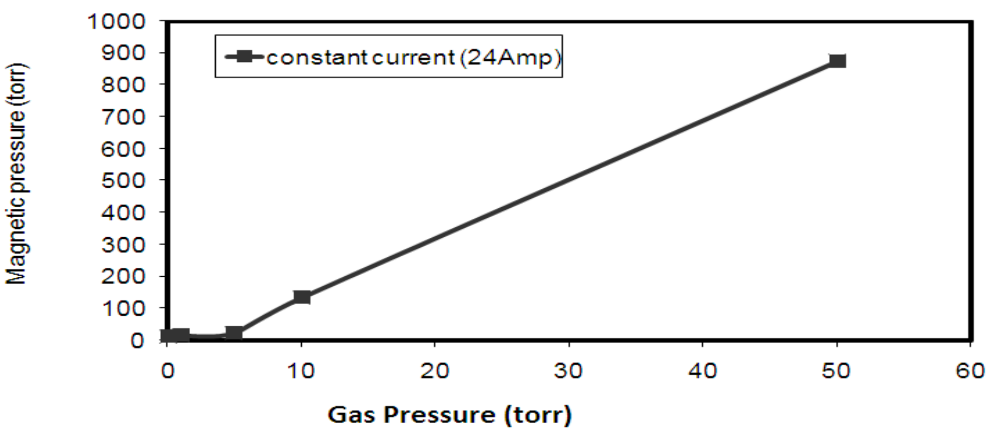
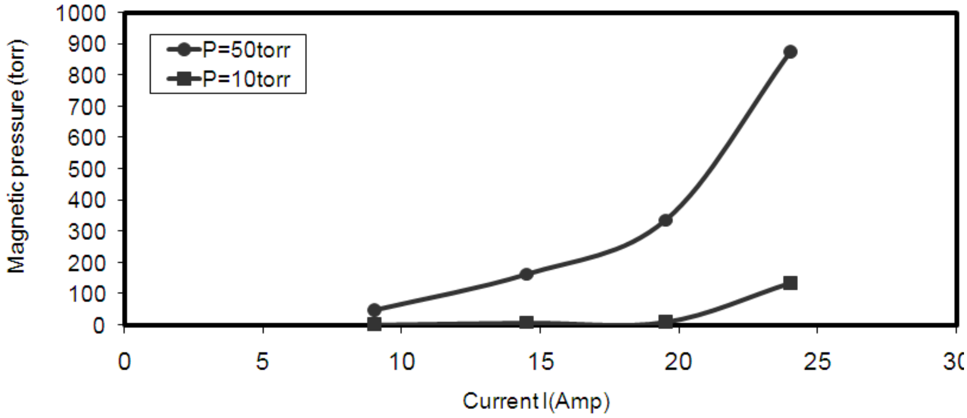


Figure (5): Magnetic pressure as a function of gas pressure



Figure(6) Magnetic pressure as a function of different currents at pressure gas(10and 50torr)

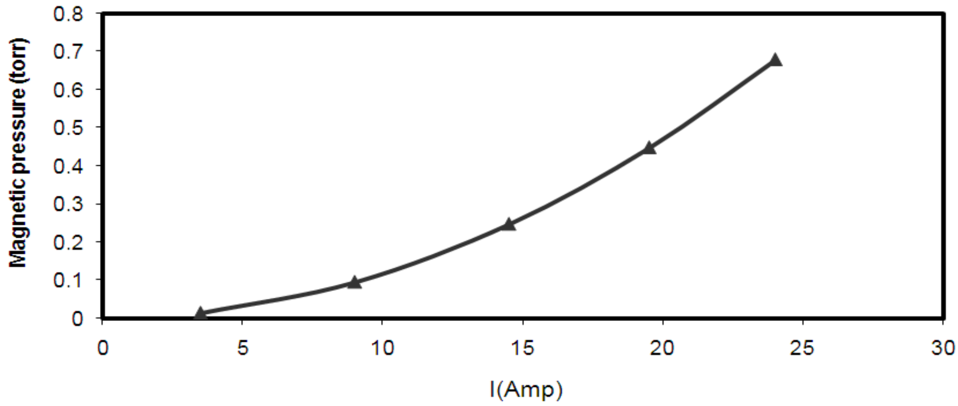


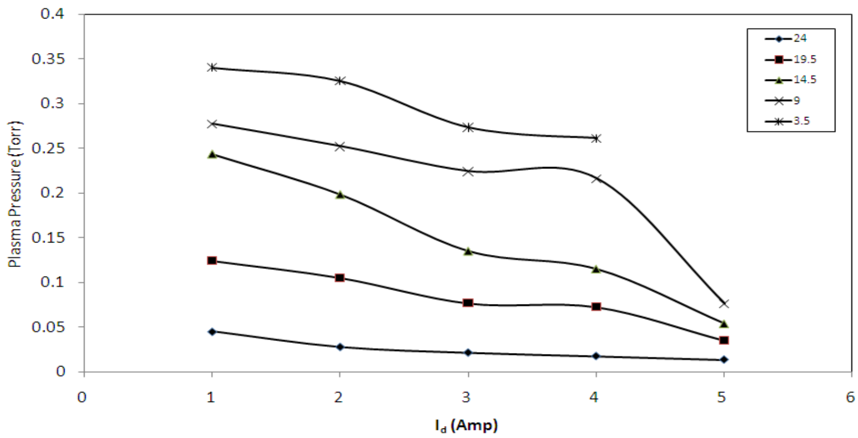
Figure (7) Theoretical magnetic pressure as a fiunction of current

