2

Chapter

Literature Review

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Coal is a heterogeneous, carbon rich material formed by the biochemical and geological processes and thermal alteration of organic debris such as leaves and plants. The inorganic and organic constituents of coal play an active role in affecting the adjoining environment and determine its quality (Jamal et al., 2002). Coal today still serves a major portion of India's energy needs. According to IEA-2012 coal feeds around 69% of energy demands in India, and 41%of all electricity in the world is produced still by coal. India is the third-largest producer of the coal after US and China. India produced about 638.46 million tonnes of coal in the year 2018-19. India is a country that mostly depends on thermal power plants to meet its power requirement. The total installed power generation capacity of India is 3,50,162 MW in March 2019, out of which the thermal power plants contribute to 2,22,927 MW, i.e. 63.7% of the total power generation capacity of India, (CEA, 2018). The coal and lignite based thermal power plants add to 1,31,093 MW and 6,260 MW respectively, i.e. 54.6% and 1.8% of the total power generation capacity of India (CEA, 2018). The mining leasehold area occupies around 0.7 million hectares, which account for 0.21 % of the total landmass in India. Currently, there are more than 2729 mines which include 570 coal mines, 2300 metalliferous mines, and other small mines. Opencast coal mining in India is a major activity and contribute more than 92% coal production of the country (Dubey, 2017).

2.2 Impacts of opencast mining

The problem in opencast coal mines is many types. Among Opencast mining of coal and minerals impacts the surface and underground water bodies in the following manner. All the surface water bodies need to be removed from the area designated for opencast mining and associated activities. All the aquifers, including the water table aquifer, above the mineral deposit to be extracted are damaged because overburden rocks are removed for exposing the mineral for extraction. In the reclaimed open pits, the filled-out areas may accumulate water in rock's interspaces which in the long run may serve the purpose of a waterbody. During rainy seasons the run-off water from the areas surrounding the mines may carry with it a large load of suspended solids into the nearby water bodies.

Domestic, agricultural and industrial effluents, when discharged into the surface water bodies, cause water pollution. The effluents when discharge on the surface pollutes the soils the water table. Water is an important aspect of all mining and quarrying developments as all mines require a water supply. It is used in mining for the following purposes: for ore concentration in washeries, for dust suppression, hydraulic power, as a coolant, workshops, etc.

2.3 Flyash

By-product after the combustion of coal in thermal power plants is known as flyash. In other words, the most voluminous fraction of Coal combustion products is flyash, which is a fine particulate inorganic matter collected through mechanical processes, electrostatic precipitators, and fabric filters from flue gas produced by the combustion of pulverized coal in boiler assembly. Flyash is spherical particles make up 10 to 85% part of the total coal ash residue, usually ranging in diameter from 0.5 to 100 microns. It is a heterogeneous material primarily consisting of amorphous alumina-silicate spheres with minor amounts of iron-rich spheres, some crystalline phases, and a small amount of unburned carbon. The Heavy metal content of Indian flyash is reported to be lower than the flyash of other countries like from Greece, Spain, China and UK. Indian flyashes are generally found to be safe from the point of view of radioactivity. The most common elements in Indian flyash is Si, Al, Fe, Ca, Mg, K and Na and trace elements such as As, Zn, Pb and Se.

2.3.1 Classes of flyash

Coal combustion-based power plants generated flyash typically fall within the American Society for Testing and materials (ASTM) flyash classes C and F **(Table 2.1)**.

Table 2.1: Characteristic of different types of flyash

Class F	**Class C**	**Reference**
Class F flyash produces by burning of harder anthracite and bituminous coal	Class C flyash produces by burning of younger lignite or sub bituminous coal	Page et al., 1979
This class of flyash contains less than 20 % of lime	This class of flyash contains more than 20 % of lime	Obla, 2008
Alkali and sulfate contents are generally lower in class F	Alkali and sulfate contents are generally higher in class C	Page et al., 1979
The quantities of Si, Fe & K oxides are higher in Class F	The quantities of Si, Fe & K oxides are lower in Class C	Murty and Narasimha, 1999
The CaO, MgO, SO3 & Na2O quantities are lower in Class F	While CaO, MgO, SO3 & Na2O quantities are higher in Class C	Murty and Narasimha, 1999
Class F flyash has been rarely cemetitious when mixed with water	Class C flyash usually has cementitious properties in addition to pozzolanic properties	Shetty, 2005

From the data provided by the Central Electricity Authority, it is clear that though the percentage utilization of the flyash is increased over the last years, still a huge quantity of flyash is being left utilized **(Table 2.2 to 2.4 and Fig. 2.1)**.

