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Collection Efficiency Models of precipitator industry

نماذج كفاءة الترسيب في المرسبات الصناعية

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Abstract

The cement industry is one of the primary producers of carbon dioxide, which is a major greenhouse gases. Electrostatic precipitators (ESPs) are common installations on coal-fired cement plants to remove over 99% of ash particles, typical efficiency of ESP as a function of geometrical and operation factors. In this paper investigation revealed a simple model, developing the Deutsch collection theory .The model evaluate the collection efficiency of ESP in cement plants depends on two operations factors, applied voltage and current density. The effects of the gap between collection-plates and discharge-wires on collection efficiency were studied.

الخلاصة

صناعة السمنت واحده من المنتجين الرئيسين لثاني اوكسيد الكاربون،الذي يعتبر من الغازات الرئيسيه للبيت الزجاجي. المرسبات الاليكتروستاتكيه من المعدات الشائعة تستخدم لازالة 99% من جسيمات الغبار الناتجة من احتراق الوقود في معامل السمنت،تعتمد الكفاءة النموذجية للمرسبات الاليكتروستاتيكية على العوامل الهندسية والتشغيلية.في هذا البحث ،تم تحقيق انموذج بسيط بتطوير نظرية ترسيبDeutsch .تم حساب كفاءة الترسيب للمرسب في معامل السمنت بالاعتماد على عاملين الفولتية المطبقة وكثافة التيار. درست تاثير المسافة بين اسلاك التفريغ والواح التجميع على كفاءة الترسيب

1-Introduction

Cement is a basic material for building and civil engineering construction. Output from the cement industry is directly related to the state of the construction business in general and therefore tracks the overall economic situation closely. It is necessary to operate the precipitator at high voltage and provide it with enough power to produce high corona current and obtain higher collection efficiencies.It was found that the collection efficiency is proportional to the applied voltage and the precipitator current[1].There are many investigations about the collection efficiency of ESP in addition to prior studies [1-4]. Giorgio Dinelli *et al.* [5] studied the efficiency of ESP in thermal power plants burning coal and proved that the required efficiency can be increased by increasing the size of the ESP, this may represent a critical factor in the retrofitting of old plants. This can be achieved by using an impulse voltage DC instead of AC rectified voltage to the ESP, which may lead to increase the collection efficiency. The results showed that impulse energization works to ensure collection efficiency from 99.6 to 99.9%, and reduction in absorbed power from about 0.5 to about 0.1.Jeong-Ho Park and Chung-Hwan Chun [6] studied the influence of turbulent dispersion coefficient due to negative corona on the performance of ESPs and used a numerical solution of the convection or diffusion equation to investigate the transport of charged particles in an ESP for various particle sizes. It is found that the increase of turbulent dispersion coefficient leads to decrease of particle concentration and increase of turbulent dispersion coefficient gradient near the collecting wall. Therefore, increment of turbulent dispersion coefficient appears as negative effect on the collection of large particle and positive for small particle.

Gabriel Nicolae Popa *et al.* [7] analyzed the collection efficiency of ESP with three sections with different factors such as voltage supplies of ESP sections, the gas particles distributions, average (V-I) curves, onset corona voltage, spark discharge voltage, current density, collection efficiency, the inlet and the outlet dust concentration for different energization of sections. It was found that the collection efficiency of ESP depends on voltage waveforms, among other factors and it is necessary to supply with different shapes voltage from section to section depending on dust resistivity to obtain high collection efficiency.

Sunil J. Kulkarni and Pallavi M.Kherde [8] illustrated that High frequency high voltage power supply(HF HV) reduces emission two times in controlled conditions while increasing energy efficiency of the precipitator, the collection efficiency increased at higher pulse frequency. Non thermal plasma can be used to agglomerate small particles in order to increase collection efficiency. It can be concluded that the conventional ESPs and the collection methods can be modified in order to improve efficiency and economy. [9] In addition, the best collection efficiency can be achieved when the wire-wire distance is different from the wire-plate spacing.

The aim of this work, a mathematical model is developed for computing collection efficiency of precipitator industry due to applied voltage and current density(operation parameters),also using new parameters (wire-plate distance) in Deutsch-Anderson Equation in order to explain the effects of this geometrical factor on efficiency.

Input data of ESP in Babylon and Kerbala cement plants are considered as a field of the study. Southern cement state company supported the input data (geometrical parameters) of ESP for Kerbala cement plant and Babylon.

