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# ASH SEPARATOR SYSTEM TO PREVENT FAILURE OF VACUUM PUMP OF DRY ASH EVACUATION SYSTEM IN THERMAL POWER PLANT

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## ABSTRACT

In Thermal Power Plants, vacuum based system is provided for dry ash evacuation from the Electrostatic Preceptor Hoppers. Vacuum pumps creates the vacuum by suction of air through the Hoppers bottom line and buffer hoppers filters separate the ash particles in suction line of Vacuum Pump. But due to damage of filters ash particles with air insert in vacuum pumps body and it damages the vacuum pump. Also it reduces its performance. This report focuses on the Design of a system work on a principal of cyclone i.e. ash separator for separation of dry ash from the vacuum pump suction line by application of water jet to avoid the failure of Vacuum Pumps.

***Key Words: - Dry Ash, Electrostatic Preceptor, Vacuum Pump, Separator.***

## I INTRODUCTION

Thermal Power Stations are having Electrostatic Preceptor (ESP) to remove the fly ash from flue gas of boiler and to collect this dry fly ash in number of hoppers. Vacuum based dry ash evacuation system is installed to evacuate this ash from ESP hoppers and to collect it in Buffer hopper before it transport to the final collection hopper i.e. Silo. Vacuum pumps are installed for this system. In buffer hopper, Vacuum pump suction inlet is separated from the collected ash by filter bags and plate. Due to damage of filter bags or leakages in plate dry ash conveyed to vacuum pump through suction line. Vacuum pumps are getting damage due to abrasive ash. This causes frequent replacement of vacuum pump which cost approximately 15 lakh and also it reduces the efficiency of ash evacuation system. To avoid the failure of vacuum pumps and improve its performance it is required to separate the ash particles from suction line of vacuum pump. For this an system is designed which work on a principal of cyclone i.e. ash separator for separation of dry ash from the vacuum pump suction line by application of water jet.

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## II LITERATURE REVIEW

Fly ash is a by-product of thermal power plants resulting from the combustion of pulverized coal in the coal-fired furnaces. Inorganic matter present in coal solidifies while suspended in exhaust gases and ultimately gets collected through electrostatic precipitator. Due to this rapid solidification process fly ash particles are generally spherical in shape. The fly ash is mainly considered to be a ferroaluminosilicate element (El-Mogazi et al., 1988; Mattigod et al., 1990) although presence of char and some amorphous and crystalline phases is common. Carbonates, silicates, sulphates, hydroxide and oxides of calcium, iron, aluminium, and other metals in trace amount (Adriano et al., 1980) also exist in fly ash. The pH of fly ash can vary from 4.5 to 12.0 depending largely on the S content of the parent coal (Plank and Martens, 1975).The physical and chemical properties of fly ash depend on the nature of the geo-morphological nature of coal deposit, mining technology, conditions of combustion, type of emission control devices and storage and handling methods. [1]

Study of the particle collection mechanism in the outer vortex is a way to understand the relationship between the cyclone performance characteristics and the design and operating parameters. The first step in this study is to characterize the particle motion in the outer vortex. In the study of particle motion and trajectory in the outer vortex, the following assumptions were made:-

-  Particle is spherical. For irregular non-spherical particles, their Stokes' diameters (also known as ESD) are used for analysis
-  the relative velocity between the air stream and particle does not change the fluid pattern, i.e. the air stream velocity profile in the outer vortex.
-  Particle motion is not influenced by the neighbouring particles.
-  the particle tangential velocity is the same as the air stream tangential velocity. In other words, the particle does not ―slip‖ tangentially.
-  Particle Re<1, the drag force on a particle is given by Stokes Law.
-  Force balance on a particle yields 50% collection probability on this particle.
-  Particle moves from the interface of inner vortex and outer vortex towards the cyclone wall, once the particle hits the wall, it will be collected. [2]

Cyclone separators provide a method of removing particulate matter from air streams at low cost and low maintenance. In general, a cyclone consists of an upper cylindrical part referred to as the barrel and a lower cone. The air stream enters tangentially at the top of the barrel and travels downward into the cone, forming an outer vortex. The increasing air velocity in the outer vortex results in a centrifugal force on the particles, separating them from the air stream. When the air reaches the bottom of the cone, an inner vortex is created, reversing direction and exiting out the top as clean air while the particulates fall into the dust collection chamber attached to the bottom of the cyclone. [3]

## III ASH HANDLING SYSTEM

The Ash Handling System in Thermal Power Station unit consists of specially designed Bottom Ash, Fly Ash System, Coarse Ash System, Silo and HCSD System. Various instruments, gauges, switches etc. require for

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efficient and safe operation of the system is provided with ash handling system. Total ash in the form of Bottom ash, Fly ash, coarse ash generated from furnace will be removed by this system. High Concentration Slurry Disposal System (HCSD), which is the latest state of art ash disposal technology have been provided with this system, where water contained in the slurry is limited.