Table 2.2: Summary of flyash generation and utilization for year 2017-18 (CEA, 2018)

Description	**Year 2017-18**
No. of thermal power stations from which data was received	167.00
Installed Capacity (MW)	177070.00
Coal Consumed (Million Tons)	624.88
Flyash Generation (Million Tons)	196.44
Flyash Utilisation (Million Tons)	131.87
Percentage Utilisation	67.13
Percentage Average Ash Content	31.44

Table 2.3: Details of flyash generation and utilization during the year 2014-15 to 2017-2018 (CEA, 2018)

Description (Million tons)	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
Flyash Generation	184.14	176.74	169.25	196.44
Flyash Utilisation	102.54	107.77	107.10	131.87
Percentage Utilization	55.69%	60.97%	63.28%	67.13%

Table 2.4: Major oxides in flyash

Component	**Bituminous**	**Subbituminous**	**Lignite**
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	May-35	20-30	20-25
Fe_2O_3 (%)	Oct-40	04-Oct	Apr-15
CaO (%)	01-Dec	May-30	15-40
LOI (%)	0-15	0-3	0-5

2.4 Overburden

In India, two types of mining operated as opencast and underground mining. Opencast mining is a developmental activity, which damages the natural ecosystem by several mining activities. During opencast mining, the overlying soil is removed and the fragmented rock is heaped in the form of overburden dumps. Dump materials are left over the land in the form of overburden dumps. These occupy a large amount of land, which loses its original use and generally gets soil qualities degraded. As the dump materials are generally loose, fine particles from it become highly prone to blowing by the wind.

Currently the following ten opencast mining projects of NCL are working in Moher sub basin. The details of production of coal and overburden for the year 2015-16 are given in the **Table 2.5**.

Table 2.5: Details of coal & overburden production during the year 2015-16 (CEA, 2018)

S. No.	Name of Project	Coal Production (MTY)	OB Removal (Mm³)
		2015-16	
1	Amlohri Opencast	10.52	41.78
2	Nigahi Opencast	15.01	58.67
3	Jayant Opencast	14.40	54.20
4	Dudhichua Opencast	13.08	63.18
5	Khadia Opencast	6.74	32.77
6	Bina Opencast	7.01	29.02
7	Kakri Opencast	1.87	8.90
8	Jhingurdah Opencast	2.51	5.32
9	Krishnashila Opencast	5.00	18.52
10	Block 'B' Opencast	4.10	27.28

2.4.1 Backfilling

Backfilling is a common operation to fill the voids created after excavation of the coal in opencast mines. Backfilling is considered the preferred option for mine closure option in many countries including India. When selecting a certain material for backfilling, one must investigate the material for short term and long-term geotechnical properties and likely behavior after placement to examine fill's capability with environmental point of view. Mining activities generate a large quantity of solid, liquid and gaseous wastes. Most of the solid wastes are being used in backfilling in case of opencast mine. Out of these, hydraulic stowing is the most popular method of backfilling and is best suited for use with mine tailings (Wayment, 1978).

2.5 Work done in India

This photograph is showing the flyash disposal in Mahanadi Coal Field Limited (MCL), but no result were generated **(Fig. 2.2-2.3)**. Hence, I wish to continue with the same and correlate with my own research work.

