



THEORETICAL AND EXPERIMENTAL ANALYSIS OF 250 MW THERMAL POWER PLANT'S ASH SEPARATOR UNIT AND ITS COMPARISON.

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ABSTRACT

In Coal based Thermal Power Plants, Electrostatic Preceptors (ESP) System is provided for separation of Ash Particles from flue gas. Separated ash particles collected in ESP hoppers and then it is transported by Vacuum line to the Buffer Hopper for final transportation to SILO. Vacuum pumps connected to buffer hoppers for generation of vacuum. These Vacuum pumps are frequently gets damage due to ingress of ash particles in it from its suction Line and hence an Ash Separator System is designed and installed to Suction line of Vacuum Pump for separation of ash particles. This report focuses on the comparison of Theoretical and Experimental results of Ash Separator and results of Vacuum Pump performance before and after installation of Ash Separator.

Key Words: - Ash, Electrostatic Preceptor, Vacuum Pump, Ash 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 15L 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 a 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. After installation of Designed system it is essential to carry out experimental analysis of results. For effective working of



Ash separator system and its performance, the theoretical and experimental results as well as data before installation of ash separator and after installation of ash separator needs to compare.

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 Ferro alumina silicate 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 geomorphological 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:-

1. Particle is spherical. For irregular non-spherical particles, their Stokes' diameters (also known as ESD) are used for analysis
2. 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.
3. Particle motion is not influenced by the neighboring particles.
4. the particle tangential velocity is the same as the air stream tangential velocity. In other words, the particle does not —slip tangentially.
5. Particle $Re < 1$, the drag force on a particle is given by Stokes Law.
6. Force balance on a particle yields 50% collection probability on this particle.
7. 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]

The ash separator system is designed for 250 mw coal based thermal power plant, which needs to install in suction line of vacuum pump. This system is provided with water jet arrangement in suction. It separates the ash particles from air and provides clean air to the vacuum pump. Various parameters need to calculate for design of ash separator. If the efficiency of ash separator is above 60 percent then the design system is effective in performance.

III FACTORS CONSIDERE WHILE ANALYSIS OF ASH SEPARATOR

3.1 Effective Turn

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

3.2 Radial Velocity of Particle

The radial velocity of a 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.

3.3 Pressure Drop

In the evaluation of ash separator design, pressure drop is a primary consideration. 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.

3.4 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. It is 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.

3.5 Cut Diameter

The real trajectory of gas and particles is difficult to analyze. The particles laden gas enters the ash separator from the sideways at a high flow rate and moves downward in a swirling/ spiral path. Solid particles are thrown outward radically due to centrifugal force. They strike the walls of ash separator and settle down. Gas, on the other hand, will move radically inward, then upward through the least hydro dynamically resistance – path to the exit. Gas moving in spiral reaches the apex of the cone, and 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. Cut diameter of a separator is the particle size above which all particles will be collected.

3.6 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.

IV DESIGN OF ASH SEPARATOR

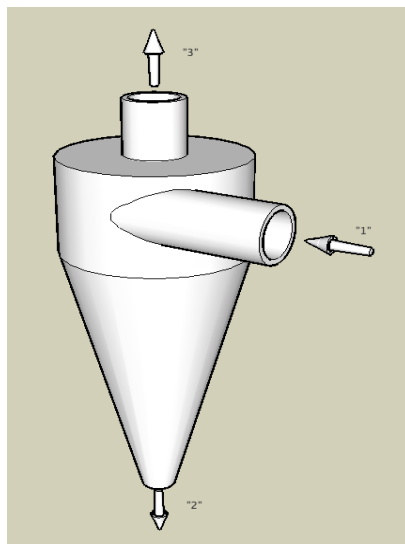
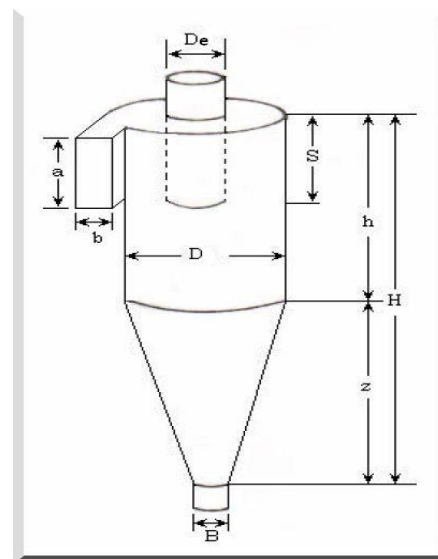


