Experimental investigation of dusty plasma characteristics in AC discharge system

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Abstract

In the present work, the effect of size of zinc dust particles on AC argon discharge characteristics are investigated experimentally. The plasma characteristics are determined by using optical emission spectroscopy (OES) techniques. The results illustrated that the electron temperature (T_e) in the present and absent of Zinc dust particle is reduced with increasing of pressure. The electron temperature decreases with increasing of Zinc dust size. Excitation temperature T_{ex} is reduces with increasing of Ar pressure in present and absent of zinc dust particles. The present of Zinc dust reduce the T_{ex} of Ar in both Zinc dust size. The electron density increasing in the present and absent of both zinc dust size. Furthermore, the introduced of zinc dust in AC discharge increasing of n_e.

عمليا تحقيق خصائص البلازما الغبارية في نظام التفريغ ذو التيار المتناوب

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الخلاصة

في هذا العمل، تم عمليا دراسة خصائص تاثير حجم جسيمات غبار الخارصين على خصائص التفريغ الكهربائي بنظام التيار متناوب لغاز الاركون تحت ضغوط مختلفة، خصائص البلازما تم حسابها باستخدام بتقنية مطياف الانبعاث الضوئي. حيث اشارت النتائج الى نقصان حرارة الالكترون في حالة وجود وعدم وجود الجسيمات بزيادة الضغط ونقصانها بزيادة حجم جسيمات الغبار. ان حرارة التهيج تقل بزيادة الضغط وفي حالة وجود وعدم وجود الجسيمات ايضاً، كما تقل عند تغير حجم الغبار للجسيمات. ان كثافة الالكترونات تزداد في حالة جسيمات الغبار مختلفة الحجم وعدم وجودها.

Introduction

The term plasma represents a microscopically neutral gas containing many interacting charged particles (electrons and ions) and neutrals. It is likely that 99% of the matter in our universe (in which the dust is one of the omnipresent ingredients) is in the form of plasma. Thus, in most cases plasma coexists with the dust particulates. These particulates may be as large as a micron. They are not neutral, but are charged either negatively or positively depending on their surrounding plasma environments. An admixture of such charged dust or macro-particles, electrons, ions and neutrals forms dusty plasma. A dusty plasma (or complex plasma) is loosely defined as normal electron–ion plasma with an additional charged component of micron- or submicron-sized particulates. This extra component of macro-particles increases the complexity of the system even further. Dusty plasmas are low-temperature

fully or partially ionized electrically conducting gases whose constituents are electrons, ions, charged dust grains and neutral atoms. [1]. The exponential growth in dusty plasma research was driven primarily by discoveries in the widely different areas of planetary science and applied plasma science: the observation of the spokes in Saturn's B ring, reported in 1982 [2], and the realization that the contamination of semiconductor material in plasma processing tools was due to particles grown in the plasma [3] Interesting in the field of plasma-particle interaction with regard to dusty plasma has grown enormously during the last decade. At present, the interest is mainly caused by applied research related to material science and, recently, also with regard to plasma diagnostics [4]. In industry, dust particles are often considered as fatal for the processes, in particular in microelectronics where extreme cleanliness is required. Thus, important investments are engaged in order to work under a controlled and filtered environment, free of dust particle contamination [1].

Experimental set up

In this work, the simplest and least expensive method of producing AC dusty plasma is shown in Fig.1. The chamber of this system was made from Quartz class and it consists of the two open ends were terminated by two stainless steel flange. One of them was connected to pumping system. While the other one was used to immerse the Argon gas. Two circular electrodes (powered and grounded electrode) were made from *Zinc metal* sheet which has diameter of 8cm and thickness of 2mm. The electrodes gap is 10 cm.
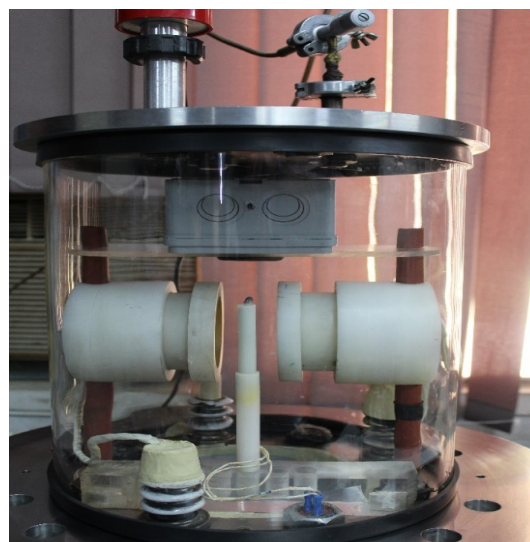