2-Theoretical Part

Current density plays important role in estimations the collection efficiency of ESP, in order to evaluate its values interelectrode region of ESP. Finite Difference Method (FDM) used as a technique to solve governing equations (Poisson and current continuity equations) with suitable boundary conditions about the ESP configuration (see fig.1), computing current density employed Fortran program to predict the collection efficiency without using migration velocity.

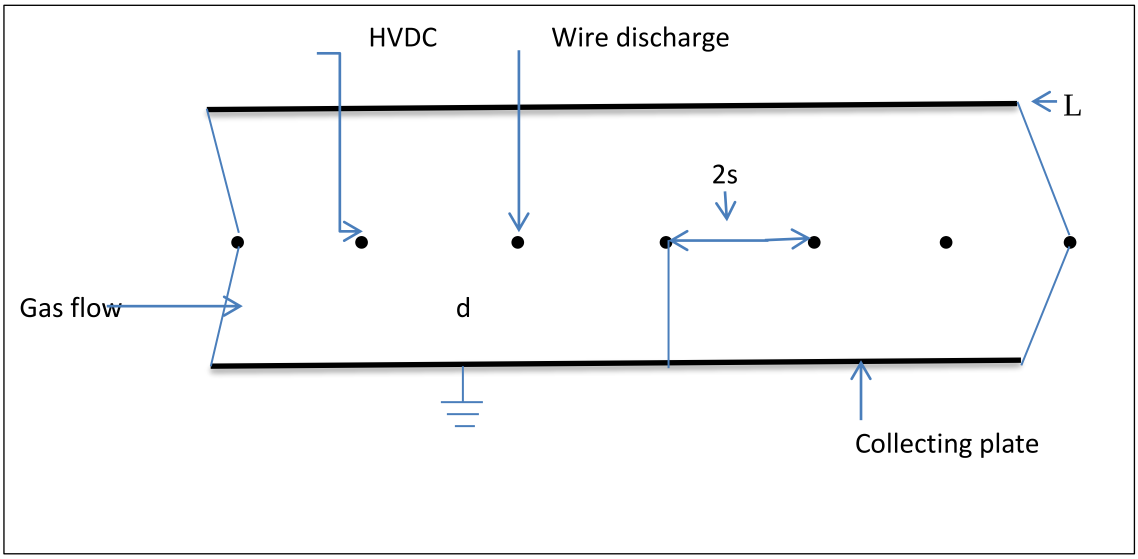

Fig.(1)Electrostatic precipitator configuration

HVDC = applied voltage, d = half distance of collecting-plate separation distance, 2d = plate width, L = plate length,2s =distance between two wires discharge

2-1Migration Velocity

Migration velocity, *we*, is the velocity that a negatively charged particle in the inter-electrode space moves along the electric field lines towards the collecting plate [10]. The particle migration velocity for larger particles depends on the strength of the electric fields (charging and collection fields), the viscosity of the gas and also proportional to the particle size [11]. Therefore, when the particle size of about 0.3 - 0.5 μm in diameter, the particle migration velocity is usually at a minimum value. In other words, the migration velocity of the particle will increase with particle size. It was found that, the migration velocities for dust particles in ESPs are substantially lower than the carrier gas flow velocity. Ignoring the Cunningham correction factor (factor depends on particle size), the migration velocity for field charging is given by [9]:

$$\omega_e = a\frac{E_c^2}{2\pi\mu} \qquad (1)$$

Where

ω_e = the migration velocity (m/s) , μ is the viscosity (kg/m.s)

E_c = the collector electric field, which is given by

$$E_c = \frac{u}{L}$$

u is applied voltage and L is collective-plate length

From the above equations it can be said that the larger particles are more easily collected than the smaller ones because of their Brownian motion smaller particles, when diffusion charging is dominated .Also it was indicated that to achieve maximum collection efficiency in an ESP the unit must be operate at high voltages. The particles whose sizes between 0.2 to 0.8 μm for which neither diffusion or field charging dominate, will be difficult to collect in an ESP thereby the migration velocity becomes low [12, 13].

In wire-plate precipitators, the relation between current density and electric field is given by [9]

$$J_c = \frac{b\varepsilon_\circ u^2}{L^3} = b\varepsilon_\circ E_c^2/L \qquad (2)$$

Where

J_c = collector current density at any collector location x (A/m^2)

b= effective mobility of charge carriers (m^2/V.s)

$\varepsilon_\circ$ = the permittivity of air (A s/V m)

$$L = d[1 + 2\left(\frac{x}{d}\right)^2]^{1/2} \qquad (3)$$

d=half wire - plate distance (m)

It is possible to rewrite equation (2) in the form:

$$E_c^2 = \frac{J_c L}{b\varepsilon_\circ}$$

By substitute the value of E_c^2 into equation (1) the migration velocity can be written as:

$$w_e = aJ_cL/2\pi\mu b\varepsilon_\circ \qquad (4)$$

Equation (3) shows the linearly proportional between current density J_c and migration velocity in wire plate precipitator. It is found that the particle migration velocity is not uniform along the collector plate because the collector current density is different at different collector location x [9].

