Fly ash and its impacts

Fly ash is a particulate matter ranging in size from 0.01 to 100 µm released into the flue stream during combustion of coal in power generating stations. The mineralogical, physical and chemical properties of fly ash depend on the type of coal, combustion conditions, emission control devices and handling methods. Chemically it is a mixture of oxides, hydroxides, carbonates, silicates and sulphates of calcium, iron, aluminum and other metals in trace amount. It is grey to black in color, abrasive, alkaline and refractory in nature. Fly ash is regarded as a pollutant due to its negative impact on the ecosystem, although it has alternate, safe and viable utilities.

Formation of fly ash: Coal is a sedimentary rock formed millions of years ago from plant materials containing combustible organic matter in the form of dehydrogenated plant fragments as well as inorganic matter in the form of minerals like alumino-silicate clays, silica, carbonates of calcium, magnesium or iron and sulphides among other traces. On combustion at high temperatures, all elements in coal excluding carbon, hydrogen, nitrogen, oxygen and sulphur undergo physical and chemical transformation to form ash. The mechanism of ash formation involves several particles that originate from a single coal particle through the initial process of fragmentation. As the combustible carbon matter surrounding the mineral components burnout, finely distributed ash components reach the particle surface. The molten ash components merge into larger particles and some part of the ash vapourise at high temperature, condense and coagulate. Vaporous pollutants and heavy metals accumulate over the ash particles. Coarse ash particles known as bottom ash (or slag), fall to the bottom of the combustion chamber, while the lighter fine ash particles called fly ash, remain suspended in the flue gas. In pulverized fuel firing systems, 70-90% is released as fly ash while 10-30% is removed as coarse-grained bottom ash. Enrichment of components is found to be higher in fly ash when compared to bottom ash.

Constituents of fly ash: Apart from high percentage of silica (SiO_2), alumina (Al_2O_3) and magnetite (Fe_2O_3), listed in Table 1, fly ash also contains oxides, hydroxides, carbonates, silicates and sulphates of different elements like phosphorous, potassium, calcium, magnesium, iron, manganese etc. The chemical composition of fly ash enables its use for the synthesis of zeolite, alum and precipitated silica. Based on the nature of coal and combustion conditions, fly ash may contain various levels of heavy metals such as antimony, arsenic, barium, boron, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, silver, and zinc.

Heavy metals in fly ash: Indian coal has very high ash content in the range of 35-40%. A study of coal thermal plants based in and around Delhi reveals the amount of heavy metals in the fly ash generated. According to an analysis on fly ash samples collected from thermal plants (ranging from 90-3000 MW capacities) in India, concentrations of toxic heavy metals such as arsenic, mercury, lead and cadmium. Analysis of heavy metals in groundwater near an ash disposal site in Orissa, India showed high concentrations of iron, barium, copper, manganese, sulphur, lead, vanadium and zinc. According to the study, the zone of attenuation for barium, iron, copper, manganese, sulphur and zinc in groundwater was about 600 – 900 m from the ash pond, while lead did not show any significant attenuation even at a distance of 1200 m.

Impact of heavy metals on natural ecosystem: Heavy metals like arsenic, lead, nickel, cobalt, chromium, boron and antimony found in fly ash are hazardous for living organisms. These elements can potentially be released to the soil, surface water, and groundwater by leaching processes also affecting the vegetation.

The leaching potential of ash ponds is higher due to diurnal and seasonal variations in temperature, moisture and other parameters. Leaching of soluble ions from ash ponds into the ground water was observed in studies near Vijayawada Thermal Power Station. Studies indicate that leachability of cationic metals such as cadmium, chromium, zinc, lead, mercury, and silver increases with decreasing pH or acidic conditions.

Bio-accumulation of heavy metals in plants lead to increased elemental composition eventually entering the food chain. An investigation of fly ash contaminated areas in Uttar Pradesh, India showed the bio-accumulation of heavy metals like Fe, Zn, Cu, Mo, B, Si, Al, Cr, Pb, Cd, Hg and As in native aquatic, terrestrial and algal species in the vicinity.

Leachate from fly ash dumpsites has genotoxic potential and may lead to adverse effects on vegetation and on the health of exposed human populations. A study on the mutagenicity and genotoxicity effects of fly ash leachate showed predominance of the metals like sodium, silicon, potassium, calcium, magnesium, iron, manganese, zinc, and sulphate. The Ames Salmonella mutagenicity assay conducted on two-tester strains and genotoxicity assay on fly ash leachate carried in vitro on human blood cells and in vivo on Nicotiana plants indicated that the leachate was directly mutagenic and resulted in DNA damage in whole blood cells, lymphocytes, and in Nicotiana plants.