Fig.1: The chamber of the system.

The chamber was pumped by two stage rotary pump to a base pressure of about 2×10^{-2} torr. Zinc dust particles ~125 μm and ~212 μm size are dropped from the top of the chamber into plasma by a dust dropper device (duster) which was design and worked by an electrical and mechanical method to produce a dusty plasma laboratory. The dust dropper device (local manufactured) consist of four main parts which are the dropper disk (circular dust container), speaker, electric circuit and remote control sticks. Disk dropper (made from Teflon) having a mesh installed on the its surface controls the quantity and size of dust inside the ionized medium ,Disk dropper directly in contact with the small speaker (peak power 40 watt) that generate vibrating waves, This vibratory movement is responsible for the introduction of dust into the plasma medium. The weight of Zn dust particle which immerses into the plasma is equal 0.1 gm.

Theoretical part

Optical emission spectroscopy (OES), which measures the light emitted from plasma as a function of

wavelength, time, and location, is one of the common remote diagnostic. Diagnostics for determining such quantities as n, KT_e, V_s, etc. that have taken for granted so far can be remote or local. Remote methods do not require insertion of an object into the plasma, but they do require at least one window for access. Local diagnostics measure the plasma properties at one point in the plasma by insertion of a probe of one type or another there. Remote methods depend on some sort of radiation, so the window has to be made of a material that is transparent to the wavelength being used. Sometimes quartz or sapphire windows are needed. In this work, quartz windows used. The primary advantage of optical emission analysis is that it is non-intrusive and can be implemented on an existing apparatus with little or no modification. It provides spatial and temporal resolution of the plasma emission spectra and has very large information content which yields much valuable information about the plasma if analyzed properly. Moreover, it is relatively inexpensive and can be used on more than one reactor. One of the most limiting factors of OES as a process diagnostic tool is the maintenance of the optical window. Deposition and/or etching of the window [5]. The complex inter relationship between the spectral emission from a plasma and its constituents depends on the plasma being in thermal equilibrium with its surrounding, Thus thermodynamic equilibrium can be assumed to prevail for a given point and time in the plasma development. The state of high-pressure plasma can be usually described using models of local thermodynamic (LTE) [6].

Evaluation of plasma parameters
1) Boltzmann plot method for excitation temperature (T_{ex}).
For plasma in LTE, the energy level population of the species is given by the Boltzmann distribution law [7]:

$$\frac{n_f}{n_i}\frac{g_{i,f}}{P_f}e^{(-\frac{E_{i,f}}{K_\beta T_e})} \qquad (1)$$

Here, the index f refers to the ionization stage of the species (f =0 and 1 corresponding to the neutral and singly ionized atoms respectively), K is the Boltzmann constant, T_e is the electron temperature, $n_{i,f}$, $E_{i,f}$ and $g_{i,f}$ are the population, energy and degeneracy of the upper energy level f respectively, n_f is the number density and P_f is the partition function of the species in ionization stage f. the integrating intensity I_f of spectral line occurring between the upper energy level f and the lower energy level i of the species in ionization stage f in optically plasma, i.e. plasma in which only very little radiation is absorbed ,is given as:

$$I_f = \frac{hc}{4\pi\lambda_{i,f}}A_{i,f}n_{i,f}L \qquad (2)$$

Where I_f is the intensity in ionization stage, h is the plank constant, c is the speed of light, L is the characteristic length of the plasma, $A_{i,f}$ is the Transition probability and i,f is the transition line wavelength.
Using Eq.(1) and Eq.(2) can be rewritten as [7]:

$$I_f = \frac{hc}{4\pi\lambda_{i,f}}A_{i,f}n_fL\,\frac{n_z}{P_z}g_{i,f}e^{(-\frac{E_{i,f}}{K_\beta T_e})} \qquad (3)$$