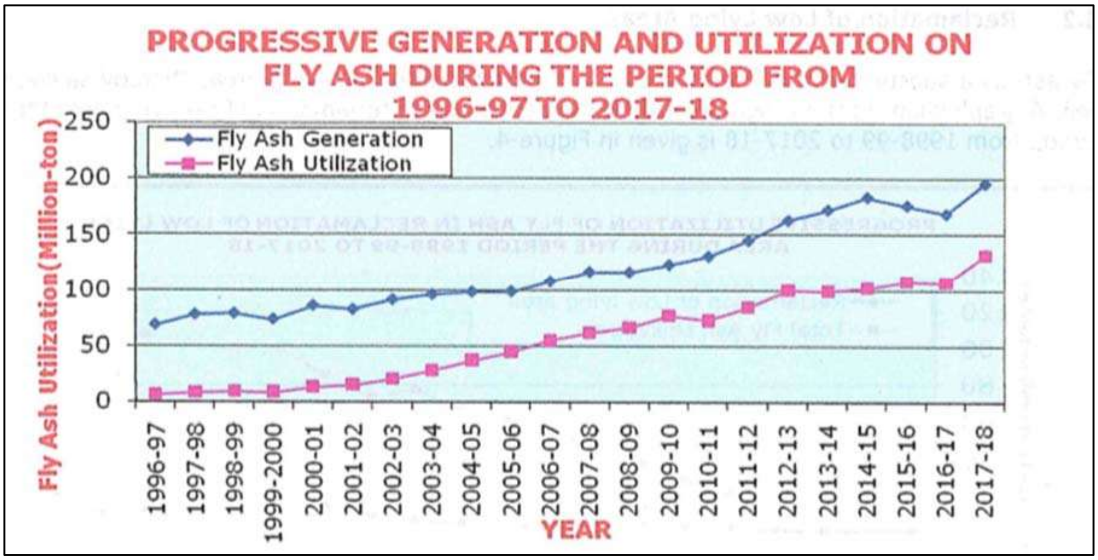

Fig. 2.1: Generation and Utilisation of flyash from 1996-97 to 2017-18 (CEA)

Fig. 2.2: Disposal of Flyash slurry through pipe line from TTPS into residual quarry of Balanda OCM, MCL

Fig. 2.3: Flyash mound formed in the used quarry of Balanda, OCM after disposal of ash slurry from TTPS

2.5.1 Flyash and flyash-mixed overburden as a backfilling material

Flyash is being used for backfilling of open cast mines and stowing of underground mines which result in the saving of top fertile soil and precious river sand. Mixing overburden with flyash improves the mechanical strength of dump as flyash absorbs the moisture from clay as well as substantially increases the strength of the resultant mixture due to the pozzolanic properties of ash (Dewangan et al., 2017; Shirin et al., 2019) because flyash is pozzolanic, which means it's a siliceous or siliceous-and-aluminous material that reacts with calcium hydroxide to form a cement.

Chen and Baker (1978) and Sleeman (1990) suggested that the wastes such as pulverized flyash and sulfate sludge from coal burning power plant processes may deliver the additional volume of fill cheaply than that of the aggregate materials such as crushed stone, sand, and gravel. However, fill materials consisting of high sulfur coal and spoil has the potential to react chemically with air and water to produce sulfuric acid.

Suciu et al. (2008) studied the feasibility of using compacted flyash or flyash mixed with sand as a construction material for waste containment liners or impermeable covers. Compacted specimens of flyash and sand mixture of different permeability were subjected to long term permeability tests. It was observed from their study that the permeability can be reduced to below 10-7cm/sec. A synthetic inorganic solution simulating a flyash landfill leachate did not have any adverse effect on the permeability of the compacted flyash. Permeability affected the concentrations of certain elements leaching or desorbing out of, or adsorbing into the flyash. Calcium (Ca), sulphur (S) and boron (B) concentrations were lower in low permeability specimens while cadmium (Cd) and zinc (Zn) concentrations were higher. The high pH of the flyash leachate helped in keeping the cadmium, zinc and boron in the flyash matrix (Grice, 1998).

Patil et al., (2012) confirmed that higher amount of flyash is needed for effective pozzolanic activity in case of poorly graded material. Flyash has good potential use in geotechnical applications. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties etc. can be gainfully exploited in the construction of roads, embankments etc.

Pradhan et al. (2014) studied flyash plus soil mixes and concluded that the addition of flyash reduces the dry density of the soil due to low specific gravity and unit weight. They also concluded that the CBR values of pure soils are 4.7%, 2.03% and 3.53%; by adding flyash up to 46%, the CBR value is increased up to 11.41%. Thus, flyash effectively utilized in the soil to get improvement in shear strength, cohesion and the bearing capacity. Flyash addition in soil can also be effectively used as the base materials for the roads, back filling, and improvement of the soil bearing capacity of any structure.

Singh et al. (2011) at Lajkura Opencast coal mine of MCL, 22m of overburden immediately above the Lajkura coal seam (having a thickness of 18 m) was being removed by a dragline. The dump material is mainly characterized by sandstone, shale and coal. Bulk density and direct shear tests were conducted on the samples collected from the mine. Kinematic analysis was included to determine the critical orientation of structural discontinuities.

The permeability of flyash or soil–flyash mixes stabilized with lime gradually decreased due to the formation of hydration products, reduced the interconnectivity between the pores (Gupta et al., 2016; Shirin and Jamal, 2018a; 2018b).

