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Study of Diesel Soot Particle Emission Control by Theoretical Modelling Of Electro Cyclone Separator

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ABSTRACT
This paper describes possibilities to separate particles with difficult dust properties from gases. Difficult dust properties are related to extreme values of particle size and shape and to the flow ability, the adhesion properties or the reactivity of the particles. Special emphasis is given to submicron particles. In cyclones, conductive particles such as diesel soot can be removed by means of additional electrostatic forces.[2]The separative performance of a cyclone can be enhanced if electrical forces are employed to supplement the inertial forces. By precharging the particles and applying a radial electric field within the cyclone, collection efficiency is improved. In the present paper, a model is developed for such an electrostatically augmented cyclone. The model assumes that turbulence promotes complete radial mixing within each of three regions: the entrance region, the down flow region and the core (or up flow) region. Based on this model, an analytic expression for the collection efficiency of cyclone separators is developed. Several solutions have been proposed to date like ceramic filtration, wire mesh filtration, direct contact type filtration systems etc., which suffer from high engineering complexity, high costs as well as increased backpressure. Most of the proposed solutions deteriorate diesel engine combustion performance and simultaneously increases fuel consumptions. This paper presents the electrostatic attraction of ultra fine diesel soot particulate matter for exhaust gas treatment and the theoretical modelling of effect of collection efficiency of ultra fine particulate matter emitted from diesel engine exhaust gas through an electro-cyclone and other operating parameters i.e. applied voltage, flow rate, the particle parameters like particle size, shape and dielectric properties, exhaust gas density, viscosity on the performance of electro cyclone separator as a Diesel Soot Particulate Emission Arrester[4].

Keywords: Diesel soot particulate, Electro-cyclone Separator, Viscosity, Density, Applied voltage.

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I. INTRODUCTION

An Electro cyclone is an inertial separator used to separate medium sized and coarse particles emitted from power plants, cement industries etc. And it is a device which incorporates electrostatic technology into a cyclone. Electro-cyclone separator having a two phase, three dimensional, swirling turbulent flow with free outer vortex (irrotational flow) [2]and forced inner vortex (solid body rotation) is a complex flow device combined with induced electric field. By applying the high voltage electric field in the cyclone, the electrostatic force is incorporated into the centrifugal force so that the efficiency of operation can be enhanced .The technology of the combination of the cyclone, electrostatic attraction has been applied in exhaust gas treatment. The significant increases of collecting efficiency of electro-cyclone with the help of electrostatic attraction have been demonstrated. Controlling diesel engine emission is one of the most important aspects of air pollution control Process for diesel soot particulate emission separation using continuous application of induced electric field inside the cyclone wall of electro-cyclone separator, presents a simple construction which produces low back pressure and reasonably high particulate collection efficiencies. The reduction of particulate emissions from diesel engine is one of the most challenging problems in modern society. Arresting of diesel soot particulate matter emitted from diesel engine exhaust reduces the DPM formation and thus keeps the environment clean. Many systems are currently being considered for the control of emissions of particulate matter by diesel engine. Of these, the most extensively researched are on the cyclone separator and electro-cyclone separator.

II. ELECTROCYCLONE SEPARATOR

The electro cyclone concept is a synthesis of cyclone and electrostatic precipitator. By applying the high voltage electric field in the cyclone, the electrostatic force is incorporated into the centrifugal force so that the efficiency of operation can be enhanced. A principal advantage of the electro cyclone is that a large diameter unit can be built to give the same efficiency as a small conventional cyclone. The clean air is provided by an axial flow separator/ electrostatic charger device positioned in the exhaust duct of an upstream cyclone. This axial flow component uses a high-voltage corona electrode to charge the dust particles and improve the separation efficiency. The vortex field in the axial flow component is provided by the swirling motion naturally present in the exhaust of a conventional reverse flow cyclone. Within the electro cyclone the separation of dust is strongly augmented by another high-voltage field applied with an electrode along the axis of the cyclone.

In cyclone, cut diameter is defined as the diameter of a particle for which the efficiency cure has the value of 0.5, i.e. 50%. Cut diameter is one of the important indexes for evaluating dust performance in a cyclone separator. The smaller the cut diameter in a cyclone separator, the better is its dust performance.