The plasma pressure was obtained using an ideal gas equation:

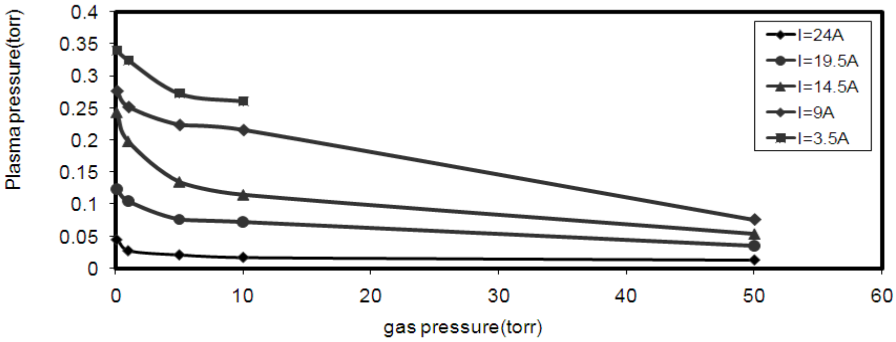
$$P = n_e \; K_B \; T_e \qquad (6)$$

Where n_e and T_e are electron density and temperature respectively, and K_B is Boltzmann constant.

Plasma pressure decrease with increasing discharge current as shown in figure (8) .Because both electron density and its temperature decrease with enhancing arc current, this in turn due to the magnetic confinement of plasma that arises from arc current itself. Also plasma pressure decrease with the gas pressure according to the decreasing exponential as illustrated from figure (9). Since the electron will loose energy to other plasma particle due to increasing gas pressure (Alfred, 1994).



Figure(8) Plasma pressure versus current discharge



Figure(9):Plasma pressure as a function of gas pressure at different currents values

The beta of plasma symbolized (β), is the ratio of plasma pressure ($P = nk_BT$) to the magnetic pressure $(P = \frac{B^2}{2\mu_0})$, so the beta of plasma is given by (Wesson, 2004).

$$\beta = \frac{P_{plasma}}{P_{mag.}} = \frac{nK_B T}{(B^2 / 2\mu_0)} \qquad (7)$$

This term is commonly used in studies of the magnetic field of the Sun and Earth, and the field of fusion designs the pressure dependence of the beta under constant arc current (24A) is shown in figure (10), the variation is close to the decreasing exponential, because increasing gas pressure reduce the electron temperature as well as enhancing magnetic pressure, therefore the beta decrease due to two terms both plasma and magnetic pressure. Also the behavior of beta versus arc current is similar to its variation with gas pressure , and this attributed to increasing magnetic pressure and decreasing the electron temperature with enhancing arc current under different gas pressure .Figure (11) represent the same behavior.

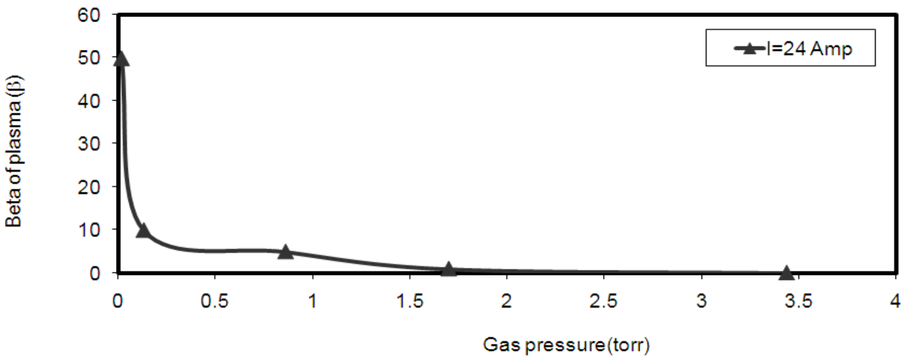
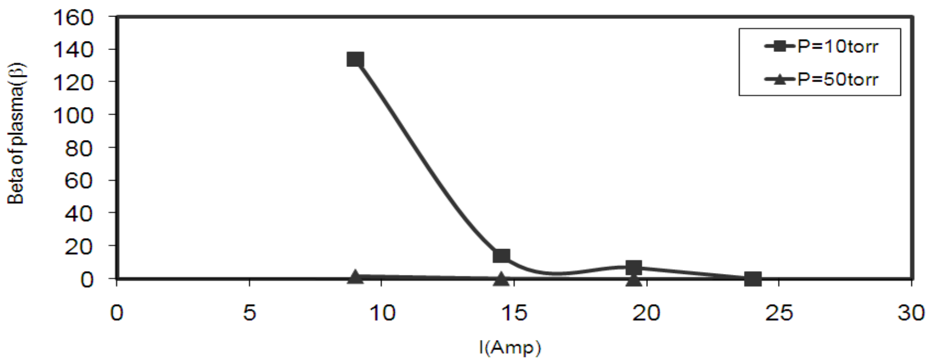