Fig.:- Ash Separator (Cyclone)



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 (ρ particle) kg/m³
3. Air Density (ρ 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

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

$$\text{Effective turn (N)} = \pi / h \times (2 \times L_{\text{cyl}} + L_{\text{cone}})$$

➤ **Radial Velocity of particle:-**

$$V_{\text{rad}} = \frac{(\rho_{\text{par}} - \rho_{\text{air}}) \times r \times w^2 \times d^2}{18 \mu}$$

➤ **SETTLING VELOCITY:-**

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

➤ **PRESSURE DROP :-**

$$P_{\text{drop}} = \frac{3950 K Q^2 \rho_{\text{gas}}}{T}$$

CUT DIAMETER:-

$$d_{\text{cut}} = \sqrt{\frac{9 \mu_{\text{gas}} W}{2 \pi N_{\text{vinlet}} (\rho_{\text{par}} - \rho_{\text{gas}})}}$$

➤ **Efficiency of ash separator (n) :-** $\frac{1}{\{1 + (d_{\text{cut}} / d_{\text{par}})^2\}}$

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
 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

V THEORETICAL CALCULATIONS

To design the ash separator system it is required to carry out the theoretical analysis on the basis of data available in standard manuals, developed drawings and the operational parameters of ash handling system from 250 MW Thermal Power Plant . Different ash analyzers are there to analyze the flue gas parameters in the ash handling system.

Following data is available to carry out the theoretical calculations:-

SR. NO.	PARAMETER		VALUE
1	CYLINDER	L cyl	0.9 m



	LENGTH		
2	CONE LENGTH	L cone	0.7 m
3	CONE HEIGHT	h cone	0.2 m
4	GAS FLOW RATE	Q gas	0.83 m ³ /sec
5	PRESSURE	P	0.533 atm.
6	RADIAL VELOCITY	V rad	5 m/sec
7	GAS VISCOSITY	μ gas	0.00001983 kg/m sec
8	PARTICAL DENSITY	ρ par	800 kg/m ³
9	GAS DENSITY	ρ gas	1.128 kg/m ³
10	RADIAL DISTANCE	r	0.5 m
11	PARTICLE DIAMETER	d par	50 micron (0.000050 m)
12	TEMPERATURE	T	45 ⁰ (318 K)

ROTATIONAL VELOCITY (w) =

$$18 * V_{rad} * \mu_{gas} / (\rho_{par} - \rho_{gas}) \text{ rd}^2$$

$$= \frac{18 * 5 * 0.00001983}{(800 - 1.128) * 0.5 * 0.000050}$$

$$= 42 \text{ rad/sec.}$$

$$1) \quad \text{PRESSURE DROP (P drop)} = \frac{3950 * k * Q^2 * P * \rho_{gas}}{T}$$

$$= \frac{3950 * 16 * 0.83^2 * 0.533 * 1.128}{318}$$

$$= 82 \text{ m}$$

*Constant K is 16 for normal tangential flow.

$$\begin{aligned}
 2) \quad \text{SETTLING VELOCITY (V)} &= \frac{\text{Radial Velocity (Vrad)}}{\text{Separation Factor (S)}} \\
 &= 5 / 1.5 \\
 &= 3 \text{ rad/sec}
 \end{aligned}$$

