Characteristics of Fly Ash from Thermal Power Plants and its Management along with Settling Pond Design

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Abstract— *World over for production of power pulverized coal fired boilers are extensively used. In India also 80% power is produced by pulverized coal fired boilers in National Thermal Power Plants. A very huge amount of ash is produced from these boilers. The quality of ash varies from plant to plant and from coke to coke depending on source of supply and type of combustion. In this dissertation an attempt has been made to categories problems and solutions related to it as given below:*

For disposal of fly ash various kinds of ash ponds have been discussed, Design and economic aspects have been given. The effect of various type of ash/fly ash on air, land, water, agriculture living creature and human beings have been described. Some solutions have also been suggested. Experimental effect of addition of polymer carboxy methyl cellulose in slurry have been found to increase ash settling rates. For getting optimum ash settling rates 2ppm addition of carboxy methyl cellulose is found to be satisfactory. Utilization of fly ash for production of useful products has been mentioned.

***Keywords—* Coal, Fly ash, Polymer, Settling time of ash, Ash utilization**

I. INTRODUCTION

World over for production of power pulverized coal fired boilers are extensively used. In India also 80% power is produced by pulverized coal fired boilers in National Thermal Power Plants.[1] A very huge amount 200 million tons of ash is produced from thermal plants. The quality of ash varies from plant to plant and from coke to coke depending on source of supply and type combustion. Fly ash is a very fine material produced by burning of pulverized coal in a thermal power plan. Fly ash is a general name used for the residual products of combustion that rise with flue gase. Fly ash, also known as flue ash, it is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. In an industrial context, fly ash usually refers to ash produced during combustion of coal. It is carried by the flue gas and is collected by the electrostatic precipitators or cyclones. Chemically and physically, fly ash can have many forms like C-fly ash and F-fly ash depending upon the type of fuel burned and handling methods. A typical fly ash contains a significant amount of silicon dioxide and calcium oxide, which make it frictional and abrasive. Usually, fly ash has a fine particle size distribution with most less than 100 microns. Given the fine particle size, frictional nature and high temperature, fly ash can be a difficult material to handle reliably. Quantity does pose challenging problems, in the form of land usage, health hazards, and environmental dangers [2].

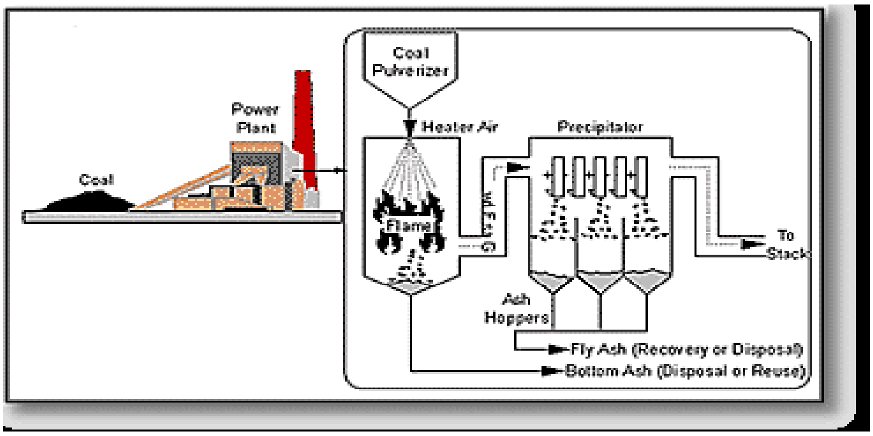


FIGURE 1. PRODUCTION OF FLY ASH IN A DRY-BOTTOM UTILITY BOILER WITH ELECTROSTATIC PRECIPITATOR.

In India coal/lignite based thermal power plants account for more than 55% of the electricity installed capacity and 65% of electricity generation. The ash content of the coal used at the thermal power plants ranges from 30-40%, with the average ash content around 38%. Since low ash, high grade coal is reserved for metallurgical industries. The thermal power plants have to use high ash, low grade coal. The thermal power plants ash generation has increased from about 40 million tonnes during 1993-94, to 120 million tons during 2005-06, and is expected to be in the range of 210 million tons per year 2012.

TABLE 1. FLY ASH GENERATION AND UTILIZATION STATISTICS (2012).