Figure (10):(β) as a fuunction of Gas pressure



Figure(11): β as a function of current at pressures (10 torr and 50torr)

4. CONCLUSION:

The obtained plasma parameters (electron density and the temperature) in the plasma of electric are discharge using double probes technique was employed to determine the magnetic plasma pressure and their ratio which represent the beta of plasma. These calculations were carried out by application of the relation of electron temperature as an explicit function of pressure – radius product in the Schottky theory. The obtained results allow making some conclusions concerning our result:

1. Langmuir probe technique can be used to determine additional plasma parameters such as magnetic and plasma pressures as well as their ratio beta of plasma.
2. The relation electron temperature as an explicit function of pressure radius product in the Schottky theory gave reasonable result of magnetic and plasma pressure.
3. The gas pressure is the most important factor that affects the obtained result.
4. The electric arc current plays the most important role on the obtained results.

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پێك ئینانا فشارا مەگناتیزي ژكڤانێ (D.C) یێ ئەلەكتریكی دتیورا شوتكیدا

پوخته

فشارێن مەگناتیزی وپلازمایی و ئەو رێژەیا دناڤبەرا واندا, كو ب (β) بێتا دهێته نیاسین, ب رێكا كڤانێ د.س. یێ ئەلەكتریكیدا هاتیە پێك ئینان دبن ڤشارا غازا ئارگونێ كو ژ (٠,١–٥٠ torr) بووه, و ئەو گرانی و گەرماتیا ئەلەكترونی یا دەركەفتی ژ هەردوو جەمسەرێن ئەلەكتریكی ژبو خواندن و ژمارتنا فشارێن مەگناتیزي و پلازمایێ و بێتایا پلازمایێ هاتنە بكارئینان. پەیوەندیا ڤێ چەندێ ژی وێ چەندێ دیاردكەت كو پلا گەرماتیا ئەلەكترونی وەكو كارەك و فاكتەرەكێ بەرچاف بو بەرهەم ئینانا فشارا غازێ دهێتە نڤیسین و بكارئینان, و قەبارێ دەرێخستنا كڤانێ شوتكی بو دەست نیشانكرنا پەرەمیتەرێ د دویڤدا دئێتە بكارئینان. ئەنجامدان وەسا دیاركر كو فشارا مەگناتیزي دگەل بلندبونا فشارا غازێ بلند دبیت و وەكهەڤی دگەل بنەمایێن تیوری یێن كڤانێ شوتكی یێ فشارا مەگناتیزي دیاربویە. بەلێ فشارا پلازمایێ و پێتایا وێ هەڤ ب هەڤ نزمبوونا تەیارێ كڤانی و فشارا غازێ ژبەر نزمبونا پلا گەرماتیا ئەلەكترونی.

ايجاد الضغط المغناطيسي لبلازما التفريغ الكهربائي القوسي المستمر(D.C) ضمن حدود شوتكي

الملخص:

تم في هذا البحث ايجاد الضغط المغناطيسي وضغط البلازما والنسبة بينهما التي تمثل معامل البلازما (β) في بلازما التفريغ الكهربائي القوسي المستمر لتيارات مختلفة (3.5-24A) لغاز الاركون تحت الضغوط (0.1-50torr) . أن قيم كلاً من درجة حرارة الالكترون وكثافته التي حصلنا عليها من خواص المجس المزدوج استخدمت لحساب الضغط المغناطيسي وضغط البلازما اضافة الى معامل البلازما.علاقة درجة حرارة الالكترون كدالة لحاصل ضرب ضغط الغاز- نصف قطر التفريغ التي تصح ضمن حدود شوتكي استخدمت لحساب معلمات البلازما حيث أظهرت النتائج ان الضغط المغناطيسي يتغير تقريباً أسياً مع ضغط الغاز، بينما يزداد طردياً مع مربع تيار التفريغ القوسي وهذا ما يطابق القيم النظرية للضغط المغناطيسي .وأخيراً أظهرت النتائج أن كلاً من ضغط البلازما ومعامل البلازما تقل أسياً مع كلاً من تيارات القوس وضغط الغاز طبقاً لنقصان درجة الحرارة.