*Consider Separation Factor 1.5

$$\begin{aligned}
 3) \quad \text{EFFECTIVE TURN (N)} &= \pi/h * (2 \text{ Lcyl} + \text{Lcone}) \\
 &= \pi/0.2 * (2*0.9+0.7) \\
 &= 40
 \end{aligned}$$

$$\begin{aligned}
 4) \quad \text{CUT DIAMETER (d cut)} &= \frac{9 * \mu_{\text{fluid}} * W}{2 * \pi * N * V_{\text{inl}} * (\rho_{\text{par}} - \rho_{\text{gas}})} \\
 &= \frac{9 * 0.000264 * 0.200}{2 * \pi * 40 * 5 * (800 - 1.128)} \\
 &= 0.000022 \text{ m i.e. 22 micron.}
 \end{aligned}$$

$$\begin{aligned}
 5) \quad \text{EFFICIENCY (THEROTICAL)} &= \frac{1}{1 + (d \text{ cut}/d_{\text{par}})^2} \\
 &= \frac{1}{1 + (22/50)^2} \\
 &= 0.84 \\
 &= 84 \%
 \end{aligned}$$



VI EXPERIMENTAL RESULTS

At 250 MW Thermal Power Plant, after installation of Ash Separator system in the suction line of vacuum pump following observation observed for different particle size. The sample of water from the outlet pipe of vacuum pump was taken in a 1 litre bottle. And after 8 hrs the ash particles are totally get settled at the bottom of bottle and the clean water get separated. The percentage of Ash & Water in a bottle was recorded. From flue gas analyzer the ash particle size is observed on different days. For different sample of ash the efficiency is calculated and recorded.

Below table shows the five different samples taken on different days. The observed data is put into the table for further analysis.

SR. NO.	WATER (%)	ASH (%)	d par (μ)
1	90	10	40
2	90	10	55
3	85	15	45
4	90	10	60
5	85	15	50
AVG.			51

For Samples 2, 3, 4 and 5 also actual efficiency is calculated as per Sample 1. The values for all the samples are put in a table below.

From table we get,

Also,

$$\text{The actual average value of Particle diameter (dpar)} = \frac{40+55+45+60+50}{5}$$

$$\text{Actual Average (dpar)} = 51 \text{ micron}$$

As actual flow rate of gas is $0.75 \text{ m}^3/\text{sec}$ obtained from the flow meter

Hence, ACTUAL RADIAL VELOCITY (V_{act}) = $Q_{\text{act}} \times \text{Area}$

$$= 0.75 \times (\pi/4 \times 0.150^2)$$

$$= 4 \text{ m/sec}$$

$$\text{ACTUAL ROTATIONAL VELOCITY (W act)} = \frac{18 * V \text{ rad.} * \mu_{\text{gas}}}{(\rho_{\text{par}} - \rho_{\text{gas}}) r d^2}$$

$$= \frac{18 * 4 * 0.00001983}{(800 - 1.128) * 0.5 * 0.000051}$$

$$= 36 \text{ rad/sec.}$$

$$\text{PRESSURE DROP (P drop)} = \frac{3950 * k * Q^2 * P * \rho_{\text{gas}}}{T}$$

$$= \frac{3950 * 16 * 0.75^2 * 0.533 * 1.128}{318}$$

$$= 67 \text{ m}$$

$$\text{ACTUAL SETTLING VELOCITY (V)} = \frac{\text{Radial Velocity (Vrad)}}{\text{Separation Factor (S)}}$$

$$\text{Separation Factor (S)}$$

$$= 4 / 1.5$$

$$= 2.5 \text{ rad/sec}$$

*Consider Separation Factor 1.5

$$\text{ACTUAL EFFECTIVE TURN (N)} = \pi / h * (2 L_{\text{cyl}} + L_{\text{cone}})$$

$$= \pi / 0.2 * (2 * 0.9 + 0.7)$$

$$= 40$$

$$\text{ACTUAL CUT DIAMETER (d cut)} = \frac{9 * \mu_{\text{fluid}} * W}{\text{}} \quad \text{=}$$

$$\begin{aligned}
 & 2\pi N V_{inl} (\rho_{par} - \rho_{gas}) \\
 & = \frac{9 \times 0.000264 \times 0.200}{2\pi \times 40^4 \times (800 - 1.128)} \\
 & = 0.000025 \text{ m i.e. 25 micron.}
 \end{aligned}$$

From actual value of d cut and d par efficiency is calculated for sample 1 as below

$$\begin{aligned}
 \text{ACTUAL EFFICIENCY (n)} &= \frac{1}{1 + (d \text{ cut act} / d_{par} \text{ act})^2} \\
 &= \frac{1}{1 + (25 / 40)^2} \\
 &= 72\%
 \end{aligned}$$

As per sample 1, actual efficiency is calculated for sample 2, 3, 4 and 5.