### 3.1 Fly Ash System

Fly ash collected in various ESP hoppers and Duct hoppers along the flue gas path shall be automatically and sequentially extracted through vacuum to the transfer tanks and pneumatically conveyed to fly ash silos. For collecting dry ash, adequately sized fly ash streams shall be provided including transfer tanks, bag filters and other auxiliaries.

The transfer tanks shall be connected to the Mechanical Exhausters. Adequately sized mechanical exhausters shall be furnished to convey ash up to transfer tanks and adequately sized non-lubricated, reciprocating type conveying air compressors for conveying of dry fly ash from tanks to fly ash silos shall be furnished.

Two fly ash silos shall be provided, each with three outlets: one for unloading of ash through rotary feeder to ash conditioner, one for unloading of ash through rotary feeder to telescopic chute for discharging ash in dry form in a closed tankers and one for unloading.

### 3.2 Electrostatic Precipitator (ESP)

The electrostatic precipitator utilizes electrostatic forces to separate dust particles from the gas to be cleaned. The gas is conducted to a chamber containing ‘curtains’ of vertical steel plates. These curtains divided the chamber into a number of paralleled gas passage. A frame with secured wires is located within each passage. All the frames are linked to each other to form a rigid framework. The entire framework is held in place by four support insulators. Which insulate it electrically from all parts, which are grounded.

A high-voltage direct current is connected between the framework and the ground thereby creating a strong electrical field between the wires in the framework and the steel curtains. The electrical field becomes strongest near the surface of the wires. So strong that an electrical discharge “the corona discharge” developing along the wires. The gas is ionized due to the corona discharge and large quantities of positive and negative ions are formed. The positive ions are immediately attracted towards the negative wires by the strength of the field. The negative ions, however, have to traverse the space between the electrode to reach the positive curtains.

En route towards the steel curtains, the ions collide with and adhere to the dust particles in the gas. The particles thereby become electrically charged and also begin to migrate in the same direction as the ions towards the steel curtains and stick on to them. These curtains are rapped periodically to dislodge the deposited dust, which is collected in the hoppers.

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**Below Table shows the chemical components present in Fly Ash for different grade coals.**

| Component | Bituminous | Sub bituminous | Lignite |
|---|---|---|---|
| **$SiO_2$ (%)** | 20-60 | 40-60 | 15-45 |
| **$Al_2O_3$ (%)** | 5-35 | 20-30 | 20-25 |
| **$Fe_2O_3$ (%)** | 10-40 | 4-10 | 4-15 |
| **CaO (%)** | 1-12 | 5-30 | 15-40 |
| **LOI (%)** | 0-15 | 0-3 | 0-5 |

## IV VACUUM PUMPS OR MECHANICAL EXHAUSTERS IN ASH EVACUATION SYSTEM

The Vacuum pumps are the low speed liquid ring type driven by an electric motor. Vacuum pumps are of proven capacity.

Silencers are provided for each Vacuum pump to limit the Noise levels to 85DBA when measured at a distance of 1 m in any direction of the equipment.

The Vacuum pump is designed to handle highly abrasive dust laden hot air under continuous mode. The design shall also take into account the possibility of Vacuum pump sucking in flue gas containing SO2 and SO3 from the ash collection hoppers. The material of construction of various components and the type of seal liquid shall accordingly select.

The Vacuum pumps are sized for the specified ash removal rates. A minimum margin of 10 percent over the above capacity is considered for sizing the Vacuum Pumps.