III. WORKING PRINCIPLE

This paper presents the electrostatic attraction of ultra fine diesel soot particulate matter for exhaust gas treatment and the theoretical modelling of effect of collection efficiency of ultra fine particulate matter emitted from diesel engine exhaust gas through an electro-cyclone and other operating parameters i.e. applied voltage, flow rate, the particle parameters like particle size, shape and dielectric properties, exhaust gas density, viscosity on the performance of electro cyclone separator as a Diesel Soot Particulate Emission Arrester .An electro cyclone is a centrifugal separator as well as electrostatic separator in which particles, due to their mass, are pushed to the outer edges as a result of centrifugal force. Incoming air is automatically forced to adopt a fast-revolving spiral movement - the so-called double vortex". This double spiral movement consists of an outer stream, which flows downwards in a spiral, and an inner stream, which flows upwards in a spiral. At the interchange between both streams, air passes from one stream to the other. The particles which are present in the air are forced to the outer edges and leave the separator via a collection device fitted to the bottom of the separator. The air speed of a cyclone lies between 6and 15 m/s, and the most common speed is ca. 9 m/s. If there are fluctuations in speed (with lower speeds), separation yield falls quite drastically. Beside this centrifugal action due to the electrode high voltage is generated in the electro cyclone separator and by the electro static precipitation action we can also separate soot particles from engine exhaust gas.

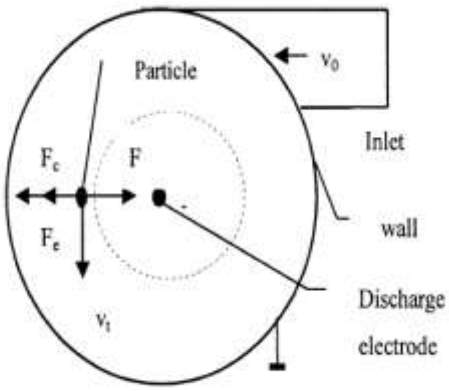
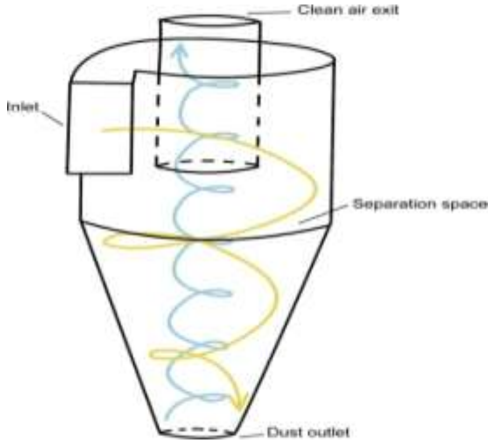


Fig. 1. The forces acting on a particle in an electrocyclone.

IV. OBJECTIVE

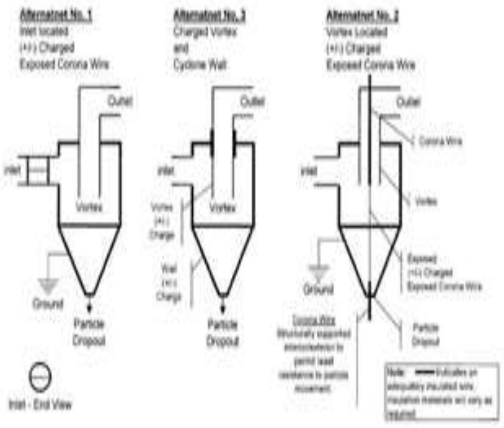
The objective of this research is to develop a low cost particulate cleanup device capable of operating at very high temperature for synthesis gas cleanup, occurring after the burning of charged particles. This research is aimed at making clean gas from the vehicular emission by reducing the enormous costs associated with hot gas clean up. To achieve this objective an electrostatic cyclonic separator was designed, which is capable of concentrating particulate matter from very high temperature gas streams into small slip streams thus enabling the bulk gas to flow particulate free through the outlet. The focus of the research was to develop an electro cyclone as a proof of concept model and to quantify the collection efficiency at the slip stream with and without the use of voltage. In order to achieve this, two sets of experiments were performed as follows.