2-2 Deutsch-Anderson Equation:

The problem of collection performance in ESP for the first time was formulated by Deutsch (one of the early theoretical investigators1922). The Deutsch collection efficiency [14] is given as

$$\eta = 1 - exp\left[-(\frac{A_p}{Q})\omega\right] \quad (5)$$

Where
A_p = plate area for the ESP (m^2)
Q = the volumetric flow rate of the gas (m^3/s)
$\omega$is the migration velocity of the particles (m/s)
This equation is used to determine the collection efficiency of the precipitator under ideal conditions. This requires several assumptions [9, 13]

- A uniform distribution of the particles is at any cross section of the ESP.
- The velocity through the ESP is uniform except at the boundary layer of the collecting surface, where the flow is weak.
- The migration velocity is a constant for all particles and has not affected by the velocity of the carrier gas at a direction perpendicular to the gas flow in the thin boundary layer near the collecting surface.
- All particles arriving near the collection plate are collected.
- Neglected the effects of collision between ions and gas molecules, erosion, particle re-entrainment, uneven gas flow, or back corona.

If all of the particles were of the same size and the electrical and operating conditions were unchanged from inlet to outlet of the ESP then these assumptions above would be simple [13].

It has been found that the particle migration velocity, predicted by Deutsch's theory is different from the value based on measured collection efficiency. The Deutsch relationship includes the ESP geometry, especially the collector electrode area and take into account the gas flow through the ESP. This equation neglects three important process variables; firstly, the dust reentrainment that may occur during the rapping process. Secondly, it assumes that the particle size and the migration velocity are uniform for all particles in the gas stream. Thirdly, the gas flow rate is uniform everywhere across the precipitator and the particle sneakage through the hopper section does not occur. When the flue gas flows down through the hopper section instead of through the ESP chambers, the particle sneakage occurs and preventing particles from subjection to the electric field. Therefore, this equation must be used for making primary estimates of precipitator collection efficiency [11].

Modifying the Deutsch-Anderson equation could give more accurate estimates of collection efficiency. This is happened by replacing the effective precipitation rate, ω_e, instead of the migration velocity ω, or decreasing the calculation of collection efficiency by a factor of k, which is constant (Matts-Ohnfeldt equation).These calculations are contributed in establishing primary design parameters of ESPs [13, 11].

2-3Modified Deutsch-Anderson Equation:

Deutsch relationship was used for many years as a design tool by the precipitation industry at different industrial applications until 1960 when Matts and Ohnfeldt. derived one of the better-known modifications [15]which is given by

$$\eta = 1 - \exp[-\omega_k\,(\frac{A_p}{Q})^k] \quad (6)$$

Where
ω_k = average migration velocity (m/s)
k = a constant, usually 0.4 to 0.6

The constant k in Matts and Ohnfeldt equation can be determined depending on the standard deviation of the particle size distribution and other dust properties affecting collection efficiency which is usually between 0.4 and 0.6 but in most cases to achieve a satisfactory results it can be used a value of k equal to 0.5. The Matts-Ohnfeldt equation becomes the same as the Deutsch-Anderson when the value of k equal 1. Lower values of k help in predicted the collection efficiency of an existing ESP when the gas flow rate is varied and gives more convenient results.

In 1982, Dr. Harry White proposed modifying the Deutsch-Anderson equation to make it more accurate in cases where all particles are not uniform in size through using the effective precipitation rate ω_e instead of migration velocity ω in the equation [16]

$$\eta = 1 - \exp(-\frac{\omega_e A_p}{Q}) \qquad (7)$$

To achieve a specified collection efficiency it can be used the effective precipitation rate ω_e, which represents a semi-empirical parameter and refers to the average speed at which all particles in the entire dust mass move toward the collection plate, to determine the total collection area necessary for an ESP. It is worth noting that there are other operating parameters, in addition to collection area, play a major role in determining the efficiency of an ESP.

The terms ω_k and ω_e in equations (6) and (7) both are similar and represent average migration velocities.

