A study on re-designing the existing ash storage pond for leachate control of thermal power station

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Abstract

Thermal stations use coal as combustion material for fuel and the chemical energy stored in coal, which is converted successively into thermal energy, mechanical energy and finally electrical energy for continuous use and distribution across a wide geographic area. A study was conducted on a particular thermal power station to identify the ash disposal & storage system and the alternate design of the existing ash storage system since thermal stations use pulverized coal as fuel to generate electrical energy and produce ash as by-product. As such, Ennore thermal power station draws coal from Indian mines like Mahanadhi coal fields, Orissa (IB Valley, Talchar), Eastern coal field, Ranikanj and also imported coal from Australia & Indonesia is used. Indian coal has a high ash content exceeding 40%, with low calorific value but economical. In comparison the imported coal has a low ash content of less than 13%, high calorific value but costlier. As the residual end product of ash is more in Indian coal. The concern on the need for safe storage, disposal for effective utilisation of flyash, a strategic approach evolving potential remedial measures to mitigate leaching of toxic minerals from the ash storage pond is necessary and the same is carried out in this study since wet ash is stored in ash ponds apart from disposal of dry ash at the source. Ash storage pond is constructed with high mounds of earth with filter media. To avoid contamination of the adjoining lands, streams and aquifers a reinforced cement channel drain along the ash bund is designed to collect the seepage of chemicals with a sloped gradient for further treatment of the leachate. Also as a Phyto-remediation specific species of plants as hyper-accumulators are planted along the downstream side slope of the bund and this absorbs the toxic minerals as well as strengthens the bund from breaching.

Key words: Coal; Fly ash; Leachate; Collection drain; Phyto-remediation.

Introduction

The most frequently used fuel for thermal power plants in India is coal. About 70% of the electricity consumed in India is generated through thermal power plants. A thermal power is generally a steam driven power plant. Pulverized coal is used as fuel for the generation of heat energy. Water in the boiler is evaporated due to the intense heat, it becomes high-pressurized steams are passing through a conduit (there is a turbine at the other end of the tunnel), it forces its way through, thus rotating the turbine at a greater speed generate electrical energy. Turbine is connected to a generator via a coupler. Rest of the steam enters a condenser has a cooling agent (namely seawater) and the steam will go through the cooling agent via a pipe. The steam thus changes back to its liquid form and returns to the Boiler. Whole process is referred as Rankine cycle.

Coal

Coal for combustion in Ennore thermal power station is mainly drawn from Indian mines like Mahanadhi coal fields in Table 1, Orissa (IB Valley, Talchar), Eastern coal field, Ranikanj and also imported coal from Australia & Indonesia and are fed into the mill plant for pulverizing through an elevated multi level conveyor system before feeding into the boiler area. Average daily consumption with plant utilization factor of 62% is 4350MT (Ananth P. Chikkathur, 2008). With the average calorific value of 3200 Kcal/Kg, fly ash generated is at the rate of 43.2%. Coal, which is,

Table 1. Characteristics of Mahanadhi Coal & Foreign Coal (Indonesian) - Proximate Analysis

Main characteristics	Indian Coal	Foreign Coal
Fixed carbon	31%	48%
Ash content	42%	12%
Volatile matter	21%	30%
Moisture content	14%	10%

consist more carbon, high volatile matter and low moisture content has high calorific value. Coal with highest UHV (Utility Heat Value) which produce low ash has been characterized as Grade-A as in Table 2, and coal with least UHV consist of low carbon, low volatile matter, more moisture content and very high ash content has been characterized as Grade-G.

Table.2. Ultimate analysis of Coal

Details %	Mahanadhi coal	Sipat	Indonesian coal	China
Carbon	31.0	30.72	48.0	62.8
Hydrogen	1.88	2.30	-	5.6
Nitrogen	0.52	0.60	-	1.4
Oxygen	6.96	5.35	-	21.7
Moisture	14.0	15.0	10.0	11.0
Sulphur	0.13	0.40	0.30	0.9
Ash	42.0	45.0	12.0	7.7
CV kcal/kg	3805	3000	6300	6087

Fly Ash

More than 40% of ash is generated by burning of coal and the balance is converted as heat energy. 'Fly ash' or Coal ash is substantially more dangerous than household garbage and the Ennore thermal plant is controlling & regulating the environment pollution in order to protect the neighborhood communities. Storing wet coal ash in ponds needs to be phased out as it has increased risk of leaking into waterways. The pollutants like arsenic, sulfate, selenium, magnesium, mercury, chlorides, iron and more in Table 3 (David French and Jim Smitham, 2007) tend to seep from coal ash pond as has been observed in many thermal ash storage ponds. Real time monitoring and preventing further pollution is on the anvil for maintaining the quality of drinking water in the nearby residential areas. The characteristic of the fly ash is the main cause for leaching of minerals. The Table 3 illustrates the properties of both Indian coal ash as well as foreign coal ash.

