Physico - Chemical Properties of Fly ash and Soil from TISCO Power Plant, Jharia Coalfield, Jharkhand, India

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Abstract: Thermal power plants produce enormous quantities of fly ash as a by- product of combustion of coal. The high ash content (30 -50%) of the coal in India makes disposal problem more complex. The enormous quantities of fly ash occupy vast tract of land area, as well as adversely affects for its storage and disposal problem. Its fine particles, if not managed well by nature of lightlessness, can become airborne easily in surrounding areas. Thus generation of huge quantity of fly ash poses serious environmental problems. Hence, it has become crucial that large scale utilization of fly ash in plantation or agriculture process, rather than dumping it anywhere. For this purpose, physico - chemical properties of fly ash and local soil from TISCO power plant, Jamadoba was carried out and analyzed for Specific gravity, Moisture content, Bulk density, Porosity, Water holding capacity, Lime reactivity, Organic carbon, Cation exchange capacity, Available nitrogen, pH, and Electrical conductivity. The detailed physical and chemical studies carried out on fly ash and soil of TISCO power plant has opened up a new prospect for their utilization in agriculture, plantation and vegetation purpose.
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Key Words: Coal, Thermal power plants, Fly ash, Cation exchange capacity, Organic carbon.

1.0 Introduction

Coal is combustible material generally occurring in sedimentary rock in layers called coal beds. Coal is composed of primarily of carbon, along with variable quantities of other elements, mainly Sulphur, Hydrogen, Oxygen and Nitrogen. Coal begins as layers of plant matter accumulate at the bottom of a body of water. In 2006, China was the top producer of coal with 38% share followed by the USA and India. Coal reserves in major countries are given in Table 1.

Table 1. Coal reserves in major countries as on 2006 (million tonnes)

S. No	Countries	Bituminous & Anthracite	Sub Bituminous & Lignite	Total
1	United states	111,338	135,305	246,643
2	Russia	49,088	107,922	157,010
3	china	62,200	52,300	114,500
4	India	90,085	2,360	92,445
5	Australia	38,600	39,900	78,500
6	South Africa	48,750	0	48,750

(Source: BP Statistics review, 2007)

Nearly 60% of India total installed power generation capacity is produced by coal based thermal power plants. The combustion of powered coal in power plants produces ash, which contains high ash content. There are about 84 thermal power stations in India producing nearly 120 million tonnes of coal ash per year. The production of ash is expected to cross 150 million tonnes of per year. The maximum portion of India's coal reserve is of low quality with high ash content. As the low-grade coals are used for thermal power plants the generation of ash in the form of fly ash has become high. Such a huge quantity does pose challenging problems, in the form of health hazards, and environmental damage in various ways. Fly ash generations of the different countries are reported in Table 2.

Table 2. Fly ash generation in different countries

S.No	Countries	Production (million tonnes)
1	China	160
2	USA	120
3	India	118
4	Europe	40
5	South Africa	24

(Source: NCMFA, 2007).

The physical and chemical properties of fly ash are quite variable, as they are influenced by particle size, type of coal and degree of weathering. Most of the ash materials contain relatively large amounts of Al, Si, Fe and Ca mostly in the oxide form (Rees & Sidrak,1956). The concept of fly ash application in agriculture and forestry because of its favorable physico - chemical properties including considerable content of K, Ca, Mg, S, and P (Kumar et al.,2001). Fly ash contains most of the essential nutrients Ca, Mg, P, K, Fe, S and acts as source of plant nutrients (Khandkar et al., 1996). It consists of mostly all the plant nutrients, except for a few (Sharma et al.,1989), showing the average contents of various constituents in both fly ash and soil. The calcium rich, alkaline type of fly ash evinced its usefulness in agriculture (Mishra et al.,1986),where it neutralize acidic soils, and facilitate re vegetation of heavy metals polluted soils (Sopper.,1989). Physical and Chemical properties of fly ash may benefit plant growth and can improve agronomic properties of the soil. Fly ash can be applied with good earth for plantation work in waste or degraded land. Fly ash can also be used as a good backfilling material to cover abandoned or vacant opencast or underground mines which will not only reclaim the degraded land but also improve the aesthetic beauty of the area (Chang et al., 1977). The total contents of the terrace elements in the fly ash are related to differences in coal composition, coal quality and coal combustion technology. The mobility for different metals generally depends on chemical nature of the complexes. Some metals are such as Cd, Cr, Ni, Pb, and Zn are enrich in fly ash while others like Al, Fe, Mn, Si, and Va have intermediate and few metals such as Ca, Co, Cu, and K are present in equal amounts (Mehra et al.,1998).Heavy metals effect of fly ash is found to be insignificant and concentration of toxic elements is found to be within permissible limit on utilization in some plantation work in many places in India (Singh., 1988). In general, fly ash contains traces of toxic elements and heavy metals but having some macro and micro nutrients in it and its peculiar physical characteristics it can be used as soil amendments and soil conditioner in many ways (Singh., 1995). The present analysis of fly ash and local soil can be useful in the vegetation and plantation process in selected mining areas of Jharia coalfield in Dhanbad district of Jharkhand state, India.