The ratio A_P/Q in equations (5, 6, and 7) is called the specific collecting area (SCA) which plays an important role in determining the precipitator efficiency. Specific collecting area (SCA) is defined as the ratio of collection surface area to the gas flow rate into the collector and used as parameter to compare ESPs and estimate their collection efficiency. It is often expressed as $m^2/(m^3/s)$. Increases in the SCA of a precipitator design will increase the collection efficiency of the precipitator depending on precipitator design conditions and required collection efficiency. Practically, SCA is widely used to describe an ESP that it is included as a separate variable [9].

2-4Developing Deutsch collection formula

In order to study the effects of wire-plate distance on collection efficiency of ESP and specified of Deutsch collection formula for constrain applications, also the data of the migration velocity which published in literatures are in wide range of values such as for cement plants(1.5-1.8)cm/s at 300 $^\circ$F [17]. Therefor substituted equation (4) in (5) obtained collection efficiency equation

$$\eta = 1 - \exp[-\left(\frac{aLJ_c}{2\pi\mu b\varepsilon_\circ}\right)(\frac{A_p}{Q})]$$

$$\eta = 1 - \exp[-K_c a(\frac{L}{d})J_c] \qquad (8)$$

$$K_c = \frac{\left(\frac{A_P}{Q}\right)\left(\frac{1}{b\varepsilon_\circ}\right)}{2\pi\mu} \qquad (9)$$

Where

K_c = a constant for a given particle size of radius a

FORTRAN program in FORTRAN language is used to solve eqs.(3, 9and 8) alternately for calculating collection efficiency at different values of wire-plate distance ,input data particle radius 1×10^{-6} ,ionic mobility 2×10^{-4} $m^2/V.s$, permittivity of air 8.85×10^{-12} A s/V m, viscosity 1.81×10^{-5} kg/m .s , A_P/Q=177

3-Results and Discussion

Wire-plate distance is important factor in design ESP, and then introduced theoretical study for effects of its factor on collection efficiency contribute in diagnostic air pollution problem .Cement manufacture distributed in the world, also in Iraq. (ESP) has been used for the control of toxic particles which were emission from many industrial fields, ESP parameters for Kerbala and Babylon cement plants are used as input data in this study. There are many factors can be effect on collection efficiency and giving rise to change it positively, the half distance wire-wire (s) ,particle radius (a),mobility of negative ion (b)and radius of discharge wire (r) are constant for models.

A-Effect of applied voltage

Figure (2) shows the relation between the collection efficiency and the applied voltage in the wire-duct ESP of Babylon cement plant. It is clear that efficiency increases with increase voltage and get high efficiency 99.99 at 98.957 kV with input data as geometrical and operation factors of ESP in Babylon cement plant. Figure (3) also shows the relation between the collection efficiency and the applied voltage but for input data of ESP in Kerbala cement plant, the high collection efficiency 99.99 investigate at 83.699 kV

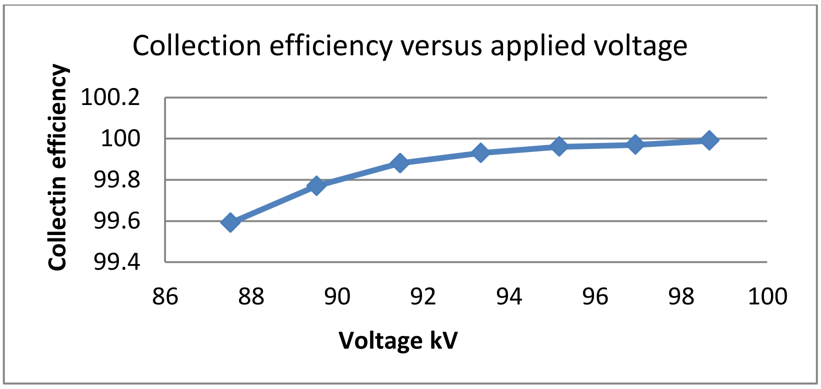

Fig. (2) Babylon cement plant, Input data: r =1mm, d = 0.18 m, s =0.25 m, b=2×10^{-4} m ^{2}/V.s, a = 1×10^{-6} m, Jc = 0.228 ×10 $^{-4}$A/m^{2}.