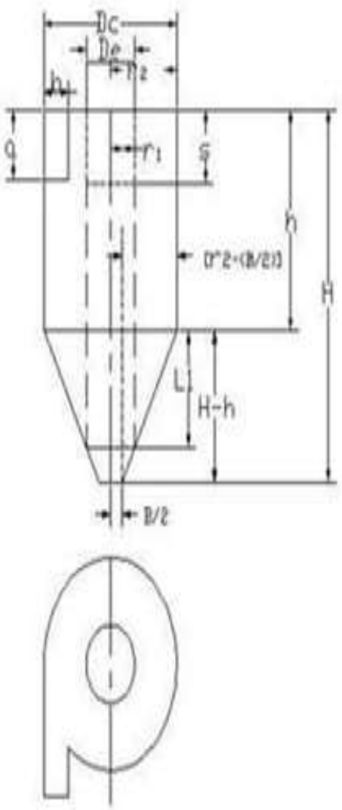


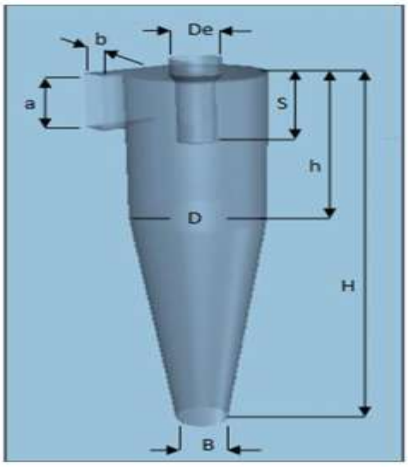
V. DESIGN

A standard design cyclone with a tangential inlet in which (at the outlet tube level) an electric field is generated in the space between an external wall and the central outlet pipe, is considered. There are three alternative by which electrical field is added to a cyclone

1. Inlet located charged corona wire
2. Charged vortex and cyclone wall
3. Vortex located charged exposed corona wire







VI. STANDARD GROMETRICAL DESIGN

Source	Stairmand	Swift	Lapple
D	1	1	1
a/D	0.5	0.44	0.5
b/D	0.2	0.21	0.25
De/D	0.5	0.4	0.5
S/D	0.5	0.5	0.625
h/D	1.5	1.4	1
H/D	4	3.9	4
B/D	0.375	0.4	0.25

VII. THEORITICAL MODELLING

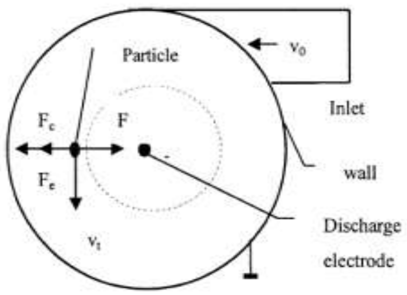


Fig. 1. The forces acting on a particle in an electrocyclone.

Centrifugal force ,

$$F_c = \frac{mpVt^2}{r}$$

If the diameter of the particle is dp and density of the particle is ρ_p then equation become[2],

$$F_c = \frac{\frac{\pi}{6} d_p{}^3 \rho_p V^2{}_t}{r}$$
……………………………………(1)

The electric field in the collecting zone produces a force on a particle proportional to the magnitude of the field and to the particle charge:

$$F_e = q_{es} E$$
………………………………………(2)

$$F_e = q_{es} \frac{V}{r}$$

The charge on particle grows with time, reaching a steady state value of,

$$q_{es} = \frac{3K}{k} + 2\pi\varepsilon_0 d_p E$$

slip correction factor for molecular slip can be calculated as,

$$C^* = 1 + \frac{2\gamma}{d_p}(1.257 + 0.4\, e^{\frac{-0.55\, d_p}{\gamma}})$$

Where,

$$\gamma = \frac{\mu}{0.449\, \rho u}$$

$$u = \sqrt{\frac{8Ru}{\pi M}}$$

Where C* = Cunningham's Correction Factor
ū = Mean molecular velocity of the particle
μ= Dynamic viscosity of diesel engine exhaust

$$F_d = \{3\pi\mu d_p (V_r - V_{gr})\}/C^*$$

Radial gas velocity will be assumed to be negligible

$$F_d = \{3\pi\mu d_p (V_r)\}/C^*$$

Vr can be written as,

$$F_d = \left\{3\pi\mu d_p (\frac{d_r}{d_t})\right\}/C^*$$
……………………………………(3)

The Electric force is proportional to the product of particle charge and the strength of the electrostatic field. The movement of a particle is determined by the balance of the centrifugal force, the drag force and the electric force.

$$F_C + F_e = F_d$$
………………………………………(4)

Putting the value of equation 1,2 and 3 in equation 4 we finally get,

$$2\{\pi\rho_p V_t{}^2 d_p{}^3 C^* + 6q_{es} C^* V\} Z_0 = 18\mu d_p Q$$

according to Stairm and model (Q = abV_{in}),

$$2\{\pi\rho_p V_t{}^2 d_p{}^3 C^* + 6q_{es} C^* V\} Z_0 = 18\mu d_p (abV_{in})$$