**Image:- Vacuum Pumps in Ash Handling Plant.**

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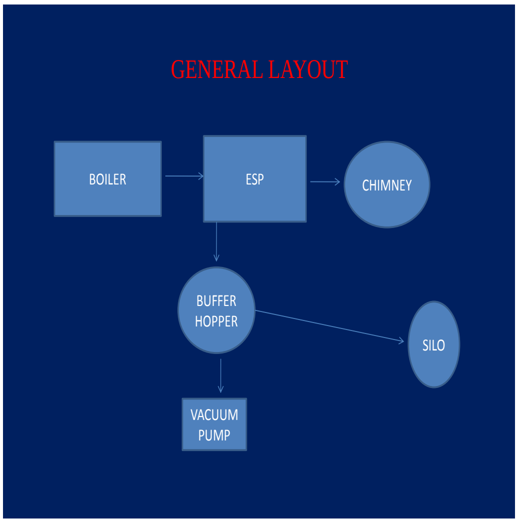



## V FAILURE OF VACUUM PUMP

The below images show the failure parts of vacuum pump. The images show how the impeller and the inner casing of vacuum pump wear out due to abrasive ash particles. These wear out parts of vacuum pump causes the poor performance of vacuum pump. The poor performance of vacuum pump is affects the ash evacuation time through the ESP hopper. It increases the Ash evacuation time and hence ash level goes high in hopper due to which it can be unloaded in open air.

It is observed that from the failure parts of vacuum pump that these are failed due to abrasive particles of ash which may get ingresses on excess amount in the pump body.

Image: Impeller of Vacuum Pump

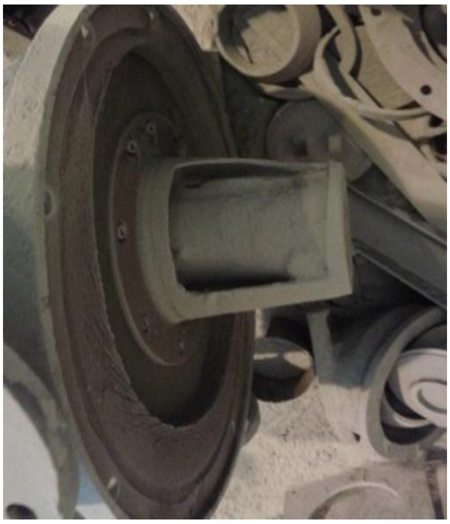
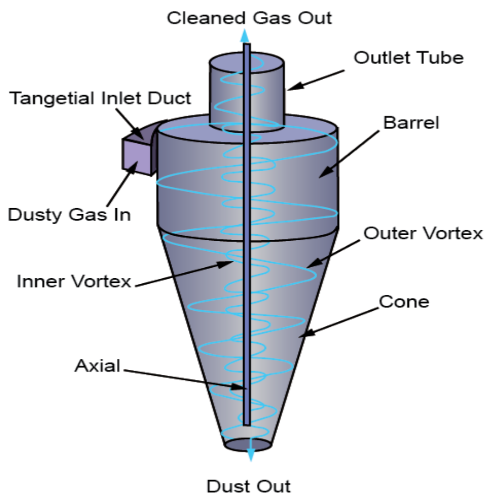


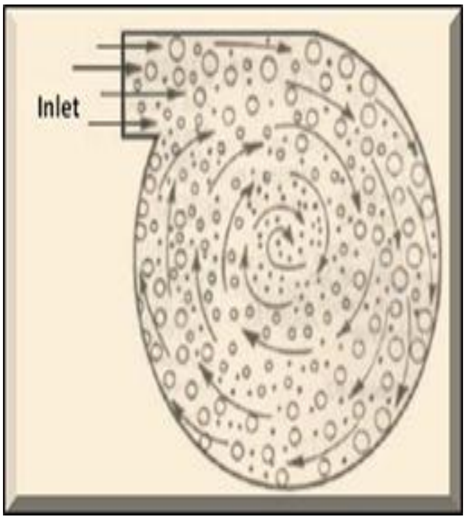
Image: Casing of Vacuum Pump

## VI ASH SEPARATOR & IT'S WORKING PRICIPLE

Ash separation by ash separator is a method of removing particulates from an air, gas or liquid stream, without the use of filters, through vortex separation. When removing particulate matter from liquids, a hydro ash separator is used; while from gas, a gas ash separator is used. Rotational effects and gravity are used to separate mixtures of solids and fluids. The method can also be used to separate fine droplets of liquid from a gaseous stream.