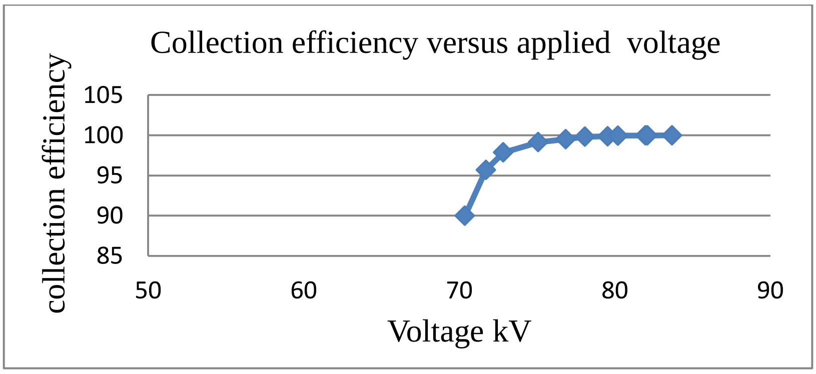

Fig. (3) Input data for Kerbala cement plant, r =1mm, d= 0.15 m, s =0.15 m, b=2×10^{-4} m ^{2}/V.s, a = 1×10^{-6} m, J_c = 2.84 ×10 $^{-4}$A/m^{2}.

B-Effect of Current density:

It is quite clear from figures (4&5) that collection efficiency increase with increasing current density for a given applied voltage, because higher current imparts a greater charge to the particles and increases the ionic contribution to the electric field. The efficiency reaches its greatest value (99.9%) when current density becomes (2.28×10^{-4} and 2.84) A/m^2 for input data of ESP at Babylon cement plant and Kerbala cement plant respectively.

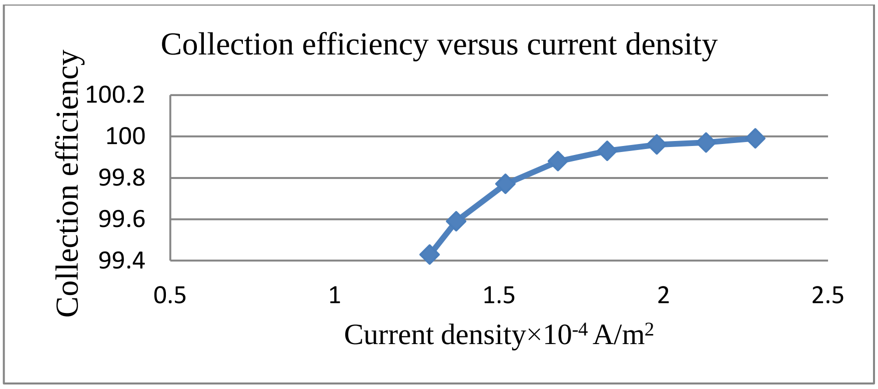

Fig. (4) Babylon cement plant, Input data: r =1mm, d = 0.18 m, s =0.25 m, $b=2\times10^{-4}$ m ^{2}/V.s, $a = 1\times10^{-6}$ m, u = 45 kV.

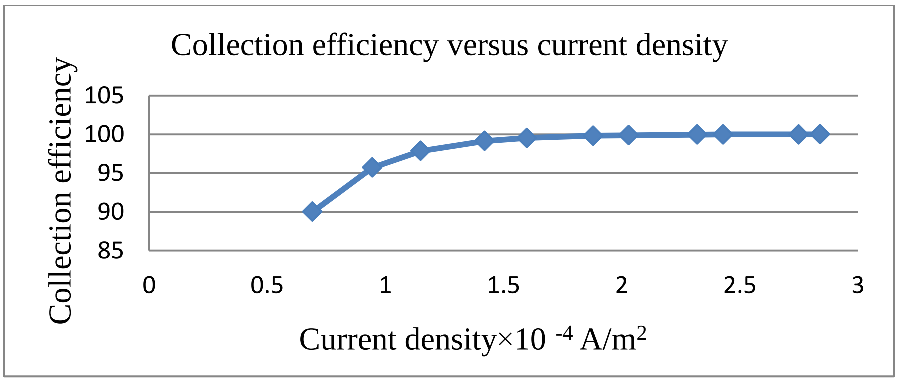

Fig.(5) Input data for Kerbala cement plant, r =1mm, d= 0.15 m, s =0.15 m, $b=2\times10^{-4}$ m ^{2}/V.s, $a = 1\times10^{-6}$ m, u = 45kV.

C- Effect of wire-plate distance on collection efficiency at different values of applied voltage

because of the wire-plate distance determine the width of duct in ESP (Fig.1) and the concentration of dust passes through it, the collection efficiency directly depends on it Figs.(6&7)show effects of decreasing or increasing this factor on collection efficiency. It is evident from fig.6 there is no increase in applied voltage (98.667 kV) at d=0.15m in comparison with (98.957 kV) at d=0.18m (fig.2) to get high efficiency 99.99, but increase in applied voltage (104.337 kV) in fig. (7), therefor d=0.15 better than d=0.18 give the same efficiency at the same applied voltage and small size of ESP.