SL NO	Country	Annual ash production, MT	Ash utilization %
1	India	112	38
2	China	100	45
3	USA	75	65
4	Germany	40	85
5	UK	15	50
6	Australia	10	85
7	Canada	6	75
8	France	3	85
9	Denmark	2	100
10	Italy	2	100
11	Netherlands	2	100

II. COMPOSITION

Depending upon the source and makeup of the coal being burnt, the composition of fly ash and bottom ash vary considerably. Fly ash includes substantial amounts of silicon dioxide and calcium oxide which are the main ingredients of many coal bearing rocks. Coal Bituminous coals, sub-bituminous and lignite coals from different mines are substantially different from each other in the combustion process. Coal blending is now used for operational and financial benefits. This results in a wide range of boiler and precipitator operating conditions. Precipitating fly ash from difficult coals can be improved with conditioning systems. However, the furnace and its associated equipment can still cause problems in the precipitator, particularly coal mills, burners, and air pre heaters. The operation of coal burners, together with the setting of the coal mills and their classifiers, affects the percentage of unburned carbon(UBC) in the fly ash. The use of Lo NOx burners increases this percentage, and causes re-entrainment and increased sparking in the precipitator. Further, the UBC tends to absorb SO3, which in turn increases the fly ash resistivity. Toxic constituents of fly ash depend upon the specific coal bed makeup, but may include one or more of the following elements in quantities or trace amounts to varying percentages: Arsenic, molybdenum, selenium, cadmium, boron, chromium, lead, manganese, mercury, strontium, thallium, vanadium, beryllium along with dioxins [3,4].

TABLE 2. NORMAL RANGE OF CHEMICAL COMPOSITION FOR FLY ASH PRODUCED FROM DIFFERENT COAL TYPES (EXPRESSED AS PERCENT BY WEIGHT).

Component	Bituminous	Sub bituminous	Lignite
Silicon dioxide,SiO2	20-60	40-60	15-45
Aluminium oxide,Al2O3	5-35	20-30	10-25
Iron oxide,Fe2O3	10-40	4-10	4-15
Calcium oxide,CaO	1-12	5-30	15-40
Magnesium oxide,MgO	0-5	1-6	3-10
Sulphur Trioxide,SO3	0-4	0-2	0-10
Sodium Carbonate,Na2O	0-4	0-2	0-6
Potassium oxide,K2O	0-3	0-4	0-4
LOI,(Loss-on-ignition)	0-15	0-3	0-5

TABLE 3. ENGINEERING PROPERTIES OF FLY ASH PARAMETER

Engineering properties of Fly Ash	
Parameter	
Specific gravity	1.90-2.55
Plasticity	Non Plastic
Proctor compaction - Maximum dry density (gm/cc)	0.90-1.60
Optimum moisture content (%)	38.0-18.0
Angle of internal friction (O)	30^0-40^0
Cohesion (kg/cm ^{2})	Negligible
Compression index	0.05-0.4
Permeability (CM/SEC)	10^5-10^3
Particle size distribution	
Clay size fraction (%)	1-10
Silt size fraction (%)	8-85
Sand size fraction (%)	7-90
Gravel size fraction (%)	0-10
Coefficient of uniformity	3.1-10.7

III. CLASSIFICATION

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO4) contents are generally higher in Class C fly ashes. Class C fly ash can be identified from its light brownish color.

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the additions of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer. Class F fly ash can be identified by its dark brownish color.[4]

Traces of industrial pollutants has been identified in isolated human, animal, and plant populations accounting to the fact that they can travel immense distances due to climatic effects not only hurting the environment in a number of ways but also imparting negative impacts on human health and life.

- The severe problems that arise from such dumping are:-
- The construction of ash ponds requires vast tracts of land. This depletes land available for agriculture over a period of time.
- When one ash pond fills up, another has to be built, at great cost and further loss of agricultural land.
- Huge quantities of water are required to convert ash into slurry. During rains, numerous salts and metallic contents in the slurry can reach down to the ground water and contaminate it.