A high speed rotating (air) flow is established within a cylindrical or conical container called a ash separator. Air flows in a helical pattern, beginning at the top (wide end) of the ash separator and ending at the bottom (narrow) end before exiting the ash separator in a straight stream through the center of the ash separator and out the top. Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream, and strike the outside wall, then fall to the bottom of the ash separator where they can be removed. In a conical system, as the rotating flow moves towards the narrow end of the ash separator, the rotational radius of the stream is reduced, thus separating smaller and smaller particles. The ash separator geometry, together with flow rate, defines the *cut point* of the ash separator. This is the size of particle that will be removed from the stream with a 50% efficiency. Particles larger than the cut point will be removed with a greater efficiency, and smaller particles with a lower efficiency.

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## VII FACTORS CONSIDERE WHILE ANALYSIS OF ASH SEPARATOR

### 7.1 Effective Turn

The number of effective turns in a separator is the number of revolutions that the particles completes while passing through the separator.

### 7.2 Radial Velocity of Particle

The radial velocity of an particle with respect to a given point is the rate of change of the distance between the particle and the point. That is, the radial velocity is the component of the particle's velocity that points in the direction of the radius connecting the particle and the point.

### 7.3 Pressure Drop

In the evaluation of ash separator design, pressure drop is a primary consideration. Because, it is directly proportional to the energy requirement. Ash separator's pressure drop was composed of the following components: Loss due to expansion of gas when it enters the ash separator chamber. Loss as kinetic energy of rotation in the ash separator chamber. Loss due to wall friction in the ash separator chamber. Any additional friction losses in the exit duct, resulting from the swirling flow above and beyond those incurred by straight flow. Any regain of the rotational kinetic energy as pressure energy.

### 7.4 Settling Velocity

If the particle is falling in the viscous fluid under its own weight, then a terminal velocity, or settling velocity, is reached when this frictional force combined with the buoyant force exactly balances the gravitational force.

Also it is define as, the rate at which suspended solids subside and are deposited. Also known as fall velocity. The velocity reached by a particle as it falls through a fluid, dependent on its size and shape, and the difference between its specific gravity and that of the settling medium; used to sort particles by grain size.

### 7.5 Cut Diameter

The real trajectory of gas and particles is difficult to analyze. The particles laden gas enters the ash separator from the sideway at a high flow rate and moves downward in a swirling/ spiral path. Solid particles are thrown outward radially due to centrifugal force. They strike the walls of ash separator and settle down. Gas, on the other hand, will move radially inward, then upward through the least hydro dynamically resistance – path to the exit. Gas moving in spiral reaches the apex of the cone, then moves upward in a smaller spiral path to the exit at the top, as the opening at the bottom is filled with solid particles. For the gas, the least resistance – path is the exit at the top. For the particles, the least resistance- path is the exit at the bottom. Mechanistically, if the centrifugal force acting on the particles is larger than the drag (inward) by the gas, the particles will strike the walls and settle down; else they will move inward along with the gas. At a radius r, where these two forces are equal, particle will rotate in equilibrium and move downward till they hit the slant walls and are collected. Gas on the other hand has a very high upward flow rate at the centre, typically in the core-diameter of . Any particle in the zone will be carried upward.

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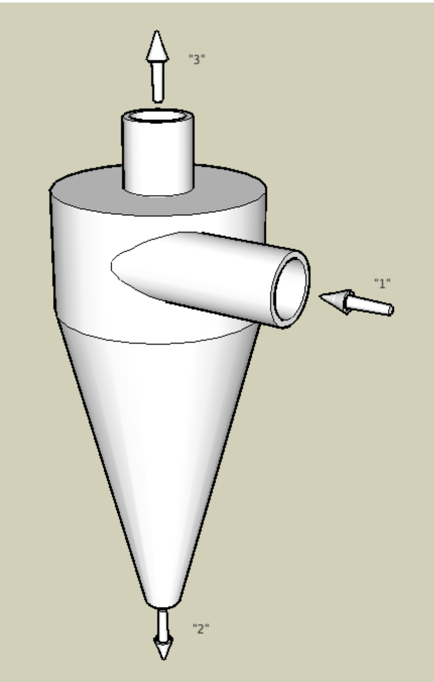
Cut diameter of a separator is the particle size above which all particles will be collected.

**VIII EFFICIENCY OF SEPARATOR**

The collection or separation efficiency is most properly defined for a given particle size. As mentioned, fractional efficiency is defined as the fraction of particles of a given size collected in the ash separator, compared to those of that size going into the ash separator. Collection efficiency of ash separator increases with increasing particle mean diameter and density; increasing gas tangential velocity; decreasing ash separator diameter; increasing ash separator length; extraction of gas along with solids through the ash separator legs.