By taking the natural logarithm, Eq.(3) can be re-written as:

$$\ln\left(\frac{I_{fi}\lambda_{fi}}{Afi\ gf}\right) = -\frac{1}{K_\beta T_e}E_f+\ln\left(\frac{h\,c\,L\,n_z}{4\pi P_z}\right)(4)$$

This yields a linear plot (the so-called Boltzmann plot) if one represents the

magnitude one the left-hand side for several transitions against the energy of the upper level of the species in ionization state z. The value of T is deduced from the slope of the Boltzmann plot. As Eq. (4) is obtained under the assumption of plasma being optically thin as well as in LTE, the

applicability of this equation is limited to LTE and optically thin plasmas [7].

2) Saha boltzmann equation method for n_e.
The electron density using atom and ion spectral lines emitted from the plasma is determined from Saha Boltzmann equation as [8]:

$$n_e = \frac{2(2\pi\, m_e k_\beta T_e)^{3/2}}{h^3} \frac{I_1 \lambda_1 g_2 A_2}{I_2 \lambda_2 g_1 A_1} e^{-\frac{(E_2 - E_1)}{k_\beta T_{ex}}} \qquad (5)$$

The lowering of the ionization energy due to interaction in the plasma is negligibly small which has been omitted in Eq.(5). The values of E, A, and g for these lines were obtained from NIST Atomic spectral database[9].

3) Ratio method for Te
The method used for determination of the electron temperature of the AC plasma requires taking the line intensity Eq.(3) ratio of two pairs of lines have the same species of ionization stage z, characterized by different values of the upper level energy ($E_2 \neq E_1$) is expressed as [8][10]:

$$kT_e = \frac{E1 - E2}{\ln\left(\frac{I2}{I1}\right) - \ln\left(\frac{A2 g2 \lambda 1}{A1 g1 \lambda}\right)} \qquad (6)$$

where I_1, λ_1, g_1 and A_1 are the total intensity (integrated over the profile), the wavelength, the statistical weight and the transition probability, respectively of one line, E_1 its excitation energy. The corresponding quantities for the other line are I_2, λ_2, g_2 and A_2. Consider two emission lines having the same upper level or as close as possible, the temperature effect of the Boltzmann factor on the reproducibility of the line intensity ratio is minimized and at the same time the consideration of the efficiency factor of the collecting system is avoided. Neglecting exponential factor

in that condition, one can find out the theoretical value of the intensity ratio of two lines by using the atomic parameters of the transitions [10].

Results and Discussions
The plasma diagnostics are crucial to understanding of the discharge physics and optimization, the electron density is one of the most fundamental parameters in gas discharge. Typical methods to measure electron density and electron temperature include the Langmuir probes, laser heterodge interferometer, laser Thomson scattering and optical emission spectroscopy (OES) [11].
Optical emission spectroscopy is one of the fundamental discharge diagnostic methods. It is universal for various plasma kinds and has the advantage of being remote and non-perturbing or no influence on the studied object. The most widely used optical emission method for measuring electron temperature (T_e), excitation temperature (T_{ex}) and electron density (n_e) sensing the presence of different atoms and molecules in the plasma .The basic premise of this technique is detected the light emitted from the plasma and resulting spectrum distribution is calibrated and plotted as intensity against wavelength. A spectrum often consists of a number of characteristic spectral lines of s particular atom or ion. These lines

(emission lines) originated from the inelastic collision of electron with neutral or ionized atoms.

