International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 1, January 2017)

A Review on Seperation of Cenosphere from Fly Ash

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***Abstract*--** **In present day scenario the most valuable component of fly ash is cenosphere. Cenosphere is a light weight, inert hollow sphere filled with inert air or gas. Cenosphere are hard and rigid, water proof and insulative. Typically 1 to 300 µ in diameter. The low density of such a particles, typically 300 to 1000 kg/m^3 is striking in many applications ranging from building materials, automobile bodies, marine craft bodies, air craft bodies to drilling fluids etc. this paper presents a review on various technologies like gravity separation, Centrifugation, inverted reflux classifier etc used for separation of cenosphere from fly ash and fly ash generation and utilization in context with Indian thermal power station.**

***Keywords*--** **Cenosphere, fly ash, gravity separation, inverted reflux classifier.**

I. Introduction

In developing countries energy is generally met from coal based thermal power plants. The process of burning coal in a boiler produces fly ash. The disposal of solid waste from coal-fired thermal power plants has become a severe alarm to the environmentalists. Approximately 80% of Coal ash is very fine in nature and is known as fly ash, which is collected by electrostatic precipitators in stacks. At present in India, nearly 172.87 MT of fly ash is generated per annum and is mostly responsible for environmental pollution. In developed nation like Germany, 80% of the fly ash generated from coal based thermal plants are being utilized, whereas in India only 58% is being consumed. (CEA, 2014). It is vital to make use of this solid waste, in order to save our environment.

As per Central Electricity Authority, India (CEA, 2014) report, the fly ash generation and utilization from various power utilities (thermal power station based on coal/lignite) in the country are as below:

- No. of thermal power stations : 143
- Installed capacity : 1, 33,381.30 x 10^3 kW
- Coal consumed : 523.52 MT
- Fly ash generation : 172.87 MT
- Fly ash utilization : 99.62 MT
- Utilization : 57.63 %
- Average ash content : 33.02 %.

More than 42% of the fly ash continues to be leftover in reservoirs that surround the power stations. Evidently if more value can be screened from the components of the fly ash, the material will be seen as a resource.

The fly ash particles are made largely of silicon dioxide, aluminum oxide and iron oxide. The particles in fly ash have different types of structures. In fly ash some particles are solid and some particles are hollow, which is called as cenospheres. There are two types of fly ash based on the type of coal used viz; Anthracite and bituminous coal produces class F fly ash whereas lignite or sub-bituminous coal produces Class C fly ash, moreover Class C fly ash possess self-cementing properties.

The word Cenosphere is derived from two Greek words Kens = hollow and Sphaira = sphere. Cenospheres are chemically inert and exempt from classication as a "Hazardous Waste" by the U. S. Environmental Protection Agency (USEPA). They are also considered reclaimable and labelled as "Environmental Sound". A cenosphere is a lightweight, inert, hollow sphere filled with inert air or gas. Cenospheres are hard and rigid, light, waterproof and insulative. Cenospheres are produced during coal combustion and are hollow spherical alumina-silicate particles, due to the hollow structure; cenospheres have lower density as compared to solid fly ash particles. Cenospheres have traditionally been reported to represent about 1-3% by weight of the total fly ash produced.

II. Review

Some of the researcher has carried out the research, has been incorporated in the following paragraph.

Tapiwa, Z. G. *et al*, (2007), reported on the selective extraction of cenospheres, particles having bulk densities 1.0 x 10^3 kg/m^3 to 2 x 10^3 kg/m^3, from combustion fly ashes by the use of a specially-designed, pneumatic transport, triboelectric separator. Processing at feed rates up to 20 kg/hr. The float-sink media built-in distilled water and mixtures of water with lithium metatungstate. The recovered particles were examined by scanning electron and optical microscopy on their physical properties. The Loss on Ignition (LOI) of a feed ash was 6.26% and it had cenosphere concentrations ~ 0.6% - for densities < 1 gm/cm3; and 17.6% - for densities between 1 gm/cm3-to-2 gm/cm3. In the cenosphere product, the concentrations of particles: having densities < 1 gm/cm3 was 6%; having densities < 1.5 gm/cm3 was 27%; and having densities < 2 gm/cm3 was 44%.