The values are put in below table.

SR. NO.	WATER (%)	ASH (%)	d cut (μ)	d par (μ)	Efficiency (%)
1	90	10	25	40	80
2	90	10	25	55	77
3	85	15	25	45	72
4	90	10	25	60	75
5	85	15	25	50	74

From the average actual particle dia. (dpar) and actual cut dia. (d cut), average actual efficiency is calculated as below.



$$\begin{aligned} \text{AVERAGE ACTUAL EFFICIENCY (n)} &= \frac{1}{1 + (d_{\text{cut act}} / d_{\text{par act}})^2} \\ &= \frac{1}{1 + (25 / 51)^2} \\ &= 80 \% \end{aligned}$$

VII COMPARISON OF RESULTS

Following Table gives the comparison of contain of Ash particles in percentage from the outlet water of vacuum pump. The Data is before installation of Ash Separator and After Installation of Ash Separator System.

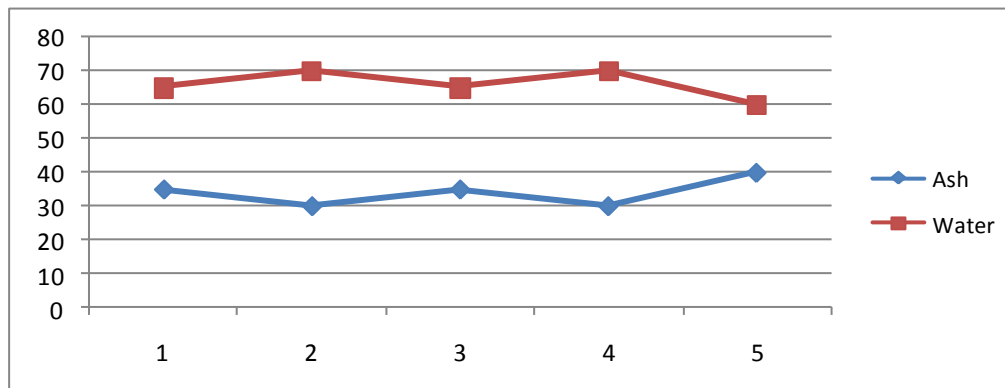
Sr. No.	Before		After	
	Water (%)	Ash (%)	Water (%)	Ash (%)
1	65	35	90	10
2	70	30	90	10
3	65	35	85	15
4	70	30	90	10
5	60	40	85	15
Avg. →	65	35	88	12

From Above Data it is observed that

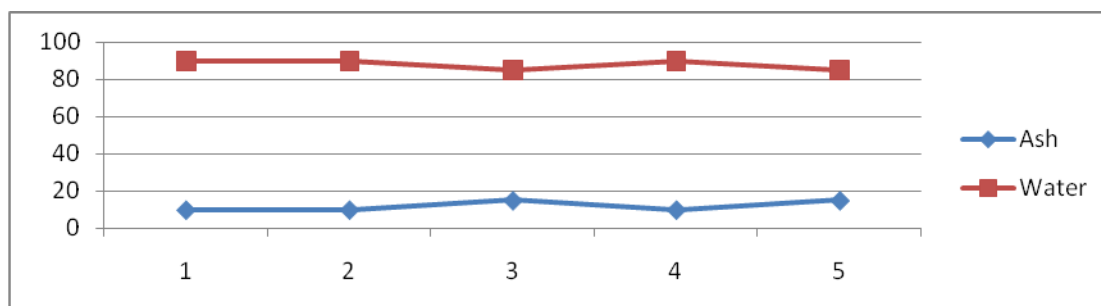
- 1) The Percentage of clean water from the outlet of vacuum pump increases from 65 % to 88 %.
- 2) The Percentage of Ash Particles reduces from 35 % to 12 %.