2.0 Materials & Methods

2.1 Study area

The present study was conducted in and around the Tata Iron and Steel Company (TISCO) power plant, at Jamadoba. The TISCO power plant currently own six collieries in the Jharia division, located in the Dhanbad district of Jharkhand, which is about 180 km away from Jamshedpur. These collieries are split into two group Jamadoba group and Sijua group. Jamadoba has a lease area of 5,508 acres and a production capacity of 1.5 million tonnes of prime coking coal. The power generation capacity of about TISCO power plant or Jamadoba power station is 10 MW (Paul, 2001). In Figure 1, location of TISCO power plant in Jharia Coalfield (JCF), Dhanbad has been shown.

Fly ash represents the non-volatile, incombustible, thermally altered particulate mineral residue (about 5 to 100 microns in diameter) that results from the burning of powered coal utility boilers. It is called fly ash, because the individual particles are carried up and out of the boiler with flue gases. The properties of fly ash are a function of several variables such as coal source, degree of pulverization, design of boiler unit, loading and firing conditions, handling and storage methods (Kumar, 1995).

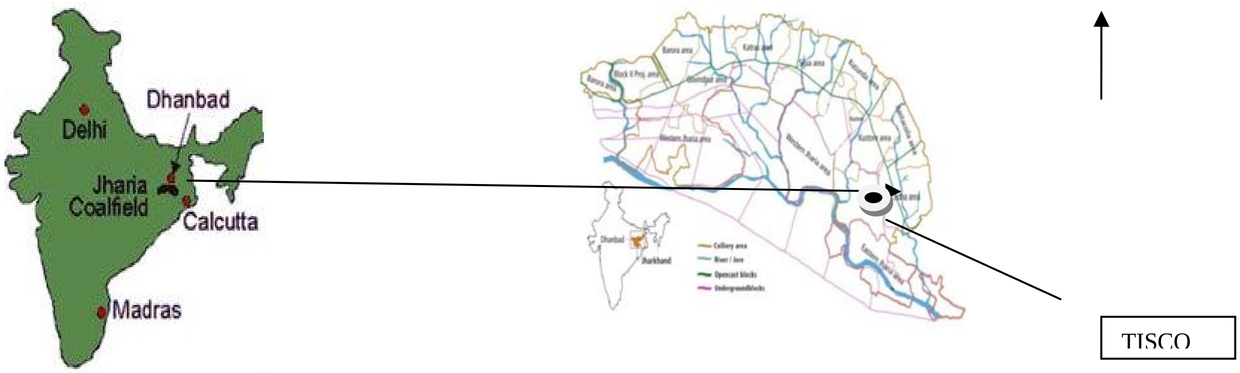

Figure 1 Map showing the location of site

Soil derives from the disintegration and decomposition of the bed rock followed by transport brought about by natural forces. There are many different kinds and types of soils. Each soil has certain characteristics including a specific color and composition. Different kinds of soils support the growth of different types of plants. Soil factors such as soil density, depth, chemistry, pH, temperature and moisture greatly affect the type of plants that can grow in a given location. Dead plants, dropped leaves and stems of plants fall to the surface of the soil and decompose. Several organisms feed on them and mix the organic material with the upper soil layers; these organic compounds become part of the soil formation process, ultimately shaping the type of soil formed (Brady.,1984).

Soil is mainly made up of oxygen (46.7%), silicon (27%), aluminum (8.1 %) and iron (5.0%). Plant nutrients like Ca, Mg, K, Na, P and S are present in the minerals and in the soil solution. O_2, Si, and Al occur as constituents of minerals and as oxides. Fe occurs mainly in the form of oxides and ferro-magnesium minerals. Ca occurs mainly in calcite, gypsum, apatite and dolomite. Mg is present mainly in dolomite and hornblende. K occurs mainly in microcline and mica. P occurs as aluminum phosphate and calcium phosphate and in the organic form as phospholipids, inositol, choline, etc. N occurs mainly in the organic form as proteins, amino acids, etc. All micronutrients like Mo, Fe, Mn, Zn, Cu, B occur in the inorganic form. Chemcial compostions of Indian fly ash are given in Table 3.