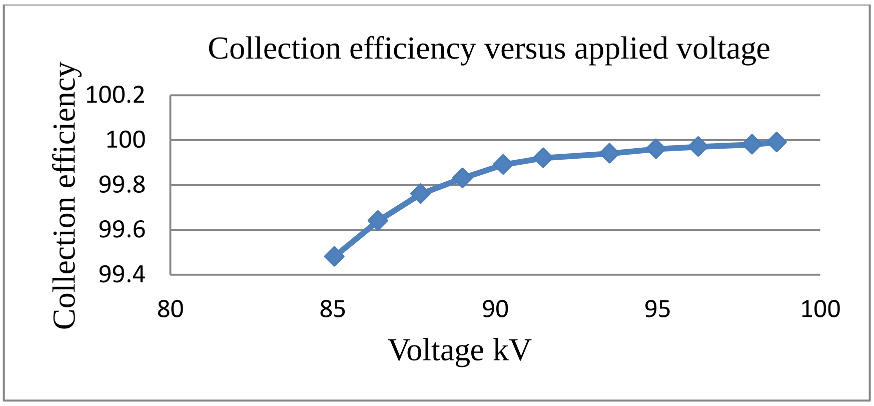

Fig. (6) Babylon cement plant, input data r =1mm, d = 0.15 m, s =0.25 m, b=2×10^{-4} m ^{2}/V.s, a = 1×10^{-6} m, Jc = 0.278 ×10 $^{-4}$A/m^{2}.

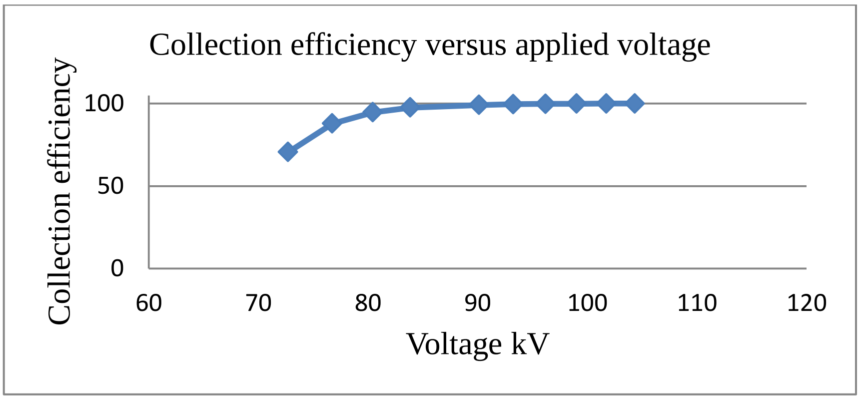

Fig. (7) Babylon cement plant, input data r =1mm, d = 0.21 m, s =0.25 m, b=2×10^{-4} m ^{2}/V.s, a = 1×10^{-6} m, Jc = 1.18 ×10 $^{-4}$A/m^{2}.

Figs.(8&9) show the same behavior of efficiency of input data of ESP in Kerbala cement plant when the wire-plate distance was changed ,for d=0.10m the applied voltage is 76.191 kV and efficiency is 99.96,for d=0.20 m the applied voltage is 91.162 kV and efficiency is 99.99,the comparison with fig.(3)illustrated that d=0.10m is better than d=0.15m in consume energy and less size of ESP.

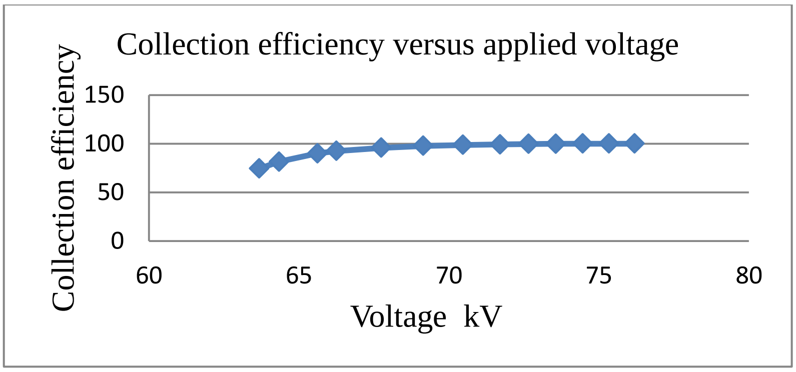

Fig. (8) Kerbala cement plant, input data r =1mm, d = 0.10 m, s =0.25 m, b=2×10^{-4} m ^{2}/V.s, a = 1×10^{-6} m, Jc = 3.44 ×10 $^{-4}$A/m^{2}.