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Deepthi, M. V. *et al,* (2010), have studied the uses of Fly ash Cenospheres, it is used as reinforcing filler in High Density Polyethylene (HDPE) to build up light-weight composites. In order to improve the interaction between the inorganic filler and the organic matrix, the Cenospheres were surface treated with silane coupling agent and HDPE-g-dibutyl maleate was used as compatibilizer. The tensile and thermal properties of the composites were measured according to ASTM methods. HDPE/Silanated fly ash Cenospheres light weight composites were prepared using maleate ester modified HDPE as an interfacial modifier. The addition of surface treated Cenospheres and the compatibilizer increased the tensile strength values exceeding that of neat HDPE. Theoretical models used to analyze the obtained experimental values indicated that the interfacial modifier could effectively anchor the two immiscible phases by undergoing reactive blending between the ester group of the compatibilizer and the amine groups of silane treated Cenospheres. However, the elongation at break values reduced as the rigid hollow spheres does not undergo elongation. ThermoGravimetric Analysis (TGA) showed an improvement in thermal stability over that of neat HDPE and is accompanied by char formation. Differential Scanning Calorimetry (DSC) thermograms revealed the lowering of crystallinity of the HDPE phase due to increased interaction between the blend components. Thus these lightweight inexpensive particulate composites can be used as potential fire retardants materials. The results revealed by them, were both surface modification of Cenospheres accompanied by compatibilization led to the substantial improvement to mechanical properties and thermal stability of the composites.

Kiani, A. *et al,* (2013), has use a novel approach, an Inverted Reflux Classifier (IRC) for separating cenosphere particles from environmentally hazardous fly ash feed obtained from a coal fired power station. This single stage, device consists of a system of parallel inclined channels, located beneath a partially enclosed vertical fluidizing chamber. The channels enhance the segregation rate of the cenospheres from the fly ash, permitting a greater downwards fluidization to aid the desliming of fine fly ash particles from the overflow product. The device was fed at a solids flux of about 2.6 t/m2/h. Results showed that the fluidization water is an important factor in controlling the grade and recovery of the cenospheres, providing a means for washing the entrained ultrafine dense silica from the product stream. Excessive fluidization, however, led to significant product loss. The product grade decreased as the feed flux increased, while the product recovery exhibited a clear optimum with respect to the feed flux.

In general, as the product flux relative to the feed flux increased, the recovery increased, and the grade decreased. The Inverted Reflux Classifier is based on gravity separation, and hence most of the loss in cenosphere recovery is related to the ultrafine cenospheres particles, less than 50 mm.

Li, J. *et al,* (2014), have performed experiments to test the novel approach of using an Inverted Reflux Classifier. In this configuration, the particles are fluidised by adding wash water from above which helps to wash any entrained dense material from the overhead product. Inclined channels are mounted at the base to minimise the loss of buoyant cenospheres in the waste underflow stream. Experiments were performed at both laboratory scale (80mm× 100mmcross-section) and pilot scale (300mm × 300mm cross section) using mixtures of cenospheres and silica, all nominally less than 100 µmin size. In batch tests, the bed expansion behaviour of the positively-buoyant cenospheres in the Inverted Reflux Classifier was found to be analogous to the behaviour of negatively-buoyant particles in the standard configuration. Continuous steady-state experiments were performed using feeds with suspension solids concentration varying from 0.3 to 9.5 wt.% solids and a buoyant cenosphere grade of 0.5 to 65 wt.%, with a range of fluidisation wash water rates, and degree of volume reduction (ratio of volumetric feed to product rate). Both units delivered high recoveries and product grades. An increase in volume reduction (decreasing overflow rate for a given feed rate), caused a drop in recovery and an improvement in grade. The throughput advantage compared to a conventional teetered (fluidised) bed separator was over 30 in some cases. Both laboratory and pilot-scale units displayed similar behaviour and the results were also consistent with existing correlations for negatively-buoyant particles in the standard Reflux Classifier. Hence this technology has clear potential for recovering and concentrating cenospheres from fly ash.