Table 3.Chemical composition of Indian fly ash

S.No	Component	Percentage
1	SiO_2	41-58
2	Al_2O_3	21-27
3	Fe_2O_3	4-17
4	CaO	3-6

(Source: Agrawal., 2010)

2.2 Sample collection and analysis

Fly ash samples were collected from the electrostatic precipitators in large amounts in polythene bags and are mixed repeatedly to represent one composite sample and subsequently used for physical and chemical analysis by standard methods as described by Jackson, 1967. Soil were also collected from several sites and mix repeatedly to represent one composite sample with the help of core cutter method in the 2 kg polythene bags for analytical studies by standard methods as described by Jackson, 1967

In figure 2, collection of local soil from selected sampling sites has been shown.

Figure 2 Sampling of local soil samples

3.0 Results and Discussions

The results of physico - chemical analysis of fly ash and soil of TISCO power plant are presented in Table 4 & 6. Classifications of basic soil components are given in Table 5.The results and discussions of TISCO power plant have been summarized below.

Specific gravity depends on the mineral and inorganic materials that are present in the samples. Specific gravity of the fly ash sample was measured as 1.89 and soil was measured as 2.34. Specific gravity of the fly ash sample was too low as compared to local soil. *Moisture content* of flyash was recorded very low 0.73% and it indicates the chances of dust emission problems, eye irritation problems in summer seasons. Whereas moisture content of local soil was recorded as 1.70% and it determines when to irrigate and how much water to apply for plantation or agriculture purpose. It has been suggested by many researchers that excessive moisture content in soil reduces yields by carrying nitrates below depths of root penetration,. It also displacing soil air for too long, causing a lack of oxygen to the roots (Calvin.,2004). *Bulk density* of flyash was measured as 0.96 gm/cc in the and it was low as compared to surrounding soil which was measured as 1.53gm/cc. The higher bulk density of the surrounding soil was due to the presence of greater amounts of coarse fraction from the sampling sites. It has been observed that increase in bulk density of fly ash sample generally indicates a poorer environment for root growth of the plants and vice versa. Pure fly ash is much lighter than local soil as it is highly porous (Phung et al.,1978). *Porosity* was measured as 36.25% which indicates that porosity of fly ash was quite normal as a result plants can grow easily. In figure 3 & 4 determination of water holding capacity by keen box method and fly ash, soil samples for cation exchange capacity are shown. *Water holding capacity* of TISCO power plant was measured as 74.55% indicating sufficient pore spaces present compared to surrounding soil and absorb sufficient water. Water holding capacity of surrounding soil was less which indicates the presence of coarse or sand particles in the sample. Another physical property which is important regarding the usage of fly ash is its Lime reactivity. Lime reactivity of fly ash is characterized by its fineness. With the increase in fineness of fly ash its lime reactivity also increases. Lime reactivity of Indian Fly ash generally varies from 35 kg/cm^2 to 65 kg/cm^2 (Page et al.,1979). Lime reactivity of TISCO power plant fly ash was 36.44 kg/cm^2 and lime reactivity of TISCO power plant fly ash increases when it was grinded. The amount of soil organic carbon depends on soil texture, climate, vegetation and current land use pattern. Soil texture affects soil organic carbon because of the stabilizing properties that clay on organic matter. Soils with high clay content therefore tend to have higher soil organic carbon than soils with low clay content under similar soil texture, land use and climate conditions. The amount of organic carbon was found low in fly ash than local soil. Organic carbon of soil was more than fly ash due to greater humus content in the sample.

Figure 3 Keen box for water holding capacity

Figure 4. Fly ash and soil samples for cation exchange capacity

Table 4 Physico - Chemical properties of TISCO power plant fly ash and local soil

S.No	Parameters	Unit	Avg. values	
			Fly ash	Local soil
1	Specific gravity	-	1.89	2.34
2	Moisture content	%	0.73	1.70
3	Bulk density	gm/cc	0.96	1.53
4	Porosity	%	36.25	-
5	Water holding capacity	%	74.55	41.55
6	Lime reactivity	Kg/cm^2	36.44	--
7	Organic carbon	%	0.36	0.44
8	Cation exchange capacity	m.eq / 100 gm	2.65	8.23
9	Available nitrogen	Kg/ha	2.7	21.15
10	pH	-	9.67	5.57
11	Electrical conductivity	mmhos/cm	0.22	0.11

Table 5 Classification of basic soil components

S.No	Soil component	Particle size range	Description
1	Boulders	More than 300 mm	Bulky, hard, rock particle
2	Gravel	60 mm - 2 mm	Passing 80 mm IS sieve, but retained on 4.75 mm IS sieve
3	Sand	2 mm – 0.5 mm	Passing 4.75mm IS sieve, but retained on 75 micron IS sieve
4	Silt	0.5 mm - 0.005 mm	Particles smaller than 75 micron, may be plastic or non plastic properties, exhibits no strength when air dried.
5	Clay	Less than 0.005 mm	Particles smaller than 75 micron, plastic nature, exhibits strength when air dried.
6	Organic matter	--	Stage of decomposition, no specific size
7	Peat	--	Spongy in nature (no specific grain size)