Z_0 is the vortex length ,also known as electro-cyclone effective length which is taken three times of the diameter of electro cyclone separator,

$$Z_0 = 3D_c$$

$$6\{\pi\rho_p V_t{}^2 d_p{}^3 C^* + 6q_{es} C^* V\} D_c = 18\mu d_p (abV_{in})$$

$$\{2.25\pi\rho_p V_{in}{}^2 d_p{}^3 C^* + 6q_{es} C^* V\} D_c = 3\mu d_p (abV_{in})$$

$$\mathbf{(6.75\pi\rho_p V_{in}{}^2 D_c C^*) d_p{}^3 - d_p (9\mu ab V_{in}) + 18 q_{es} C^* V D_c = 0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This is a cubic equation of and it can be solved by Cardon's method. Since the discriminate of the roots is < 0, therefore we may get one real value of and other two imaginary values. Neglecting the imaginary values we get $d_{p_{50}}$ imaginary values we get $d_{p_{50}}$.

VIII. EFFICIENCY

Particle collection efficiency η, is defined as the percentage of particles in number collected by the electro cyclone over the total number of particles entering the electro cyclone separator.[6] Lapple (1950) found a correlation between the collection efficiency and $\frac{D_{p50}}{D_p}$,which wasshown by Theodore and Depaola (1980).

$$\eta = \frac{1}{1 + (\frac{D_{p50}}{D_p})^2}$$

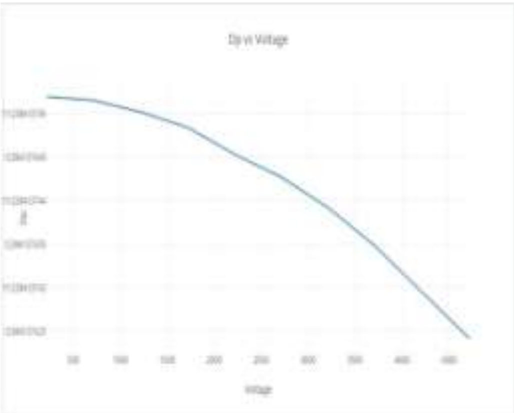
IX. PARAMETERS

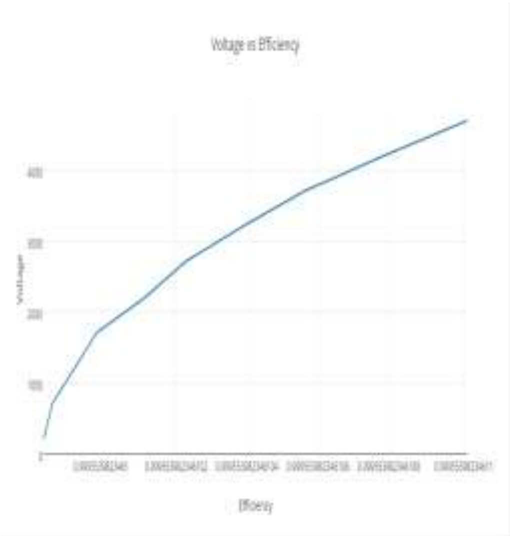
Parameter	Value(S. I. UNIT)	Reference
Density of soot particle	1600-2000	Muntean (1990)
Volume flow rate	0.02-0.40	Mayer (1995)
Diameter of the soot particle	0.1-1	Dementhon Martin (1997)
Dynamic viscosity	(1-10) micron	Dementhon Martin (1997)
Cunning ham correction factor	3.187	