## IX DESIGN OF ASH SEPARATOR



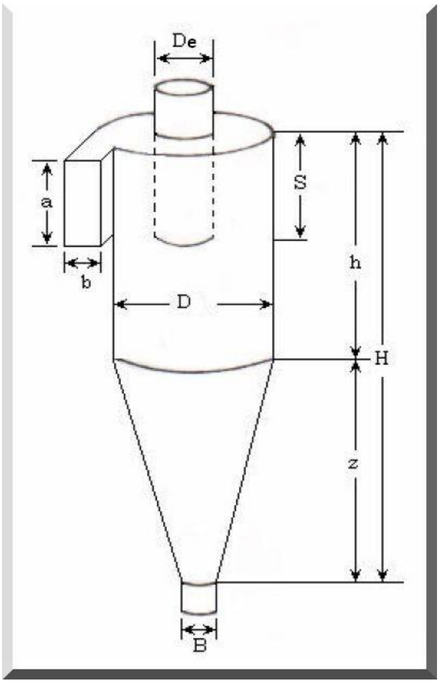




Fig.:- Ash Separator (Cyclone)

The design of ash separator system is based on cyclone separator. While design of this system following parameters needs to be consider:-

| | | | |
|---|---|---|---|
| 1. | Radial Velocity of particle | (v rad) | |
| 2. | Ash Particle Density | (þ particle) | kg/m3 |
| 3. | Air Density | (þ air) | kg/m3 |
| 4. | Radial Distance of particle | (r) | m |
| 5. | Rotational Velocity of Particle | (w) | rad/sec |
| 6. | Particle Diameter | (d) | m |
| 7. | Ash Viscosity | (μ) | kg/msec |

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- **Effective turn of mixture formed by ash & water –**

**Effective turn (N)** = π / h x (2 x L cyl. + L cone)

- **RADIAL VELOCITY OF PARTICLE:-**

$$V\,rad = \frac{(þ\,par - þ\,air) \times r \times w^2 \times d^2}{18\,\mu}$$

- **SETTLING VELOCITY:-**

$$V = \frac{\text{RADIAL VELOCITY (V rad)}}{\text{SEPARTION FACTOR (S)}}$$

- **PRESSURE DROP :-**

$$Pdrop = \frac{3950\,KQ^2 Pþgas}{T}$$

- **CUT DIAMETER :-**

$$d\,cut = \sqrt{\frac{9\mu gasW}{2\pi Nvinlet\,(þpar - þgas)}}$$

- **EFFICIENCY OF ASH SEPARATOR (n) :-** $\frac{1}{\{1 + (d\,cut / d\,par)^2\}}$

**Where,**

$v_{radial}$ =radial velocity

$v_{inlet}$ =inlet velocity

$p_{particle}$ =particle or particulate density

$p_{air}$ =air density

r =radial distance

w =rotational velocity

d =particle particulate or diameter

$P_{drop}$ =pressure drop

Q =gas flow rate

P =absolute pressure

$p_{gas}$ =gas density

u =air viscosity

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$u_{gas}$ =gas viscosity

K =proportionality factor

T =temperature

v =settling velocity

S =separation factor

N =approximate effective turns

h =inlet height

$L_{cylinder}$ =cylinder length

$L_{cone}$ =cone length

$d_{cut}$ =cut diameter

W =inlet width

## X CONCLUSION

In coal based thermal power plant, Fly ash in flue gas from Boiler gets separated in Electrostatic Preceptors (ESP). Fly ash or Dry ash is abrasive in nature.

Due to damage or dislocation of filter bags in Buffer Hoppers of ESP system, the dry ash with air enters in Vacuum Pumps via suction line. This abrasive ash results in erosion & damage of Vacuum Pumps. Maintenance & replacement cost of vacuum pump is very high up to 15 lacks in 6 months.

This paper provides the design of "Ash Separator System". Installation of this unit to the suction line of Vacuum Pump will separate the ash particles from the suction air of Vacuum Pump & clean air will pass through the pump. This design if work above 60 % efficiency. Which means maximum amount of ash particles gets separated.

Due to this Unit erosion & damages of vacuum pumps will reduces to minimum level. It results in improvement of performance of Vacuum Pumps & total ash evacuation system and also save the high cost of maintenance & replacement of Vacuum Pumps.

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