Other pollutants in fly ash: Certain organic constituents contained in coal, during combustion results in formation of organic pollutants (mutagens and carcinogens) like Polycyclic Aromatic Hydrocarbons (PAH) and Polycholorinated biphenyls (PCB) which are adsorbed to the fly ash.

The impact of organic pollutants adsorbed to fly ash also reflects on water, soil and vegetation. Based on the fly ash generated from thermal plants in India, the concentration of Benzo(a)Pyrene which is the most potent carcinogenic and mutagenic Polycyclic Aromatic Hydrocarbons (PAH) varied as 0.82- 18.14 ng/g. The total PAHs and PCBs in the fly ash samples were found to be in the range of 43.61-936.14 ng/g and 7.34-178.69 ng/g respectively. Studies on fly ash also reveal the increased threat of radioactivity and its impact on the ecosystem including humans. According to a study based on 30 power plants in India, natural radionuclides like Ra-226, Th-228 and K-40 gets enriched by 2-5 times in the resulting fly ash compared to the parent coal.

Utilization of fly ash: Fly ash generated from coal based thermal power plants are usually stored in ash ponds which contaminate the top soil and water resources while also affecting the biodiversity. However, utilization of fly ash for alternative purposes has the following benefits: 1. minimizing environmental impact of direct disposal, 2. minimizing disposal costs, 3. enabling other uses of the land since less area is reserved for fly ash disposal, 4. procuring financial returns from the sale of the by-product 5. replacing scarce or expensive natural resources.

In India, one of the major areas for fly ash utilization is in construction (cement production, brick manufacturing and road embankments). Typical highway engineering applications include fly ash for encapsulated purposes and unencapsulated purposes:

Encapsulated purposes 1) Pozzolan in Portland Cement Concrete (PCC): Fly ash generated during pulverized coal combustion is categorized as pozzolan which are siliceous and/or aluminous materials that together with water and calcium hydroxide form cementitious products at ambient temperatures. The pozzolanic properties of the ash, including its lime binding capacity and fineness makes it useful for the manufacture of cement, building materials concrete and concrete-admixed products. Asphalt filler: The spherical shape and particle size distribution of fly ash makes it good mineral filler in Hot Mix Asphalt (HMA) applications which improves the fluidity of flowable fill and grout.

Minimizing the environmental impact of fly ash usage in road construction [Water contamination]. While using fly ash for road construction, potential impacts to ground water and soil must be considered and studied. While determining the possible degree of leaching, it is necessary to have an understanding of the hydrological conditions and the permeability of materials and soil. The pavement structure and its designed thickness is an important parameter when evaluating harmful effects of fly ash on the environment. Take care when using or disposing off any construction material in a hydro-geologically vulnerable area. Follow proper engineering requirements when using unencapsulated fly ash. Dust control and erosion prevention measures are essential during construction phase. Scientific proportion of fly ash in the construction materials should be practiced. The amount of leachate produced should be controlled by assuring adequate compaction, grading to promote surface runoff, and daily proof-rolling of the finished subgrade to impede infiltration. When construction is finished, a properly seeded soil cover will reduce infiltration. For highway embankments, the pavement may be an effective barrier to infiltration occupational issues include the handling of dry ash prior to or during its inclusion in a concrete mix or exposures during demolition of concrete structures. In such cases, work inhalation and skin contact precautions should be observed

Environmental impact of fly ash utilization in road construction: Fly ash is a waste material with variable chemical and mineralogical composition. Its unrestrained application could affect the environment adversely if proper and scientific methodologies are not adopted.

During road construction phase: When large quantities of fly ash are used, the quantities of toxic elements that can leach into the waters and soil become significant. Particularly, if the drainage from fly ash storage near the construction site is directly released into the watercourse, the aquatic living organisms in it are affected. These waters supplied to the people also threaten their health. Before embarking on construction activities involving fly ash, potential impact of water and soil must be studied.

i. Encapsulated purposes: Fly ash used for encapsulated purposes like PCC, asphalt filler etc have shown minimal heavy metal leaching impact. Since fly ash is bonded with asphalt or cement, significantly lower leaching abilities are observed for the following reasons: 1) ash particles are surrounded by asphalt or cement layer preventing water seepage, 2) bonded materials are mainly used for upper base courses that are thinner compared with the lower base courses. These materials when well compacted have a very low permeability and there is no significant influence of heavy metals on the surrounding waters and soil due to leaching.

ii. Unencapsulated purposes: Studies on fly ash used for unencapsulated fly ash purposes like soil-road base stabilization, fill/embankments etc show leaching potential of heavy metals into the environment under certain conditions.