Figs. 2, 3 and 4 show, the typical spectrums recorded for argon gas at electrode distance 10 cm for different gas pressures with and without zinc dust particles, at (125 and 212) µm.
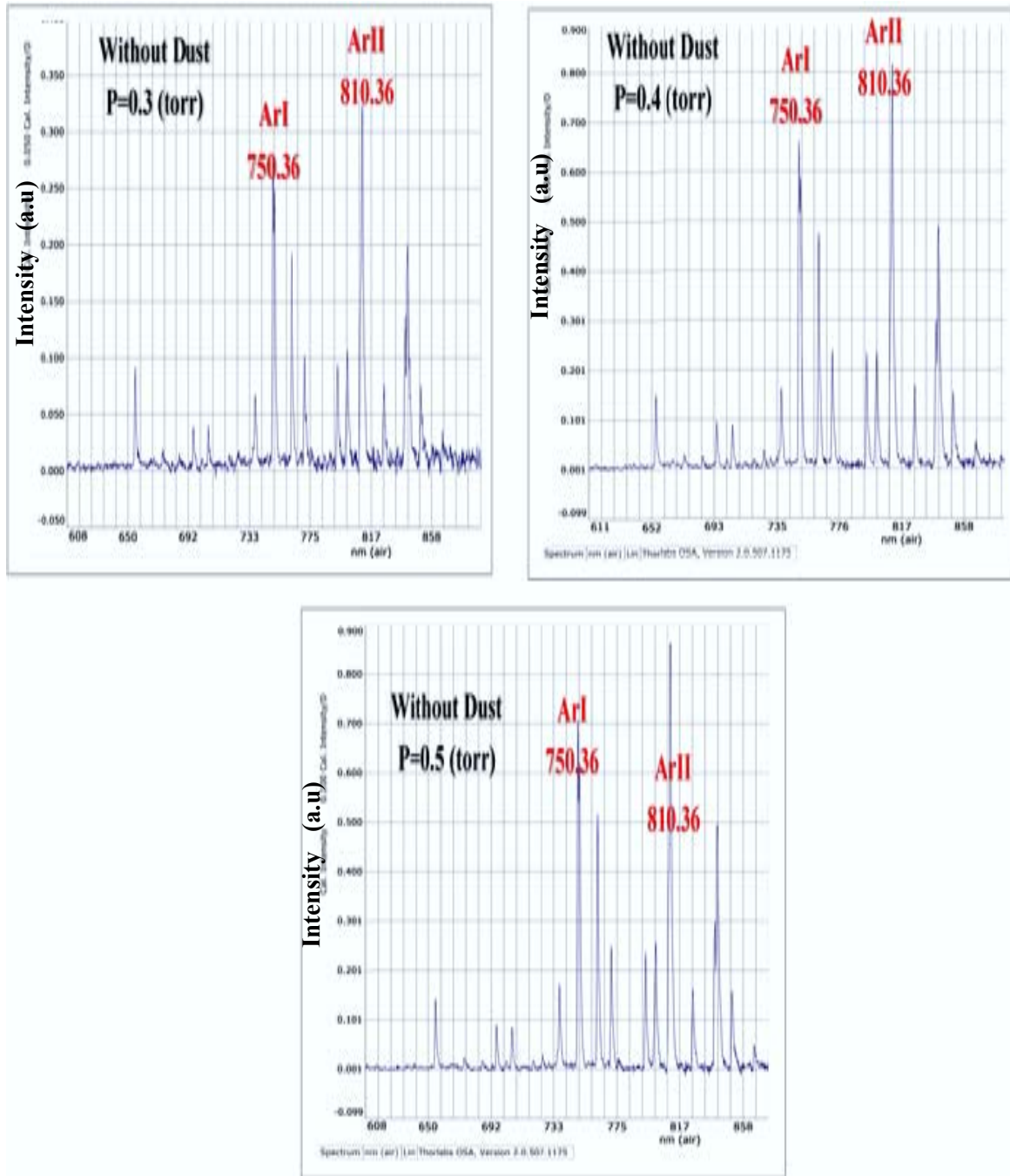