IV. PROBLEMS ASSOCIATED WITH DISPOSAL OF FLY ASH

Primarily, the fly ash is disposed off using either dry or wet disposal schemes. In dry disposal, the fly ash is transported by truck, chute, or conveyor at the site and disposed off by constructing a dry embankment (dyke). In wet disposal, the fly ash is transported as a slurry through pipe and disposed off in impoundment called "ash pond". Ash ponds have been provided at all coal based stations except Dadri where Dry Ash Disposal System has been provided. Ash ponds have been divided into lagoons and provided with garlanding arrangements for change over of the ash slurry feed points for even filling of the pond and for effective settlement of the ash particles. Ash in slurry form is discharged into the lagoons where ash particles get settled from the slurry and clear effluent water is discharged from the ash pond. The discharged effluents conform to standards specified by CPCB and the same is regularly monitored. At its Dadri Power Station, NTPC has set up a unique system for dry ash collection and disposal facility with Ash Mound formation. This has been envisaged for the first time in Asia which has resulted in progressive development of green belt besides far less requirement of land and less water requirement as compared to the wet ash disposal system Land Requirement- Some of the factors affecting land requirement are ash utilization, PLF (Plant load factor), height of dyke, shape and topography of land, substrata, land use pattern, seismic zone, coal parameters etc. Most of the power plants in India use wet disposal system and when the lagoons are full, Four basic options are available:-

- Constructing new lagoons using conventional construction material.
- Hauling of fly ash from the existing lagoons to another disposal site.
- Raising the existing dyke using conventional construction material and
- Raising the dyke using fly ash excavated from the lagoon (ash dyke).

The option of raising the existing dyke is very cost effective because any fly ash used for constructing dyke would, in addition to saving the earth filling cost, enhance disposal capacity of the lagoon. An important aspect of design of ash dyke is the internal drainage system. The seepage discharge from the internal surfaces must be controlled with filters that permit water to escape freely and also to hold particles in place and the peizometric surface on the downstream of the dyke. The internal drainage system consists of construction of rock toe, 0.5 meter thick sand blanket and sand chimney. After completion of the final section including earth cover the turfing is developed from sod on the downstream slope [5].

V. ENVIRONMENTAL CONSIDERATIONS

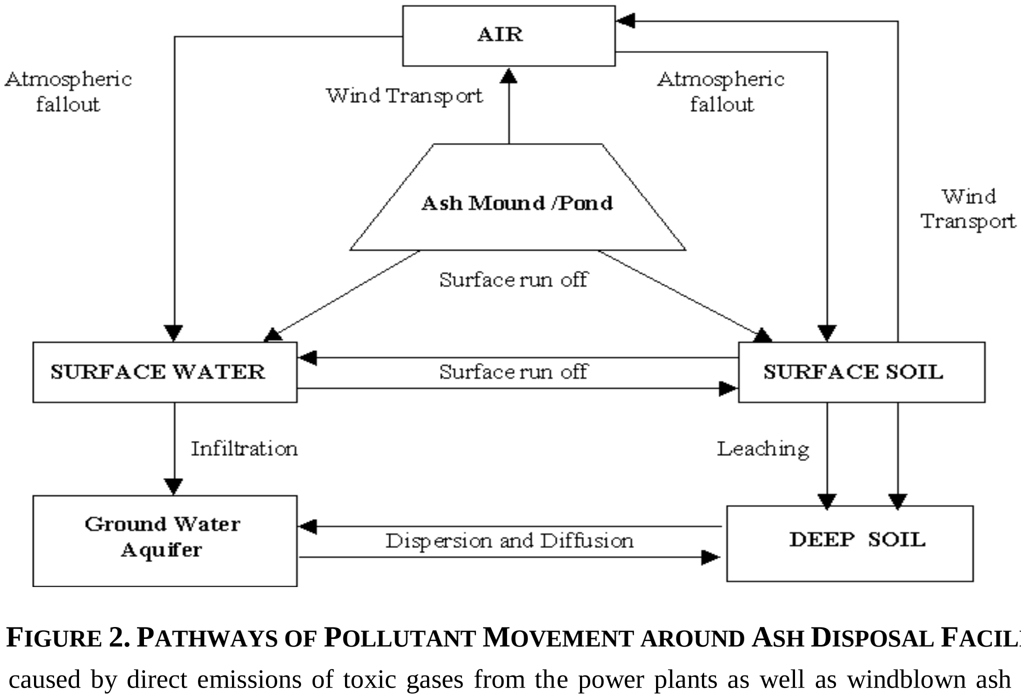


FIGURE 2. PATHWAYS OF POLLUTANT MOVEMENT AROUND ASH DISPOSAL FACILITY.

Air pollution is caused by direct emissions of toxic gases from the power plants as well as windblown ash dust from ash mound/pond. The airborne dust can fall in surface water system or soil and may contaminate the water/soil system. The wet system of disposal in most power plants causes discharge of particulate ash directly into the nearby surface water system. The long storage of ash in ponds under wet condition and humid climate can cause leaching of toxic metals from ash and contaminate the underlying soil and ultimately the groundwater system. However, most of these environmental problems can be minimized by incorporating engineering measures in the design of ash ponds and continuous monitoring of surface and groundwater water systems [6].