Table.3. Proximate analysis of Fly Ash

Parameters	Indian coal ash	Australian coal ash
SiO_2 Silicon dioxide	57.90%	56.80%
Al_2O_3Alumina	32.54%	26.30%
Fe_2O_3 Ferric oxide	2.69%	9.50%
CaO Calcium oxide	0.69%	1.40%
MgO Magnesium oxide	0.49%	0.805
LOI (Loss of Ignition)	0.46%	-
SO_3 Sulphur tri-oxide	0.13%	0.30%
Na_2O Sodium oxide	1.44%	0.20%
K_2O Potassium oxide	0.87%	0.70%

Discharge of ash slurry

Collectively, bottom ash and dry fly ash resulting from the combustion of nearly 4350MT coal every day and produced as waste at 43.20% (i.e. 1900MT). Out of this, around 1250MT of dry fly ash is sold out to various companies with 650MT of fly ash left is mixed with sea water at the ratio of 1:12.5 at the power house. It is transported as ash slurry via 4 numbers of Basalt pipeline of 350mm dia to a distance of around 8 Km and discharged into the primary ash pond (Nivit Kumar Yadav, 2007).

Fig.1. Location showing Ennore thermal station. (Source-Google map)

Study Area

Ennore thermal plant

Ennore thermal station located at a distance of around 15 Km on the northern outskirt of the Chennai city, with an installed capacity of 450 MW has started functioning from 1970. Coal requirement at the time of commissioning was 11880MT per day at the calorific value of 3200 Kcal/Kg (approx). The plant has an ash storage pond spread to 262 acres on the N-W direction as mentioned in (Fig.1).

Materials and methods

Existing Ash Storage Pond

Ash pond is a common available disposal facility for thermal power plants. The pond ash is subjected to weathering and the ions present in ash migrate to the surrounding soil and subsequently to the nearby land and ultimately to the ground water aquifers over a period of time. Ash storage pond in this thermal power station spread across 262.15 acres of land (Power Engineer's Hand Book, 2002) in (Fig. 2) surrounded by earthen mound of 35m bottom width and 4m top width with impervious core soil at centre adjoining three layers of filter media on d/s side. The ash mound is constructed on stone columns of 900mm dia, 7m deep at every 2.5m criss-cross distance below the bund to withstand the earth load (Simsiman, 1987). Filter media allows seepage of leachate and collected by drain of 500m deep at d/s of the bund.

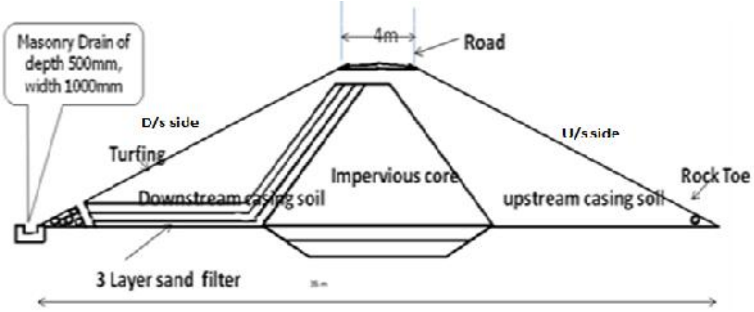


Fig.2. Cross sectional elevation of the ash

The ash bund has two ponds such as primary pond & discharge pond. Ash slurry discharged in the primary pond settles for a considerable period of time and the supernatant decant water flows to the discharge pond for pumping to the clarifier system for treatment before letting into the Buckingham canal leading to sea. A study has been conducted at the storage pond site to monitor the soil quality in order to determine presence of the toxic minerals and its potential impact on ash ponds. Soil samples at various depths from 0m to 4m have been taken at the distance of 20m from the outer edge of the bund. Samples are taken at a single point at surface layer (0m), (1m), (2m), (3m) and (4m). Permeability of soil was very low that resulted in taking up soil sample at single location. Analysis on soil quality was carried out for its toxic constituents like fly ash ions (macro and micro such as Fe, Ca, Mg etc.) which were leached out from the ash up to some extent.