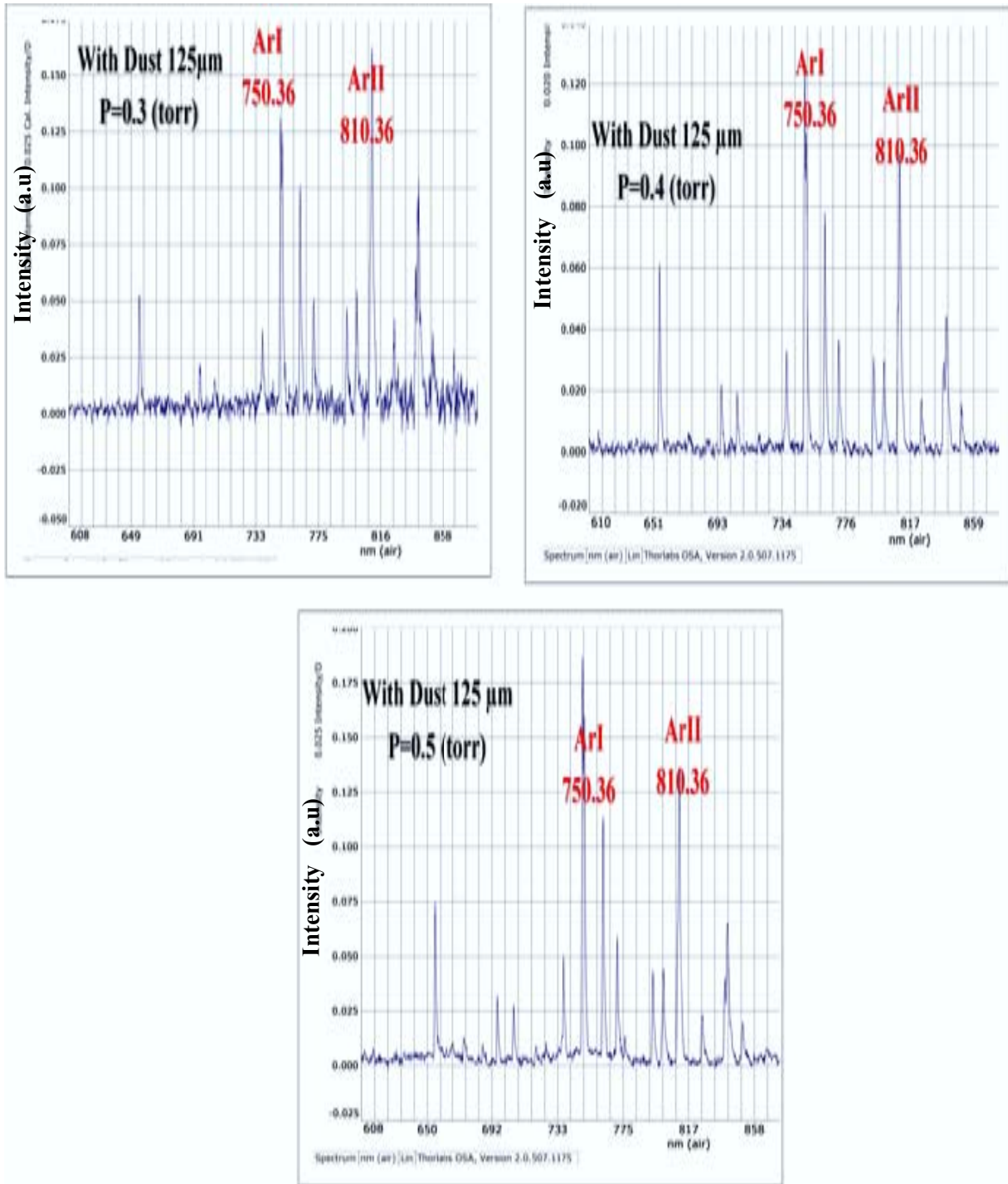*Fig.2: Typical spectrum recorded for argon gas without dust at different Ar pressure (0.3, 0.4, 0.5)torr.*