VI. METHODOLOGY

An ash pond is an engineered structure for the disposal of bottom ash and fly ash. The wet disposal of ash into ash ponds is the most common ash disposal method, but other methods include dry disposal in landfills. Dry handled ash is often recycled into useful building materials. Wet disposal has been preferred due to economic reasons, but increasing environmental concerns regarding leachate from ponds has decreased the popularity of wet disposal.The wet method consists of constructing a large "pond" and filling it with fly ash slurry, allowing the water to drain and evaporate from the fly ash over time.[2,7] Ash ponds are generally formed using a ring embankment to enclose the disposal site. The embankments are designed using similar design parameters as embankment dams, including zoned construction with clay cores. The design process is primarily focused on handling seepage and ensuring slope stability[8]. Leachate from fly ash can contain heavy metals in excess of allowable RCRA standard.The flow of water through the fly ash and into ground water is controlled by using low permeability clay layers and cut off trenches/walls. Low permeability clays have permeability on the order of 10^{-7} cm/s. Vertical flows through the foundation are controlled by fly ash ponds on areas of thick clay or rock layers that provide suitably low permeability through the base of the pond. Areas with high subsurface permeability can be improved by importing suitable clay. Horizontal flows through the embankment are controlled using clay zones within the embankment. Cut off trenches and cut off walls are used to connect the embankment clay zones and the foundation clay layers. Cut off trenches are trenches that are dug into the selected low permeability subsurface layer and backfilled with clay to key the embankment clay zone into the subsurface.

VII. PARTS OF ASH HANDLING SYSTEM

- Bottom Ash Handling System ,
- Coarse Ash (Economizer Ash)handling system
- Air Pre Heater ash handling system
- Fly ash handling system
- Ash slurry disposal system