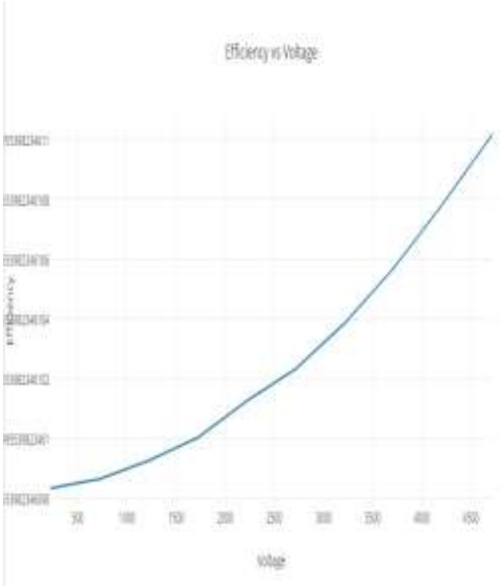
X. TABLE AND GRAPHS

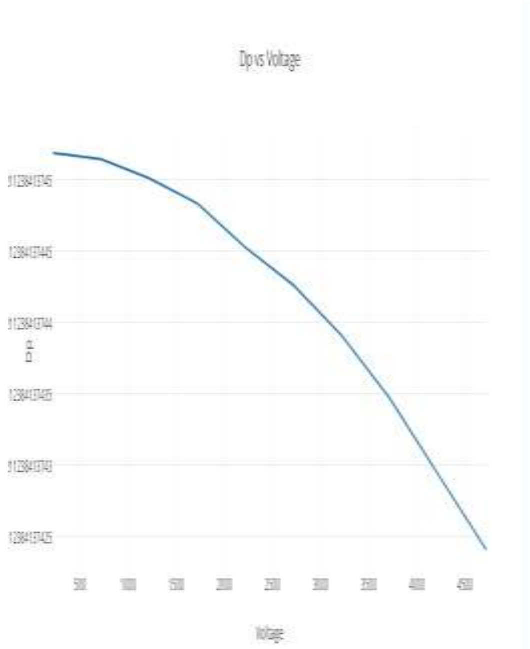
Iteration	Voltage	Root	Efficiency
1	220	0.0021123841374518513	0.9995539823460984
2	720	0.0021123841374514093	0.9995539823460986
3	1220	0.002112384137450084	0.9995539823460993

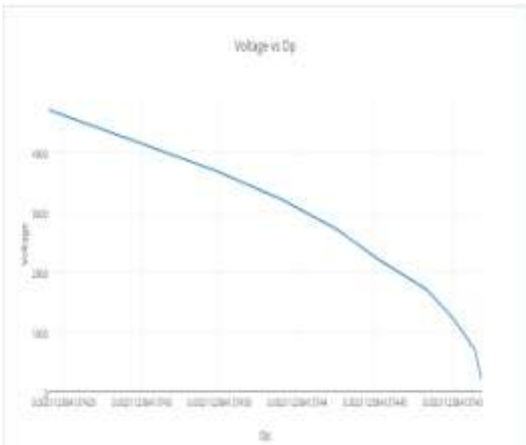
4	**1720**	**0.0021123841 37448317**	**0.99955398 23460999**
5	**2220**	**0.0021123841 374452246**	**0.99955398 23461013**
6	**2720**	**0.0021123841 374425744**	**0.99955398 23461024**
7	**3220**	**0.0021123841 374390403**	**0.99955398 23461039**
8	**3720**	**0.0021123841 37434623**	**0.99955398 23461057**
9	**4220**	**0.0021123841 374293215**	**0.99955398 23461079**
10	**4720**	**0.0021123841 374240207**	**0.99955398 23461101**