Tripathy, S. K. *et al,* (2014), have attempted to evaluate the performance of different types of classifiers with reference to principle, mechanism and application with a focus on hydraulic classifiers. Their study shows that, the performance of conventional classifiers in processing was not up to the desired level for both mineral and coal industries to treat the fine size range particles. The recently developed hindered classifiers possess tremendous potential was concluded.

Kolay, P. K. *et al,* (2014), made an attempt to analyze physical, chemical and mineralogical properties of cenosphere. Cenospheres of different densities vary in their physico-chemico-mineralogical properties.

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In their study, distilled water was used as the medium for extracting light weight particles from fly ash i.e., floaters or cenosphere of density less than 1.0 x 10^3 kg/m^3; while Lithium Metatungstate (LMT) solution of density 1.5 x 10^3 kg/m^3 is used as the medium for extracting floaters or cenosphere of density greater than 1.0 x 10^3 kg/m^3 and less than 1.5 x 10^3 kg/m^3. The Scanning Electron Microscope–Energy Dispersive Spectroscopy (SEM–EDS) and X-ray Diffraction (XRD) has been used for the analysis of physical, chemical and mineralogical properties of floaters or cenospheres. The results show that percentage of hollow spherical particles or cenosphere is much more with densities between 1.0 and 1.5 x 10^3 kg/m^3 as compared to the cenosphere having densities less than 1.0 x 10^3 kg/m^3. The particle sizes of the cenospheres of two different densities were similar but the average shell thickness of density 1.282 x 10^3 kg/m^3 was little higher as compared to density 0.857 x 10^3 kg/m^3[7].

Bhusal, S. (2014), studied that cenospheres exists in various densities and they vary in their physical, chemical and mineralogical properties. Further incorporated the fabrication of a new dry separator system and subsequent modifications of the separator to extract cenospheres from fly ash. The dry method of separation of cenospheres from fly ash was performed using a centrifugal air classifier. Several factors e.g., geometry and dimensions of the separation chambers, location and rate of the tangential air injection, speed of the rotor and the rate of feeding of sample are found responsible for creating an appropriate air field inside the separation chamber for efficient separation. Author concluded that the extraction of cenospheres from fly ash is still having a problem in the newly fabricated dry separator and needs further modification [2].

Tsuyoshi, H. *et al,* (2010), have estimated the quantity of separated cenosphere from coal fly ash for both wet and dry separation processes by applying the concept of terminal velocity. Particle diameter and density were determined by sieving industrial cenospheres and coal fly ash type IV, the model particles and in turn utilized to calculate the terminal velocity required to estimate wet and dry separation processes. Based on this estimation, the dry separation process performed similarly to the wet separation process, with an optimum Newton's efficiency of 0.54, only slightly lower than that of the wet separation process of 0.6. Moreover, they have observed that the cenospheres were concentrated in the underflow product, whereas for the wet separation process the reverse was true. The results were verified using a micron separator. Similar tendencies in the concentration of cenospheres in the underflow products were obtained. Optimum Newton's efficiency achieved was high as 0.44 with 66% recovery of the cenospheres.

The recovery of the cenospheres was only 4% lower than the estimated value (70%), from which they concluded that dry separation processes are interesting technologies for recovery of cenospheres from coal fly ash because of their high efficiencies.