Fig.3: Typical spectrum recorded for argon gas with present of 125 µm Zinc dust size at different Ar pressure (0.3, 0.4, 0.5)torr.
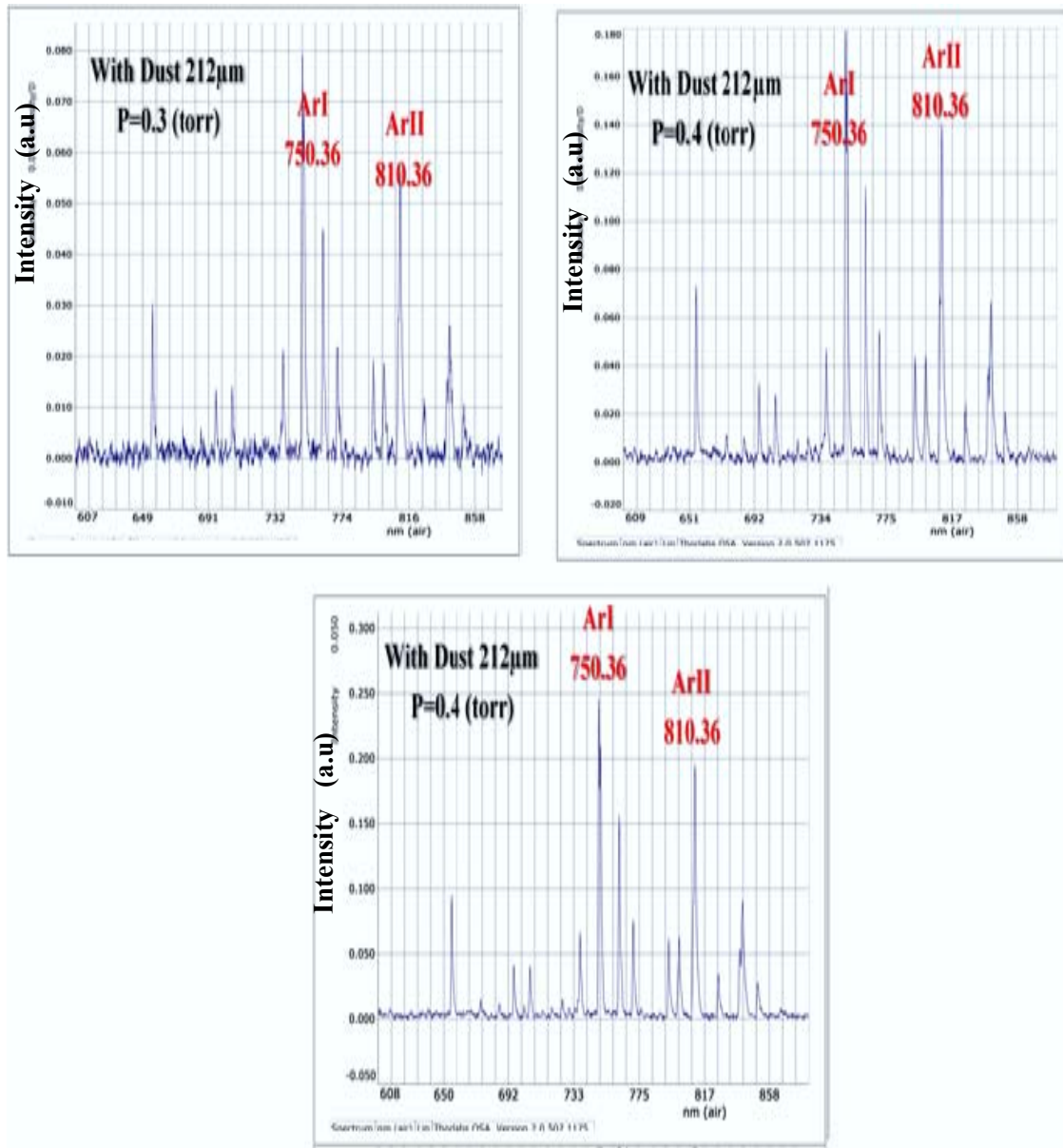
Fig.4: Influence of 212 μm Zinc dust size on typical spectrum record for Argon at different Ar pressure.