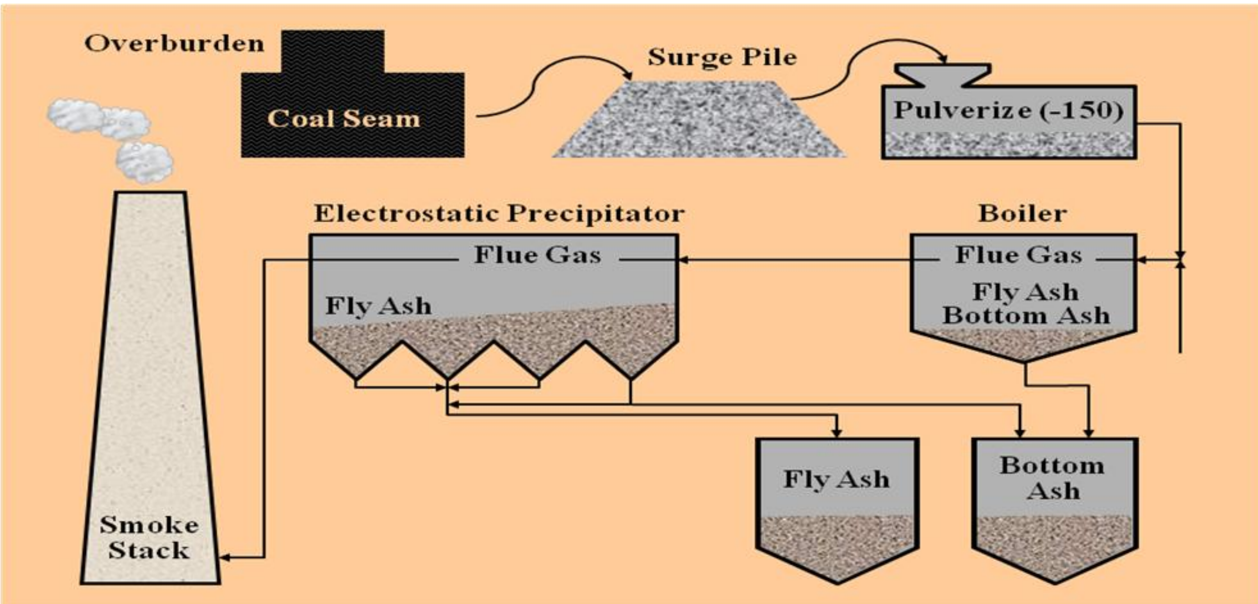


FIGURE 3. VIEW OF ASH HANDLING SYSTEM

VIII. ASH POND DESIGN AND MAINTENANCE

Fly ash from the electrostatic precipitator and bottom ash from the bottom of the boiler are mixed together and is subsequently mixed with water in a ratio varying from 1 part ash and 4 to 20 parts of water. The slurry is then pumped into the ash ponds which are located within or outside the thermal power plant. Depending on the distance and elevation difference, energy required for pumping is very high and requires booster pumps at intermediate locations. No well design procedure or codal provision exists for the ash pond construction and maintenance. There are several examples of failures in ash ponds which resulted in leakage of fly ash-water slurry into the surrounding areas including water bodies and creating environmental hazard. The ash pond is designed economically and proper procedures are adopted to avoid any kind of leakage from the ash ponds. Hydrostatic pressure over the full height of the bund is minimized by decanting the water which travels away from the bund forming a sloping beech and only the ash being settled close to the bund [7].

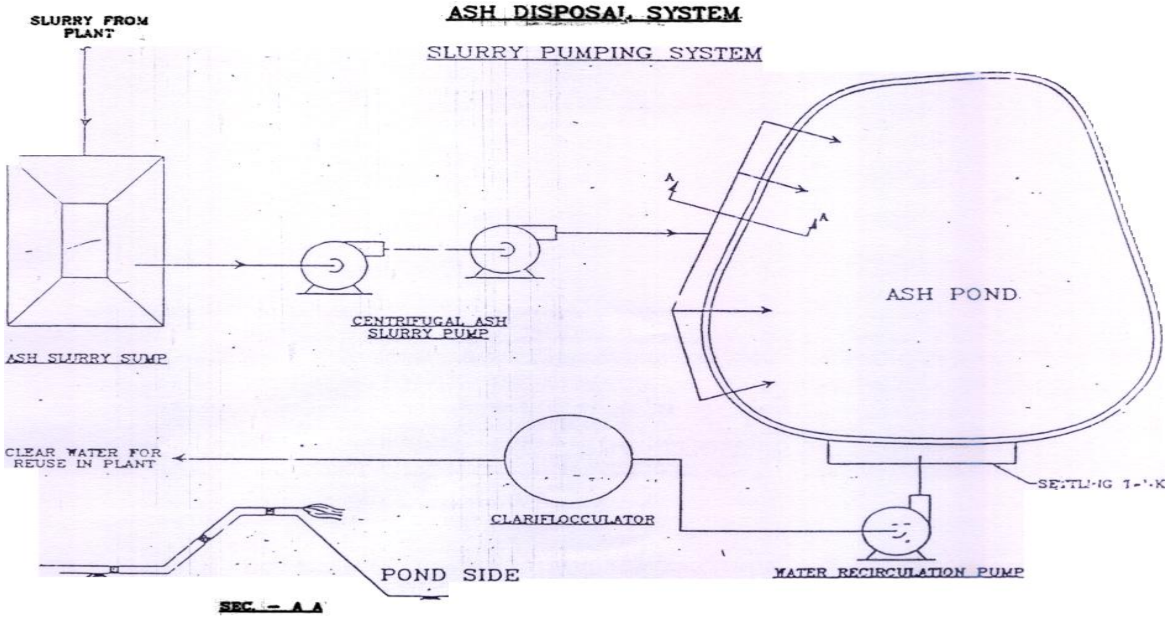


FIGURE 4. ASH DISPOSAL SYSTEM

IX. DESIGN OF BUND

The increased embankment height, and the corresponding increase in the ash pond level, imposes greater load on existing embankment and foundation. At the same time, the pore pressure and seepage condition also gets significantly affected. The necessary design features associated with the raising of the embankment are: height of the embankment, crest width, side slope, compacted soil cover to preserve the compaction moisture content, graded filter to arrest piping and having suitable drain characteristic to reduce exit gradient, toe drain to evacuate the seepage water emanating from the foundation and dyke to control the development of excess pore-water pressure, and a trench drain to collect and dispose the emanated water. The suitability of existing filter and other drainage elements must be reevaluated and re-designed at various stages of raising to account for the change in the hydraulic conditions and phreatic line. Furthermore, compacted gravel drains can be installed below the proposed embankment to reduce the possibility of soil liquefaction during earthquake, and to accelerate the consolidation settlement with a target to improve the strength characteristics of the underlying soil. Unlike a water reservoir, the ash pond is generally constructed in stages, each raising having a height of 3-5m. The various methods of stage-wise construction are described herein:[7,8]