Petrus, H. *et al,* (2011), have investigated alternative techniques for wet separation process. Air classifier is one of the techniques adopted for separation. In their study, two types of air classifiers, viz, a closed-type pneumatic separator and a micron separator have been investigated. In terms of separation efficiency, they found that the micron separator have the potential to be applied in cenospheres recovery from coal fly ash, giving a Newton's efficiency of 0.44, as compared to a value of about 0.26 for the closed-type pneumatic separator. The cenosphere recoveries of both pieces of equipment at their optimum Newton's efficiencies were similar at over 60 wt%. The separation performance was further assessed from the particle distributions of the overflow and underflow products obtained from both pieces of equipment, as well as from SEM images. They have found that the lower Newton's efficiency of the closed-type pneumatic separator was due to the re-concentration of fine particles in the underflow product at air-flow rates higher than 2.2 m/s (the underflow product yield was about 55 wt.%).

In order to further confirm the applicability of their technique, the micron separator, which had provided higher separation efficiency and cenospheres recovery, was deployed in a cenospheres recovery unit prior to the use of a wet-separation process (float and sink tank). About 80% of the cenospheres was recovered, with an 87.8% reduction in the total mass of fly ash to be separated in the float and sink tank. Consequently, much less water was needed for the process of cenospheres recovery. Moreover, they have also confirmed that the micron separator could yield higher quality fly ashes, that is, fly ash types I and II, from lower feed quality of fly ash type IV, which is the lowest category in commercial classification of fly ash according to JIS A6201.

Hurst. *et al, (1978),* have contributed for the benification of flyash by implementing the flotation technique for separation of cenosphere from fly ash. The under flow from the second tank of flotation cells is fed to a thickener or scalper in which the cenospheres are floated off. After removal of the carbon by flotation, the cenospheres which are the lightest component of the fly ash, and are readily separable by allowing the fly ash slurry to settle a few minutes and scalping off the cenospheres that have floated to the surface. These may consist of about 0.3 percent of input and are subjected to filtration, drying and storage. The yield of cenosphere was able to increase by a brief agitation of the slurry followed by a second settling.

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Cenosphere continue to rise to the surface during several stirring – settling – scalping cycles. The cenosphere are themselves, commercially valuable as acoustical insulation and as light weight ballast material. Microwave drying was used to dry the cenospheres. They thaught it was important to remove the cenospheres from the product, particularly where an enhanced pozzolan is produced, as these hollow spheres are weak and crush rather easily, and degrade the strength of the concrete product.

Manocha, L. M. *et al*, (2011), have estimated the recovery of cenospheres using float and sink method. Different liquids viz. water (1 g/cc) and acetone (0.789 g/cc) were used for separation of cenosphere from fly ash. Fly ash is taken in a vessel to which water is added. Complete mass is stirred for four hours and is then allowed to settle for ten hours. All cenospheres having density less than 1 g/cc float up and are separated. Same process is used for separation using aceton (density- 0.789 g/cc). Water separation have resulted more cenospheres than aceton. But the experimental findings were different. Cenospheres separated using aceton were more than using water because fly ash has cementitious property. Cementitious property is more in water than in acetone. So more wt.% of cenosphere are separate in acetone compared to water. About 80-85 % of the cenospheres could be recovered. Careful washing of the recipient was done to avoid solid particles. After density separation, these fly ash fractions were weighed.

Chavez, J.F. *et al*, (1987), The researchers tried to recover cenospheres by two methods viz, flotation and simple sedimentation. The flotation experiments were carried out by using four different frothers as unique reagent. The frothers were Metyl Isobutyl Carbinol (MIBC), two Polypropilen- Glicol with molecular weights of 200 and another of 400 and Pine Oil. Each experiment conducted with a fly ash sample of 100 g and dilution of 5: 1, the best results was obtained with MIBC. However, simple sedimentation techniques used for separation of cenospheres gave directly the cleanest cenosphere concentrate. For this, 100 g of fly ash were mixed with water in a weight ratio of 1: 10, then it was allowed to settle in a 1 litre glass vessel. The thickened product was the tail and the floating product was the concentrate, i.e., the product containing the cenospheres. They monitored that the settling rate of the fly ash in water was very low and difficult to determine the slurry volume; therefore other tests were performed with the addition of flocculants, being easily identified the slurry volume by the limit between the clear solution and the thickened product. In their study, four flocculants were employed, all of them polyacrilamides. The flocculants A and B were anionic with molecular weight of around 7×10^6 and the C and D are of non-ionic type with molecular weights of around $l.5 \times 10^7$.