Analysis of this data shows that after installation of the Ash separator system the ash particle accumulation in the Vacuum pump from suction line reduces to minimum level and improves the performance of the Vacuum pump and prevents the failure of pump.

Ash and Water Percentage before installation of Ash Separator System

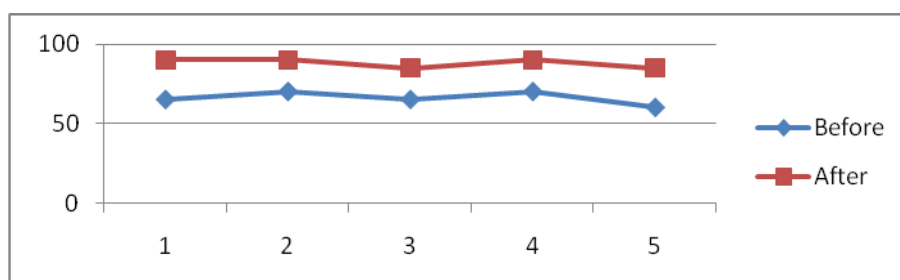


Ash and Water Percentage after installation of Ash Separator System



Graphical Comparison:-

1) Percentage of Water

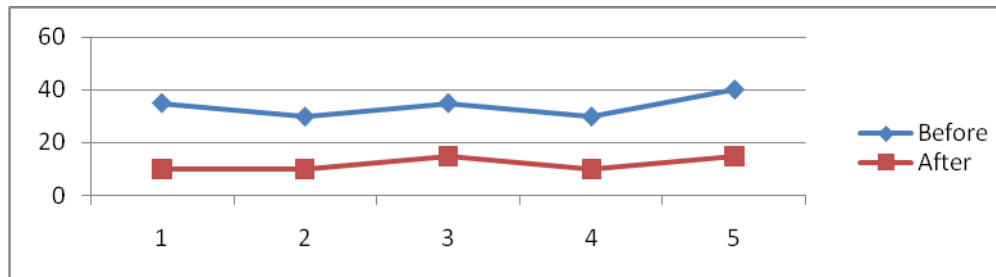


Before Ash Separator System Vs after Ash Separator System

Series 1:- Percentage of Water Contain in a Sample from the outlet pipe of Vacuum Pump before installation of Ash Separator System.

Series 2:- Percentage of Water contain in a sample from the Outlet pipe of Vacuum Pump after installation of Ash Separator System.

2) Percentage of Ash



Before Ash Separator System Vs after Ash Separator System

Series 1:- Percentage of Ash Contain in a Sample from the outlet pipe of Vacuum Pump before installation of Ash Separator System.

Series 2:- Percentage of Ash contain in a sample from the Outlet pipe of Vacuum Pump after installation of Ash Separator System.

Theoretical Efficiency Vs Actual Efficiency

Theoretical efficiency calculated for ash separator system is 84 %, whereas actual efficiency calculated after the installation of ash separator system is 80 %.

As the actual efficiency is above 70 % which means the design system is proven and gives the best results for separation of ash particle from the suction line of vacuum pump.

VIII CONCLUSION

The ash mix water sample from vacuum pump outlet are taken before installation of system which gives average 60 % water and 40 % of ash particles. This indicates the poor performance of vacuum pump.

After design and development of ash separator system a theoretical efficiency and actual experimental efficiency is calculated for the system. The theoretical efficiency is 84 % and the actual experimental efficiency is up to 80 % which is nearer to theoretical efficiency.

Also the ash mix water samples from the vacuum pump outlet are taken which gives average 88 % of water and 12 % ash particles.

After comparison of results it is observed that, the percentage of clean water from the outlet of vacuum pump increases from 65 % to 88 % and percentage of ash particles theoretical efficiency and both are above 70 %.



From all above results it is proved that the designed water jet ash separation system is effective and gives optimum performance. This will help to avoid the damage and failure of vacuum pumps and improve its performance. Also it saves the cost of maintenance and replacement of vacuum pumps.

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