(Source: Ranjan and Rao, 2000)

Table 6 Grain size distribution of fly ash and soil

S. No	Mesh size	Avg. values of Fly ash (%)	Avg. values of local soil (%)
1	+72 mesh	2.18	Does not come in this mesh size due to coarser than fly ash sample.
2	-72 +100 mesh	4.37	
3	-100 + 200 mesh	5.36	
4	-200 + 300 mesh	45.45	
5	-300 mesh	42.62	

Cation exchange capacity of fly ash and surrounding soil was 2.65 and 8.23 m.eq / 100 gm respectively. A fly ash with a very low cation exchange capacity has little or no clay or humus content Sandy soil with very little organic matter have a low cation exchange capacity but heavy soil with high levels of organic matter would have a much greater capacity to hold cations (Page et al.,1979). Nitrogen in the soil is the most important element for plant development. It is required in large amounts and added to the soil to avoid a deficiency. Nitrogen is a major part of the green color of plants. A park with a nitrogen deficiency will lose it's green color and begin to turn yellow (Kalra.,1988). Available nitrogen of fly ash and local soil was found 2.7 kg/ha and 21.15 kg/ha respectively. As stated by Kalra et al., (1988), the deficiency in available nitrogen in fly ash was probably caused by the reduction in soil microbes. A similar decreasing trend was also observed for the organic carbon and cation exchange capacity. pH of the fly ash or soil is directly related to the availability of macro and micro nutrients activities .pH indicates that whether fly ash or soil is acidic or alkaline in nature. The neutral pH may be generally used in amending both acidic and alkali soils. pH range between 5.5 and 7.5 is considered suitable for vegetational programmed. pH of fly ash was recorded as 9.67 whereas soil was recorded as 5.57. Fly ash of TISCO power plant was alkaline in nature and used in the reclamation of acidic soil. Local soil has a good potential for plant growth. If the pH of the soil solution is increased above 5.5, Nitrogen (in the form of nitrate) is made available to plants. Phosphorus, on the other hand, is available to plants when soil pH is between 6.0 and 7.0 (Maiti et al., 1990). By mixing of fly ash with the local soil pH has been increased which is beneficial for plant growth. Electrical conductivity indicates the availability of different ions in the fly ash sample as well as soil sample. Electrical conductivity of the fly ash affects the properties of salinity. The conductivity less than 0.75 mmhos /cm shows low salinity hazards in soil system (Singh.,1990). Cation exchange capacity and electrical conductivity decreased with the increasing age of the soil (Kundu,1998). Electrical conductivity of fly ash and soil was measured as 0.22 and 0.11mmhos /cm in the respective sample of TISCO power plant. It does not create any problem for plantation purposes. Many literature and researchers suggests the enormous potential for the application of fly ash from TISCO power plant alone and in combination with soil to reclaim waste land for plant growth.

In Table 5, basic components of soil and its range in (mm) are given. Separation of the fly ash sample into various size ranges was done using standard sieves of 72 mesh, 100 mesh, 200 mesh, and 300 mesh size stacked in descending order. The separation of grain size ranges was done to determine which range contained the largest mass of fly ash. The values in percentages given in Table 6 show that the largest fractions of fly ash particles have diameters between -200 mesh and +300 mesh. The grain size distributions shows that percentage of sand is the highest followed by silt and clay. Whereas the local soils has percentage of sand is the least, followed by silt and clay. Fly ash can be used for texture modification of local soils with good characteristics as well as reclamation of degraded land.

Conclusion

It has been concluded that local soil from TISCO power plant contains sufficient organic carbon, cation exchange capacity, and available nitrogen required for plant growth. After several months it starts improving its physico- chemical quality by mixing with the fly ash. Fly ash changes the pH as well as electrical conductivity of the local soil for suitable for plant growth.

It has been also observed that when fly ash was added to the local soil, it has shown slow improvement in the growth of plantation. If major percentage (20% - 30%) of fly ash is added to the local soil it has shown large growth of plantation. Thus, fly ash acts as an important medium of reclamation of waste land. If some plantation were done on the fly-ash mix with soil materials physico - chemical properties improves due to addition of nutrients (Ca, Mg, P, K) from fly ash and in later years such amended fly-ash gets ready to support useful greenery in and around power plant.

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Abbreviations

1. JCF: Jharia coalfield, Dhanbad.
2. TISCO: Tata Iron and Steel Company,
3. FAUP: Fly Ash Utilization Programme
4. DST: Department of Science and Technology, Govt. of India.

Note:

The views expressed in these articles are that of the authors and not necessarily of the organization to which the authors have affiliation.

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