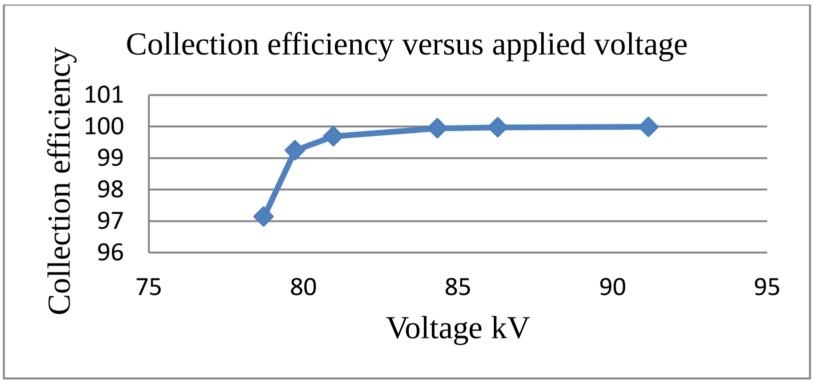

Fig. (9) Kerbala cement plant, input data r =1mm, d = 0.20 m, s =0.25 m, $b=2\times10^{-4}$ m ^{2}/V.s, a = 1×10^{-6} m, Jc = 2.23 $\times10^{-4}$A/m^2.

D- Effect of wire-plate distance on collection efficiency at different values of current density

Current density at interelectrode region in ESP is necessary for charging toxic particle which inlet ESP then chooses adequate wire-plate distance introduced high current density .figs(10&11)show the effects of factor (d) on current density of ESP in Babylon cement plant ,it is clear that high efficiency 99.99 satisfy at 2.74×10^{-4} A/m^2 for d=0.15m and current density is 1.95×10^{-4} A/m^2 for d=0.21m .In the same way the influence of factor d on current density of ESP in Kerbala cement plant illustrated in figs.(12&13),high efficiency 99.99 investigates at current density 2.23×10^{-4} A/m^2 in case of d=0.20m and the efficiency reaches 99.96 value for current density3.44×10^{-4} A/m^2 for d=0.10 m,it is evident from figs(10,11,12,13) that the convenient wire-plate distance of ESP in Babylon cement plant is d=15m and ESP in Kerbala cement plant is d=0.10m.

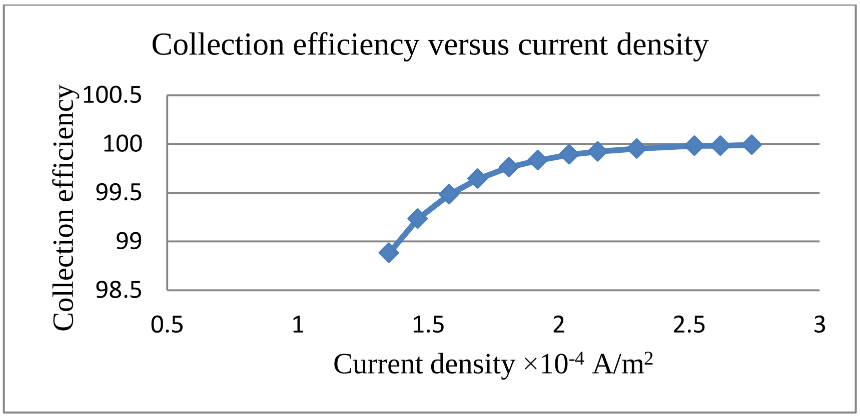

Fig. (10) Babylon cement plant, input data r =1mm, d = 0.15 m, s =0.25 m, $b=2\times10^{-4}$ m ^{2}/V.s, a = 1×10^{-6} m, u = 45kV.