The cost of construction of a single ash pond is generally high. But this cost can be reduced by constructing the ash pond in stages by various methods like (i) Upstream construction method, (ii) Downstream construction method and (iii) Centre line construction method. Each stage has an increasing or incrementing height of 3-5 m. The above methods are described in brief and their advantages & disadvantages:-

(i) Upstream construction method:

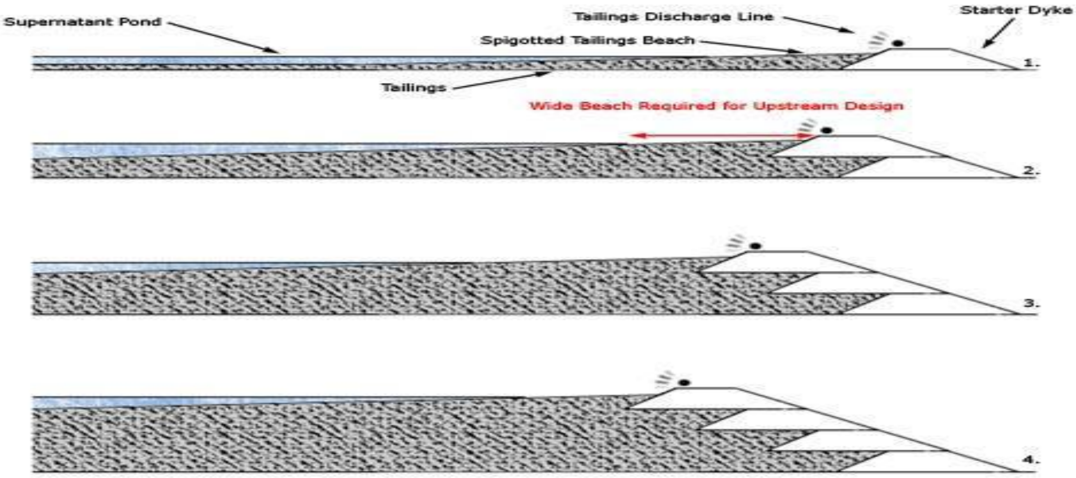


FIGURE (I) UP-STREAM CONSTRUCTION METHOD.

The above construction method has the minimum cost involved in it. Operational requirements such as haul and access roads, culverts, diversion and perimeter ditches may be constructed easily to serve the entire useful life of facility. This is the most preferred method of construction as the quantity of earthwork required is minimal.Disadvantages- Since the total weight of the new construction is supported by the deposited ash, the ash deposition should be perfect in order to have adequate load bearing capacity.As the height of the pond increases, the area of the ash pond goes on decreasing and beyond certain stage, it becomes uneconomical to raise further height of the dyke.The drain at the upstream face should be well connected to the drain of the earlier segment, else ineffective drainage can result in reducing the stability of the slope.The ash pond cannot be operational while raising the height of the dyke by this method of construction. The pond needs to be dried to initiate the construction work.

(ii) Down-stream construction method:

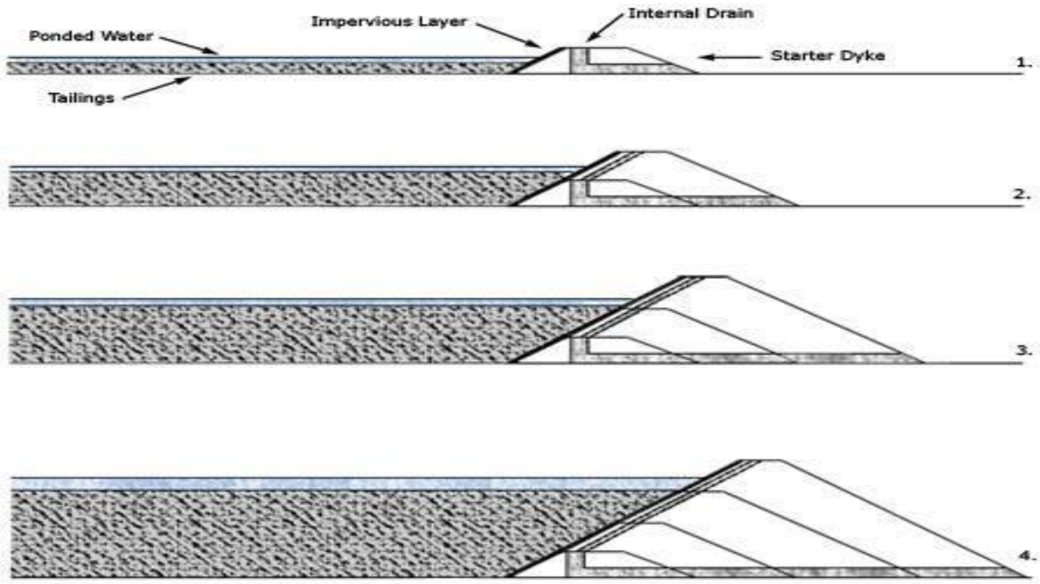


FIGURE: (II) DOWN-STREAM CONSTRUCTION METHOD

After the pond gets filled up to the first stage, the pond height is increased by depositing the fly ash or earth on the downstream face of the dyke as shown in the figure. The advantage of this method of construction of ash pond is that the height of the dyke can be raised even if the pond is operational. Disadvantage of this method is that it involves approximately the same cost and amount of construction as in single stage construction.

(iii) Centre line construction method:

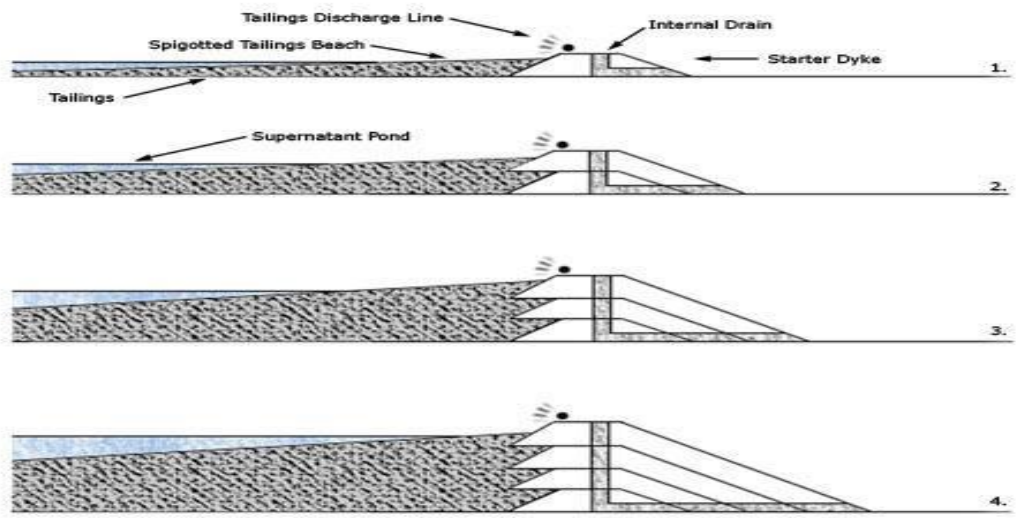
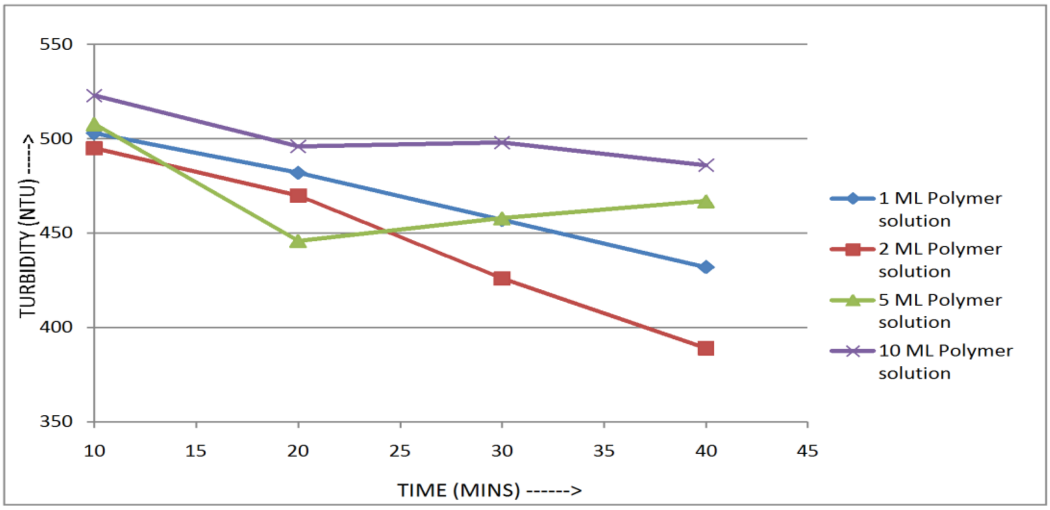


FIGURE:(III) CENTRE LINE CONSTRUCTION METHOD.