Finally they concluded that the amount of cenosphere recovered in setteling technique was independent of flocculant used. The average yield of cenosphere was 1.7 wt % of fly ash and 1 wt% of carbon content present in the cenospheres, verifying that is not constituted by unburn fine coal.

Kiani, A. *et al*,(2015), In their work, the multi stage Inverted Reflux Classifier (IRC), a system of parallel inclined channels installed underneath an inverted liquid fluidized bed, was applied to the separation of cenospheres from fly ash. At the optimum feed solids concentration, three stages of IRC were applied to upgrade the cenospheres in the fly ash. In the first stage IRC, the primary aim was to operate at a relatively high feed rate, while insuring high recovery of the cenospheres. Here an upgrade of about 20 was deemed satisfactory. The focus of the latter stages was on the further upgrading of the cenospheres from the fly ash.

The product grade of the first stage was relatively low at about 17% but the recovery was significant at about 80%. This stage of the process was carried out at the optimum feed solids concentration of about 39% and the solids throughput of about 4.0 t/(m2 h). The fluidization water was around 0.83 m3/(m2 h), and the product rate was set at about 20% of the feed volumetric rate. In the second and third stages, however, the lower feed fluxes and higher split ratios were used. In the second stage, the product grade of cenospheres was raised to about 77% however the recovery obtained from this stage was about 69%. In the third stage, the cenospheres grade was increased to about 97%, and the cenospheres recovery to around 92% was achieved.

However the size and density analysis suggested that the second stage of the process was less effective in recovering the fine and dense cenospheres. The low total solids concentration of the feed in the latter stages and hence the lack of the bulk streaming formation effect were the likely reason for the lower overall recovery. Keeping in view the multi stage results, concluded that, at one stage process, conducted at a reduced feed rate, may provide the best approach for achieving the target grade and recovery.

Elena, V. *et al*, (2011), Have investigated interrelation between the composition, morphology, structure, and helium permeability for the shells of narrow fractions of nonmagnetic non-perforated cenospheres. The narrow fractions of nonmagnetic non-perforated cenospheres have been separated from concentrates of cenospheres of the sialic fly ash type with the use of the technological scheme, including stages of hydrodynamic gravitational separation, magnetic separation, grain-size separation, and aerodynamic classification.

They have established that, in the range of variation in the Al2O3 content from 20 to 38 wt %, the concentrations of the major components of the chemical composition of the products obtained are related by a linear regression equation with a correlation coefficient of –0.98 and also they have found that, when the Al2O3 content changes in the range from 20 to 38 wt %, the content of the mullite (0) phase increases from 1.3 to 42.4 wt %, which leads to an increase in the helium permeability of the glass-crystalline shell of the cenospheres by more than two order of magnitude. Further concluded that, for the globules of narrow fractions, separated from concentrates of cenospheres of fly ash produced from the combustion of coals from the Kuznetsk Basin, an increase in the Al2O3 content leads to a decrease in the diameter of cenospheres, as well as in the thickness and porosity of the shell of globules, the inverse relationship has been observed.

III. CONCLUSION

The traditional method of recovery through an open pond has become ineffective. Dry separation is ineffective given the significant density of the cenospheres and the silica relative to that of air. (Kiani, A. *et al*, 2013). It is very clear from the literature that the present dry and wet system of segregation of cenospheres from fly ash is not efficient and there is need to modify or redesign the process of segregation of cenosphere in harmony with Indian industries.

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