In more recent years, for economic and environmental reasons, renewed attention has been given to the use of 'waste' materials in lieu of conventional aggregates in pavements According to (Jamal et al, 2016), the use of mixture of flyash with some waste rock is expected to improve the gainful utilization of flyash for improvement in water quality.

The above study on laboratory scale suggests that the acid neutralizing property of flyash will be an asset for coal mines suffering with slight to moderate acid drainage problem both at exploitation and abandoned stages.

In a study conducted by **Johnson et al. (2007)** observed that backfilling of coal mines using mine wastes directly or in combination with any other waste or additives is a technologically feasible, economically viable and environmentally compatible way that can be performed in conjunction with mining (in case of underground mines) or even after a mine has been abandoned. The most significant impacts of backfilling are a reduction of mine subsidence, the increment of coal recovery, enhanced ventilation control, reclamation of mined out surface land, minimization of ground coal mine fire and spontaneous combustion. The lime stabilization of soils or soil-flyash mixtures have been extensively described in the literature which involves the physico-chemical mechanisms of both short- and long-term reactions**.** The enhancement of mechanical strength and micro structural development of flyash with addition of lime has been reported elsewhere.

Behera et al. (2012) Surface coal mine overburden, typically treated as waste material, consists of a mixture of coarse-grained particles, rock fragments and fine-grained particles. It often causes geotechnical and environmental problems at the disposal site. Flyash, a coal combustion by-product, has the potential to change the behaviour of other similar products when mixed at optimum conditions. Both flyash and overburden are still being treated as waste products. An investigation has been carried out to evaluate the utilisation prospects of both combined. This article describes the results of an investigation on the compressive strength and bearing ratio behaviour of surface coal mine overburden material and flyash mixes stabilised with quick lime at varying percentages. The same has also been compared with results obtained from flyash-mine spoil and mine parting mixes and flyash-soil.

Chakravorty et al. (2013) and Jayantu et al. (2012) studied overburden, overburden+15% flyash, overburden+25% flyash and overburden +30% flyash of Kakatiya Khani opencast mine of Singagreni Collieries Company Ltd located in Bhupalpalo, Andra Pradesh and coal mine of Jindal Power Ltd, Raigarh. They pointed out that the cohesion of overburden is less than overburden + flyash, but the angle of friction and density of overburden is more than overburden + flyash.

Deb and Pal (2014) carried out a series of experiments and found that the soil sample mixed with 30% flyash may be used in backfilling, landfilling and embankments in the area of geotechnical engineering. With the increase in flyash content in the soil, some geotechnical properties such as specific gravity, plasticity index, linear shrinkage, maximum dry density, degree of saturation, uniaxial compressive strength, swelling potential, and free swelling index are found to be decreasing.

Ratna and Darga (2015) studies California bearing ratio (CBR) and strength aspects of flyash-granular soil mixtures by taking gravelly sand from Gandi Misamma, Telangana. The soil was mixed with 0%, 5%, 10%, 15%, 20%, 25% of flyash proportions by dry weight. They found that properties of granular soil did not change much with 20% to 25% addition of flyash. The angle of internal friction decreased with increase in the percentage of flyash in the soil-flyash mixture.

Sharma et al. (2018) examined the independent impacts of lime and cement on the stabilization of a mountain soil by examining their geotechnical and microstructural properties. They found that cement is a relatively better additive than lime when it comes to mechanical behaviors. The increase in compressive strength in the soil matrix by the additives was observed to be due to cation exchange and pozzolanic reactions, which led to the development of cementitious compounds within the soil specimen.

2.5.2 Leaching

Leaching may be defined as the loss or extraction of certain materials (metals) from a carrier into a liquid. Coal contains significant quantities of various trace elements and, during combustion of coal, trace elements are enriched as a result of carbon loss as carbon dioxide and the trace elements are associated with the surface of the ash particle due to evaporation and condensation. The characteristics of the coal used, and the type of the installation employed in generating the solid combustion wastes (flyash) have a direct influence on the chemical and mineralogical composition of flyash **(Jamal et al., 2015)**. The disposal of flyash is considered a potential source of contamination due to the enrichment and surface association of trace elements in the ash particles. The elements Mn, Ba, V, Co, Cr, Ni, Ln, Ga, Nd, As, Sb, Sn, Br, Zn, Se, Pb, Hg and S in the coal are volatile to a significant extent in the combustion process. However, the elements Mg, Na, K, Mo, Ce, Rb, Cs, and Nb appear to have smaller fraction volatilized during combustion. Whereas, Si, Fe, Ca, Sr, La, Sm, Eu, Tb, Py, Yb, Y, Se, Zr, Ta, Na, Ag, and Zn are either not volatilized or only show minor trends related to the geochemistry of mineral matter **(Chattopadhyay, 2015)**. During transport, disposal and storage phases, the residues from coal combustion are subjected to leaching effects of rain and part of the undesirable components in the ashes may pollute both ground and surface waters **(Singh et al., 1998)**. These solid residues (flyash) can be leached in higher concentrations than drinking water standards and can cause contamination in drinking water sources.