Results and discussion

Soil analysis

Table. 4. Soil characteristic near the ash bund at various depths

Properties	Value gms/Kg at the level				
	0m	1m	2m	3m	4m
Calcium as Ca	140	120	176	100	70
Magnesium as Mg	80	66	94	54	46
Iron as Fe	170	140	21	12	10
Chloride as Cl	490	228	5	2	25
Sulphate as SO4	92	60	71	82	52
Phosphate as PO4	11	12	13	14	15
Sodium as Na	10	9	13	11	8
Potassium as K	2	2	4	3	2

Soil characterization tests have revealed that the soil is a clay type. Much leaching of the heavy metals is not possible through the sub soil layer as the permeability of the soil is $1x10^{-3}$ ft/day in Table 4. However, there was every possibility that leaching and seepage through the bund was allowed by the provision of filter media with various layers of filter media. On porous, silty type of soils, leaching of heavy metals was unavoidable in other thermal power stations such as Mettur thermal power station where the soil is of the nature of loose boulders. Permeability of clay soil 'K' is approximately varies from 0.01 to 0.001 feet per day ($1x10^{-3}$). Particle size distribution of clay soil is less than 0.002mm. A Graph showing the particle size distribution of soil & its classification is given in Fig.3.

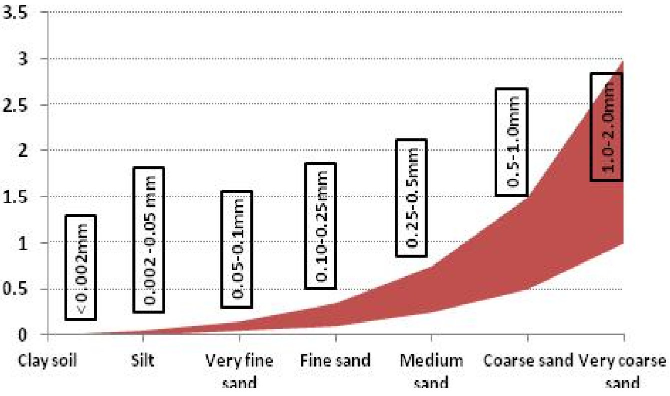


Fig.3. Particle size distribution of soil & its classification

Soil properties have also been analyzed and the characteristic of the soil at the site is given in Table 4. From the Table 4, it was ascertained that the presence of minerals, which exceeded the tolerant limit were Ca, Mg, Fe, and Chloride and thus have to be collected for treatment. Excess chloride ions in soil lead to decreased water uptake by plants. High salts concentration results in high osmotic potential of the soil solution, so the plant has to use more energy to absorb water. Under extreme salinity conditions, plants may be unable to absorb water and will wilt, even when the surrounding soil was saturated. Too much iron can affect plant chlorophyll, causing it to change and inhibiting the plant's ability to properly absorb energy from sunlight. Problems associated with high Mg soils may include the following; reduced vine growth and crop load, K deficiency, poor soil structure and slow water infiltration, and cracking clays. Excess calcium levels in the soil can reduce a plant’s uptake of other nutrients such as phosphorus, potassium, magnesium, boron, copper, iron, or zinc, resulting in deficiencies of these nutrients.

The potential problems and their consequences due to fly ash disposal have been well studied around the world (Yashpal Singh, 2010). It has been determined that leaching of heavy metals was more from the bund above the ground level with the provision of filter media in the core of the bund. Due to uplift pressure, the leaching of stored ash through bund and the stone columns below the bund guide the seepage to the downstream side of the bund. Increase of depth of the drain on the d/s side is very much essential. Depth of 0.50m provided for the drain is required to be increased to grab leaching behavior upto the depth of 2.5m.