According to Figs.2, 3 and 4, the electron temperature (T_e) was determined by taking the intensity ratio of two spectral lines of the same species and ionization stage have the largest difference in their upper energy level by using the intensities of two liens excited neutral peak ArI (750.386 nm) and excited ion peak ArII (810.369 nm) and then applied Eq. (6). Fig. 5 indicated the influence of Zinc dust size on the relationship between T_e and Argon pressure.
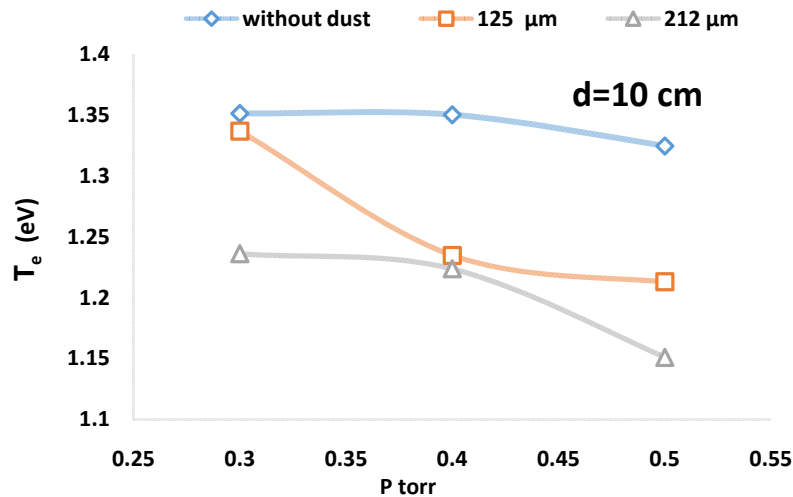
Fig.5: Influence of Zinc dust particle size on the relationship between T_e and Ar pressure as detected by OES.

It is pointed out from this figure, the electron temperature in the present and absent of Zinc dust particle is reduced with increasing of pressure. This behavior can be explained as with increasing pressure, the electron collision frequency increasing and would cause to reduce the electron energy. Another features can be noted from Fig. 5, when the Zinc dust particles immersed in discharge, the electron temperature decrease (which decreasing further with increasing of Zinc dust size). This decreasing of T_e with increasing of Zinc dust size attributed to increasing of electron collision with neutral particle and zinc dust particles which lead to reduce the electron energy.

The excitation temperature (T_{ex}) was calculated using the Boltzmann plot method, the logarithmic term of Eq.(4) yields a straight line the inverse slope of this line represented T_{ex}. This method required peaks that originate from the same atomic species and the same ionization stage. These peaks are taken form typical spectrum that plotted in Fig. 2, 3 and 4 with peak information that listed in Table 1, The T_{ex} was calculated, by using Eq. (4) and substitute values of A, E and g from Table 1, the influence of zinc dust size on the relationship between T_{ex} and Ar pressure is plotted in Fig. 6.

Table 1: Spectroscopic parameters of ArI lines used for OES diagnostic (from the NIST standard data) [9].