Gutierrez et al. (1993) conducted leaching of waste flyash samples using strong acids in sequence: HCl^+ HNO_3, H_2F_2, $HClO_4$ and concluded that flyash particles of smaller size generate a somewhat higher concentration of trace metals. **Pendowski (2003)** found that different elements have different leaching behaviours because of differences in elemental properties and pH of the solution and leaching time, which strongly influence the leaching behaviour. The trace-element leaching from bottom ash is slower and often requires that the entire bulk matrix be dissolved.

Jamal et al. (2015) categorized the factors controlling leaching into namely physical, chemical, and biological factors. The physical element is design and configuration of the area, climate and meteorological environment, vegetation, hydrogeology, heterogeneity of the fill material, particle size, shape, surface area, permeability, flow rate and viscosity of the leaching fluid and temperature during leaching. They identified the chemical factors as equilibrium (relatively fast chemical dissolution reactions) and kinetic, based reactions, solubility properties of constituents, the existence of non-aqueous phase liquid, pH of the fil material and leachate fluid. The biological factors identified by them included microorganism such as bacteria, fungi, algae, etc.

Kusuma et al. (2011) studied that when overburden rocks have a significant amount of reactive sulfide minerals rather than alkali minerals, Acid Mine Drainage (AMD) is most likely to occur upon the exposure to oxygen and water. Presence of oxygen and water inside the dump is controlled by the physical structure of the dump, local climate, and geochemistry of OB rocks.

Krishnan (2013) concluded from the study of flyashes from the electrostatic precipitators (fresh flyash) and the flyash pond (pre-leached flyash) that due to the high pH, lower metal leaching takes place resulting in low contamination of the leachate.

Yaseen et al. (2012) studied the physico-chemical characteristics of overburden dump materials from Raniganj Coalfields. They observed that the overburden samples collected from the coal mining areas was found to be poor in organic carbon, available nitrogen and available phosphorus due to lower amount of microbial activities in the overburden samples.

Rai et al. (2011) studied about overburden dumps at different mining areas under Jharia coalfields. The overburden samples were collected during the summer months. Physico-chemical characteristics such as Bulk density, Grain size distribution, pH, Electrical conductivity, Organic carbon, Organic matter, Available nitrogen and phosphorus were determined.

Loubser et al. (2008) demonstrated, with practical examples from different industrial application, how combined XRF and XRD use can provide truly quantitative phases analyses. XRF is used to verify XRD data and vice versa.

Gupta et al. (2013) studied the bentonite samples from the different parts of Jharkhand and Daltanganj and their analysis using X-Ray Fluorescence (XRF). The XRF analysis of twenty-three samples was done to obtain chemical composition, which was then used for derivation of the theoretical molecular formula.

2.6 Research gap

From the review of literature, it could be clearly seen that most of the researchers have studied the stability of overburden with 0% to 25 % addition of flyash. In order to utilize the maximum amount of flyash backfilling in opencast mines, the stability of OB with flyash is required to be studied. Although research and field applications have been carried out on overburden and flyash backfilling, a limited number of studies have been carried out on the leaching behaviour of these wastes. Out of these limited studies, the researcher focused on the leaching of flyash and overburden separately. Since these wastes are used in combination for backfilling, there is a need for studying their joint leachability potential. Limited literature have been found on examination of water quality near the backfilled area as this is necessary to ascertain as to what extent leaching of the backfilled waste affect the water bodies like mine sump from where excessive water is pumped out to the nearby water bodies apart from being applied for several mining activities such as dust suppression, firefighting, plantation etc. The public sector enterprise NCL has a number of coal mines in Madhya Pradesh. There are several opencast mines. However, no comprehensive study has been carried out which addresses the adverse impacts of backfilling such as the leaching potential, water quality within as well as outside of the mine, and the impact on soil geochemistry. It may be noted that all these coalfields are surrounded by villages and towns which are highly populated.

In this research work, an attempt has been made to address the above problems so that the mine management and the regulating agencies can play and implement appropriate remedial measures.