Design of RCC drain

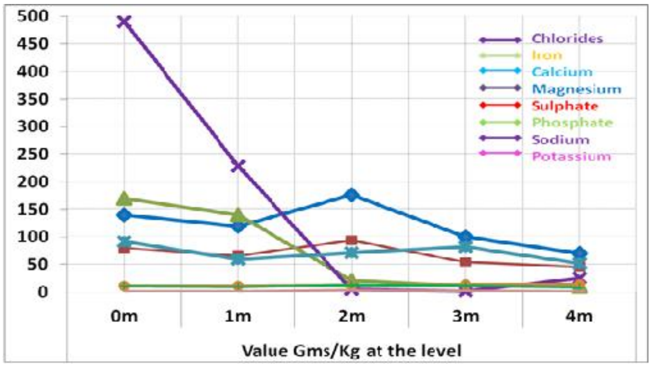


Fig.4. Presence of minerals at various levels of depth near the Ash bund

As the inference from the results revealed that, the leaching of toxic minerals has been more upto the depth of 2.50m and hence it was necessary to design a suitable method for collection of leachate upto this level. Hence, it was necessary to provide the drain to a size of 2.50m wide and 2m deep. The presence of vegetative cover and plant growth on the downstream slope and fly ash ponds, which were covered by soil, may effectively control the leaching of ions. A Reinforced Cement Concrete (RCC) drain of 2.0m (w) x 2.5m (d) was designed based as per the provisions of I.S.456, S.P-34 in Fig. 5 with design check for safe shear. The drain was to be provided all along the periphery of the ash bund length of 4km only on the landside leaving the periphery of the bund where the river adjoins. The collected leachate is taken for further treatment at the existing clarifier system apart from planting specific species of trees, which absorb the heavy metals from leaching into the d/s side.

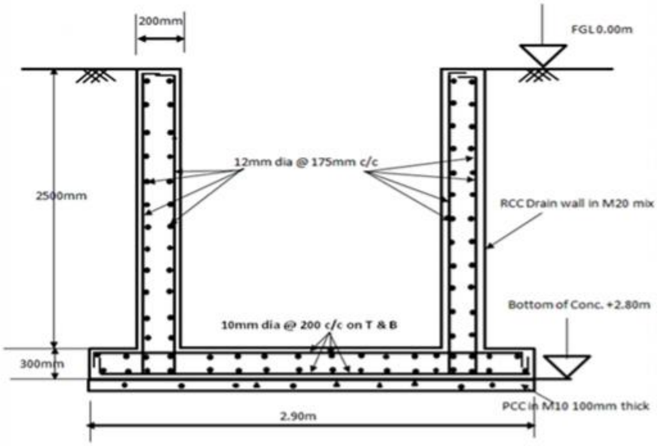


Fig.5. RCC drain section of size 2m (w) x 2.5m (d)

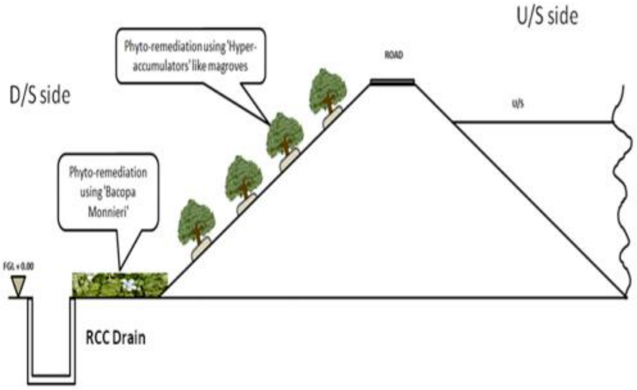


Fig. 6. Phyto-remediation along the slope of the ash bund

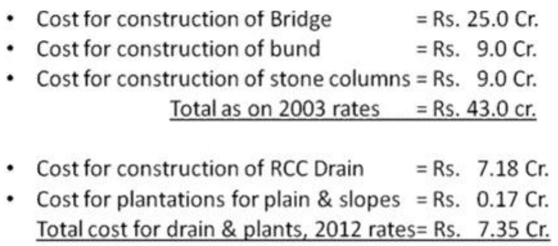
Phytoremediation using Hyper-accumulators

Plants offer many environmental advantages as the plants have extensive root systems that find every crevice in the soil. In addition, to absorbing the toxic chemicals, the root systems stabilize the soil against erosion and preventing the kind of washout that transports soil-borne pollutants into adjoining land, rivers and aquifers (Rai and Amit Pal, 1999). To top it all, plants look much more appealing than bacterial slime. Among the metal-absorbing plants is *Streptanthus polygaloides*, which grows in nickel-contaminated soil and accumulates large amounts of the metal. Members of the genus *Thlaspi* also take up large amounts of heavy metals. These plants are called *Hyper-accumulators*, their tissues contain from 1,000 to 10,000 parts per million (ppm) of certain heavy metals (Bably Kumar and Kajal kumar mondal, 2008).