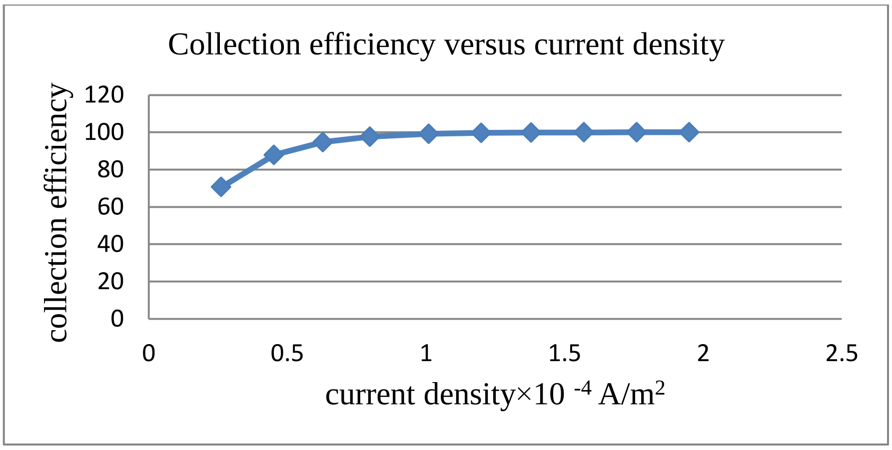

Fig. (11) Babylon cement plant, input data r =1mm, d = 0.21 m, s =0.25 m, $b=2\times10^{-4}\ m^2/V.s$, $a = 1\times10^{-6}$ m, u = 91.162kV.

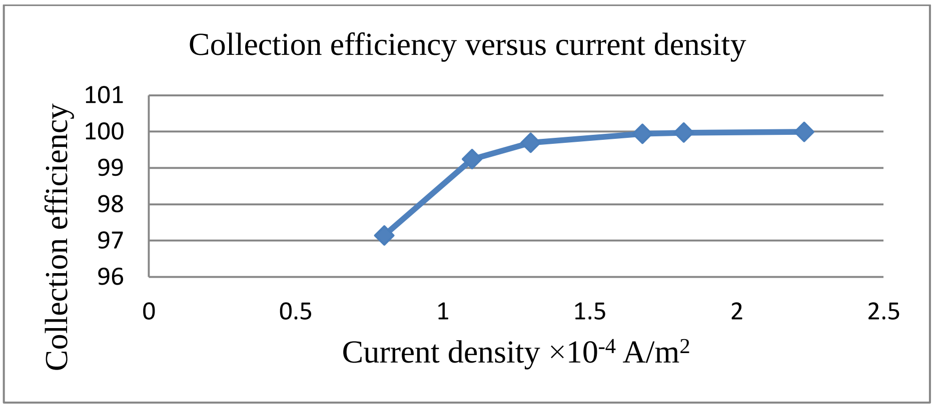

Fig. (12) Kerbala cement plant, input data r =1mm, d = 0.20 m, s =0.25 m, $b=2\times10^{-4}\ m^2/V.s$, $a = 1\times10^{-6}$ m, u = 45kV.

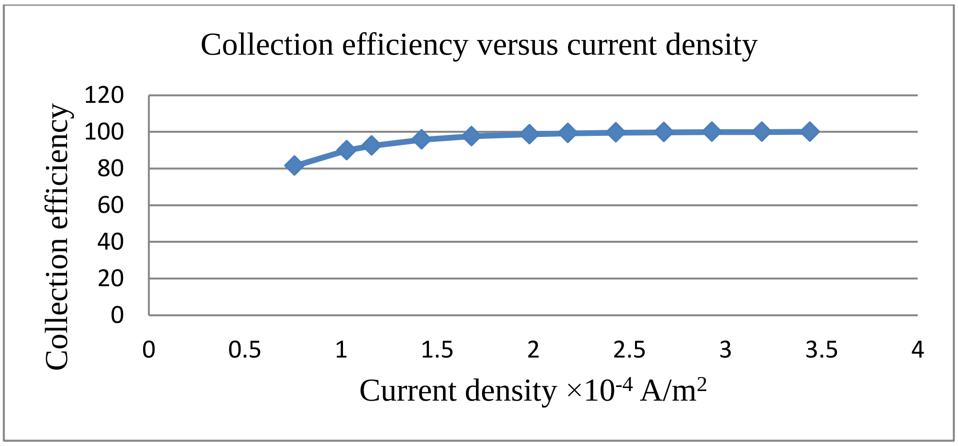

Fig. (13) Kerbala cement plant, input data r =1mm, d = 0.10 m, s =0.25 m, $b=2\times10^{-4}\ m^2/V.s$, $a = 1\times10^{-6}$ m, u = 76.191kV.

4-Conclusion

The model which presented in this work can be used for other ESP configurations in determining the collection efficiency. It has been shown, that a new wire-plate distance (d=0.15m) for ESP of Babylon cement plant is suitable for getting high collection with consume less energy and small size and increasing current density contributed in charging toxic particle which inlet ESP, also the same result for ESP of kerbala cement plant for wire-plate distance (d=0.10m).

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