After the pond gets filled upto the first stage, earth or fly ash is deposited on either side of the centre line of the dyke so that the centre line of the dyke remains at the same location as shown in the figure above. The amount of material required for raising the height of the dyke is less as compared to the downstream construction method. The construction cannot be initiated while the pond is operational. As the material is required to be deposited on the settled fly ash, it is not possible to carry out the construction when the pond is in operation.

X. SETTLING CHARACTERISTICS OF FLY ASH

The slurry of fly ash i.e bottom ash and fly ash with water is pumped into ash ponds.It is very important to know that the ash settles down in the pond quickly.The rate of settling of fly ash is much slower in water.[9]Therefore, some chemical solutions are needed to speed up this process. In this research paper a solution of carboxy methyl cellulose was taked in different concentrations with samples of ash and distilled water (standards solution). The turbidity of the mixtures were measured. The graph shows the variation of turbidity. It has been found that 2ml polymer solution addition brings down the turbidity to a value 389 NTU.



GRAPH 1. TURBIDITY VS. TIME CHARACTERISTICS

XI. UTILIZATION OF FLY ASH

Demonstration projects are taken up in areas of Agriculture, Building materials, Mine filling etc. The utilisation of ash and ash based products is progressively increasing as a result of the concrete efforts of these groups for improving the plant economy and in reducing environmental impact.[1,10,11] Some of the major uses of fly ash have been listed below : -

- Fly ash bricks / blocks
- Cellular concrete products
- Light weight aggregates
- Concrete and mortar
- In manufacture of cement
- In manufacture of asbestos products
- Road construction
- Embankment/back fills/land development
- Controlled low strength material (CLSM)
- In agriculture
- Mine filling
- Manufacture of fertilizer

XII. CONCLUSION

For disposal of fly ash various kinds of ash ponds have been discussed, Design and economic aspects have been given. The effect of various type of ash/fly ash on air, land, water, agriculture living creature and human beings have been described. Some solutions have also been suggested. Experimental effect of addition of polymer carboxy methyl cellulose in slurry has been found to increase ash settling rates. For getting optimum ash settling rates 2ppm addition of carboxy methyl cellulose is found to be satisfactory. Utilization of fly ash for production of fly ash bricks/blocks, cellular concrete product, light weight aggregates, cement production, agricultural land fills, mine filling and in road construction have been suggested.

REFERENCES

[1] Fly Ash-Wikipedia, the free encyclopedia En.wikipedia.org/wiki/Fly_ash-12k.Xiuping Feng, Boyd Clark, Evaluation of the Physical and Chemical Properties of Fly Ash products for use in Portland Cement Concrete, 2011 world of coal Ash (WOCA) Conference held in Denver, Co. USA on May 9-12, 2011

[2] Electricity Sector in India ,ash pond-Wikipedia,the free encyclopedia. en.wikipedia.org/wiki/Electricity_sector_in_India.

[3] Narayanan C.M, Bhattacharya B.C, “Mechanical operations for chemical engineers”, khanna publishers, 2005.

[4] Masa Eisa S, saleh Abdel hady M, Taha Taha A, mollo Anos M El, “Effect of chemical additives on flow characteristics of coal slurries”, july 31, 2008.

[5] Disposal and Management of Fly Ash. Anil Kumar Dixit and Lokesharappa.Naresh,D.N. 2011 International Conference on Life Science and Technology, IPCBEE Vol.3 (2011) © (2011) IACSIT Press, Singapore.

[6] Parisara, State environmental related issues, Department of forest, ecology and environment, government of Karnataka, vol.2 no. 6, January 2007.

[7] Gandhi S.R, “Design and maintenance of ash pond for fly ash disposal”, IGC-2005, 17-19 December 2005.

[8] Raju V.S, Datta M, Seshadri V, Agarwal V.K, Kumar V, “Ash ponds and disposal systems”, Narosa publishing house, 1996.

[9] Kumar Hemant, Mishra D.P, Das samir kumar, “Settling characteristics of fly ash of Talcher thermal power station”. 1st Asian mining congress; The mining geological and metallurgical institute of India (MGM),centenary, 16-18 January, 2006.

[10] Fly Ash Utilization-Present vision. Pinaki Sarkar, CSIR-Central Institute of Mining and Fuel Research.1999,2013, Dhanbad, India.

[11] Sahu Patitapaban, “Characterization of coal combustion by-products (ccbs) for their effective management and utilization”, Department of mining engineering, 2009-2010.