Organic compounds can be degraded by enzymes, which are expressed in the plant membranes of popular trees. These plants may also stimulate the growth of chemical-degrading bacteria around their roots. The presence of vegetative cover and plant growth on the downstream slope and fly ash ponds, which are covered by soil, may effectively control the leaching of ions. In India, aquatic vascular plants (Sciencedaily, 2011) like Magroove trees, *Hydrilla verticillata, Spirodela polyrrhiza, Bacopa monnierii, Phragmites karka* and *Scirpus lacustris* in Fig. 6 have been used to treat chromium contaminated effluent and sludge from leather tanning industries.

Cost Benefit Analysis

The total cost for the construction of the ash bund along with other facilities such as bridges across the river enroute to the disposal site including the cost of pipes and supports, stone columns etc. was Rs. 43Cr. The cost for HDPE membrane lining in all over the inner surface of the ponds is an alternate method for arresting the leachate worked out to Rs. 20 Crores. Membrane lining subjected to the high risk of damage at the time of removal of wet ash using the heavy machineries and there is no guarantee for the safe leak proof joints, which may be torn off due to the overburden weight of the wet ash.



- Cost for construction of Bridge = Rs. 25.0 Cr.
- Cost for construction of bund = Rs. 9.0 Cr.
- Cost for construction of stone columns = Rs. 9.0 Cr.

Total as on 2003 rates = Rs. 43.0 cr.

- Cost for construction of RCC Drain = Rs. 7.18 Cr.
- Cost for plantations for plain & slopes = Rs. 0.17 Cr.

Total cost for drain & plants, 2012 rates= Rs. 7.35 Cr.

The construction of a RCC drain and planting of hyper-accumulators cost only Rs. 7.35 Cr. (approximate) which accounts for 17.10% of the cost of the entire ash disposal system and only 36.75% on the cost of the HDPE lining. Hence, it is economical as well.

Conclusions

As the overall concern for the environment and the need for the safe disposal of fly ash, a strategic approach evolving potential remedial methodologies to mitigate leaching of toxic minerals is designed for ash storage ponds. It is having high mounds of earth with filter media allowing leaching of coal ash substances and the leaching is subsequently collected in the drain to for further treatment. As a Phyto-remediation technique, plants with its extensive root systems that find every crevice in the soil in addition to absorbing toxic chemicals. In addition, root systems stabilize the soil against erosion, preventing the kind of washout that transports soil-borne pollutants into rivers and aquifers and hence trees are suggested to be planted on the slopes of the bund. The Low Temperature Thermal Desalination method offers ideal scope for utilization of the already hot water which need not require pre-heating as the method of desalination utilizes the increased temperature in the flash vessel by mass transfer of liquid to gas and condensation of the steam. An emphasis is made here for avoidance of purchase of raw water for all purposes and eliminates tapping of ground water with zero environmental pollution.

References

1. Ananth P.Chikkathur (2008) India Coal Reports. Kennady School Govt., Harvard University, MA,
2. David French and Jim Smitham (2007) Fly Ash characteristics and feed coal properties. CSIRO Energy Technology, Australia.
3. Nivit Kumar Yadav (2007) Thermal plants to bear flyash disposal cost. http://www.downtoearth.org/author/.
4. Prasad B and Mondal KK (2008) Heavy metal leaching in Indian Fly Ash. J Environ Sci Eng., 50(2), 127-32.
5. Power Engineer's Hand Book (2002) Edition-6, (P.P), TNEB Engineers.

6. Rai UN and Amit Pal (1999) Toxic Metals and Phytoremediation, National Botanical Research Institute, Lucknow, India, 5(4).
7. ScienceDaily (2001) Disease fighting foods May be derived from Metal loving plants. Available at: http://www.sciencedaily.com/releases/2001/08/010815082019.htm.
8. Simsiman GV, Chesters G and Andren AW (1987) Effect of ash disposal ponds on groundwater quality at a coal-fired power plant. Water Research, 21(4), 417-426.
9. Yashpal Singh (2010) The Ecology of Thermal Power UP Pollution Control Board, PICUP Building, Vibhuti Khand, Gomti Nagar, Lucknow –India.

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