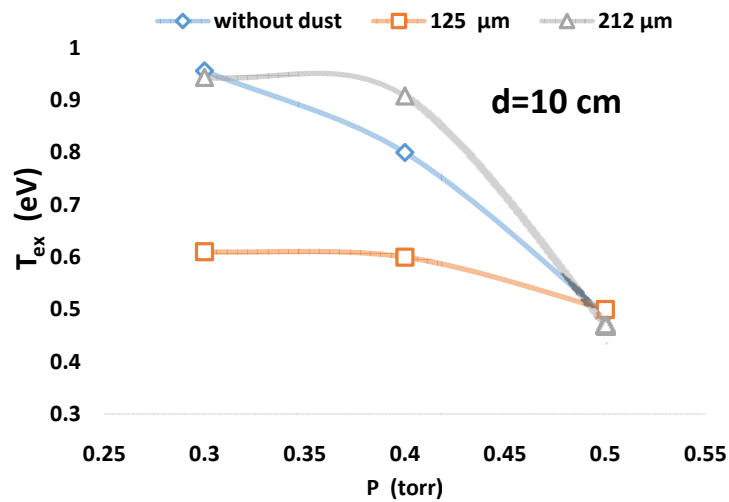| λ nm	A_{ij} (s^{-1})	E_k (cm^{-1})	E_k (eV)	g_k
696.5431	6.39E+06	107496.4	13.32751	3
750.3868	4.45E+07	108722.7	13.47954	1
763.5106	2.45E+07	106237.6	13.17144	5
772.3761	5.18E+06	106087.3	13.1528	3
794.8176	1.86E+07	107131.7	13.2823	3
801.4786	9.28E+06	105617.3	13.09453	5
826.4522	1.53E+07	107496.4	13.32751	3
840.821	2.23E+07	107289.7	13.30188	5

Fig.6: Influence of Zinc dust particle size on the relationship between T_{ex} and Ar pressures as detected by OES.

Several points can be observed from this figure, T_{ex} is reduces with increasing of Ar pressure in present and absent of zinc dust particles. The present of Zinc dust particles reduce the T_{ex} of Ar. The increasing of electron collision with increasing of Ar gas pressure in the present and absent of zinc dust particles is responsible for the decreasing of $T_{ex.}$ While the collision of electron with dust particle is responsible for the reducing of electron energy in the present of dust.[12].

In addition to the above plasma parameter that measured by OES method, the electron density (n_e) was calculated by using Saha-Boltizman equation (Eq. (5)) in the present and absent of zinc dust size particles. The result of this equation is plotted in Fig.7.
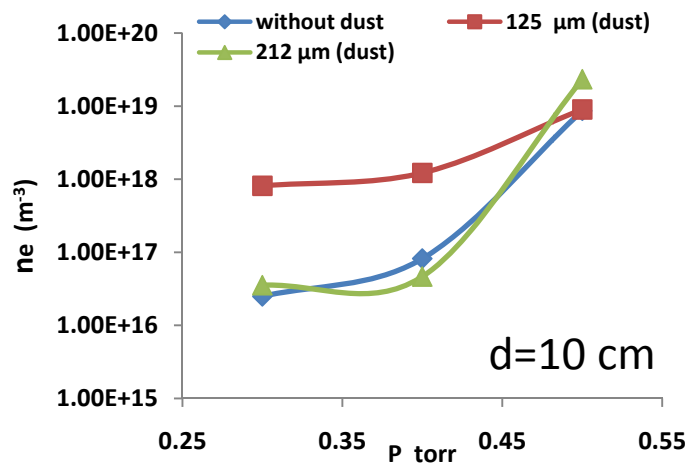

Fig.7: Effect of Zinc dust particle size on the electron density at different Ar pressure.

The result shows that, the electron density is increasing with Ar pressure in the present and absent of zinc dust size particles. The increasing of electron collisions with Ar atoms due to the increasing of Ar pressure in the present and absent of Zinc dust is responsible for this increasing of $n_e.$ Furthermore, the trend of Fig. 7 shows that the introducing of zinc dust

particlr increase the n_e. The collision of electron with dust particle is responsible for this behavior.

Conclusions

In this paper, the effects of gas pressure and zinc dust particle on the AC discharge characteristics are studied. The results indicated the fact that the immersed of zinc dust particle into the discharge plasma column have influence on the discharge characteristics. Where the excitation electron temperature and electron temperature are reduce in the present of zinc dust particles size. On the other hand, the calculated electron density is increased when zinc dust particles are introduced to the discharge at different rate depends on the dust particles size.

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