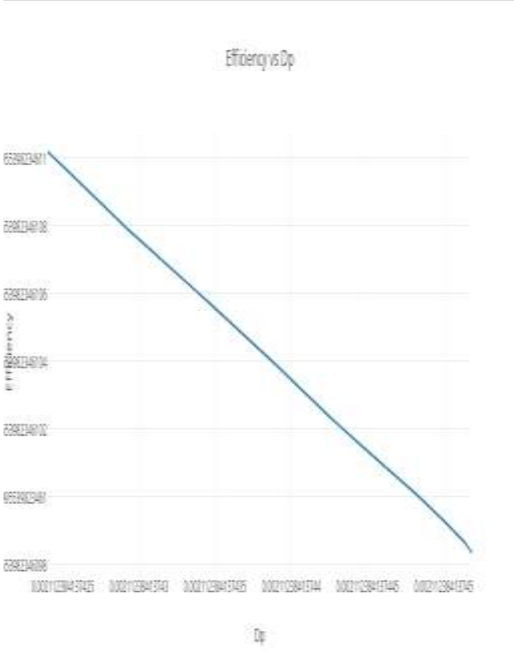


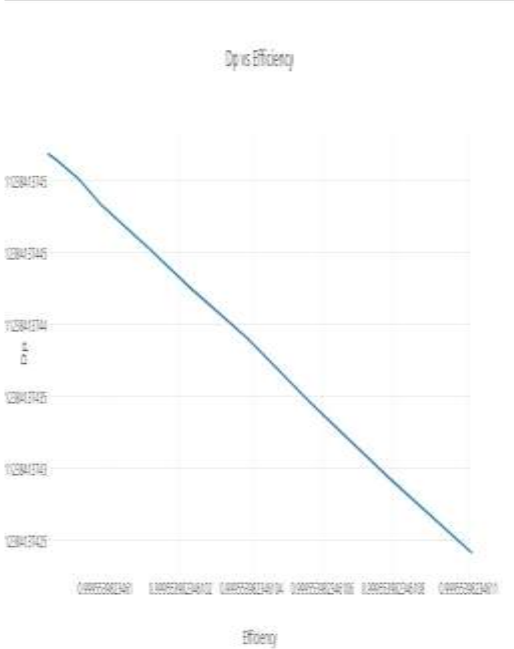












XI. RESULT

From the above table and graphs we can easily see that,

1. With the increase of Applied Voltage the size of particle is reducing and efficiency is increasing at a fixed velocity.
2. When the voltage decreases the particle size also decreases.
3. With the decrease of particle size the collection efficiency is increases and vies versa.

XII. CONCLUSION

We have observed that cut off dia is dependent on **Electric field** ,**Velocity** of engine exhaust, **Applied Voltage, Flow rate [2].** Maximum collection efficiency is obtained at the highest voltages. With the increase of voltage collection efficiency increases and vice versa. Also with the increase of collection efficiency the particle size decreases at fixed velocity. At the voltage of 1 kV, the influence of electrostatic field is too weak to make any notable difference compared to the cyclone without electrostatic (0 kV). It is still the centrifugal force that dominates particle collection so that particle cut-off size decreases with the increasing of flow rate. When the voltage goes up to 5 kV, there is a kind of independence of particle cut-off size of the airflow rate. The collection efficiency [3] is the balance result of centrifugal separation and electrostatic attraction. At lower flow rate, weaker centrifugal force is compensated by electrical force. At higher flow rate, increasing centrifugal force compensates reducing electrostatic enhancement. When the tension increases to 10 kV, a reverse effect of flow rate on cut-off diameter has happened. The cut-off diameter increases with the increasing of flow rate because particle residential time is becoming less and less important and not enough to enable the particles to migrate to cyclone walls [1].

XIII. SCOPE OF FUTURE WORK

There are various scope for future work in this field which will be given as ,

1. Electro Cyclone separator can be used in running vehicles.
2. Practical model will be develop and compare with the theoretical model of electro cyclone separator .what is residual error occurs in this project will be calculate.
3. A ceramic filter will be use at outside of the vortex finder to increase the collection efficiency and compare with the existing model.
4. We will also going to study the behavior of collected particle with surface roughness of electro cyclone inner wall.
5. We will also going to study the geometry of discharge electrode, which geometry have higher collection efficiency.

XIV. NOMENCLATURE

DESCRIPTION	SYMBOL
Air stream radial velocity [m/sec]	V_{gr}
Cut size diameter of the particle [μm]	$d_{P_{50}}$
Centrifugal force [N]	F_C
Charged induced on the particle [Culomb]	q_{es}
Collection efficiency electro-cyclone separator	□
Diameter of electro cyclone separator [m]	D_c
Diameter of the vortex finder [m]	D_e
Diameter of soot particle [μm]	d_P
Dielectric constant of the particle	**k**
drag force acting on the particle [N]	F_d
Density of the particle [kg/ m3]	ρ
dynamic viscosity of the gas [kg/m-sec]	μ
Electrostatic force acting on the particle [N]	F_e
Electric field strength [Volt/m]	**E**
Electro-cyclone effective length [m]	Z_0
Inner vortex core diameter [m]	Z_d
Inlet Velocity of exhaust gas [m/sec]	V_{in}
Inlet height of the electro-cyclone [m]	**a**
Inlet width of the electro-cyclone [m]	**b**
Length of the cylindrical portion of the cyclone [m]	**h**
Mean free path of the particle[m]	γ
Mass of the particle	m_p
Permittivity of vacuum	ϵ_0
Permittivity of AIR	ϵ_1
Radial velocity of particle [m/sec]	V_r
Radius of electro-cyclone well [m]	**R**
Radius of electro-cyclone separator [m]	**r**
Tangential Velocity of exhaust Gas [m/sec]	V_T
Universal gas constant, in N-m/kmolk	R_u
volume flow rate [m3/sec]	**Q**
Voltage applied [Volt]	**V**

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