Development Engineering Project Report

On

Effective Deposition of Fly Ash

Submitted as per CP301(Development Engineering Project) course requirements under the guidance of Dr. Resmi Sebastian

By :-

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DECLARATION

We hereby declare that the report titled "Effective Deposition and Utilisation of Fly Ash" presented by us, for the course on Development Engineering Project in the Third year of the B.Tech Programme at IIT Ropar, is true and correct. We declare that this written submission contains our ideas as well as the ideas or words of others. In the event of other people's ideas or words, we have properly cited and referenced the original sources. We have not misinterpreted any idea/data/fact/source to the best of our knowledge. Therefore, we state that our group has adhered to all principles of academic honesty and integrity.

DATE: 23/04/2023

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ACKNOWLEDGEMENT

Presentation, inspiration, and motivation have always been crucial to the success of any business effort. We began our endeavour with this in mind. At the outset of our report, we'd like to offer our heartfelt gratitude to all those who engaged with us to work as a team and complete this project despite the extraordinary circumstances. Without their ongoing support and advice, the report would not have been possible. We are grateful to everyone who came out to assist us by filling out our surveys and providing us with the needed information. We'd also want to express our gratitude to our institute, Indian Institute of Technology, Ropar, for integrating the course 'Development Engineering Project' in our curriculum, which allowed us to complete this project while also expanding our knowledge.

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INTRODUCTION

Fly ash is a powdery and fine substance, a byproduct of burning pulverized coal in power plants. When coal is burned, it produces various types of ash, including bottom ash, which settles down at the bottom of the combustion chamber, and fly ash, which gets carried away by the flue gases.

It is produced as a waste by the flaming of coal, having fine particles which rise up with the flue gases. However, nowadays, before the flue gases of coal-fired power plants reach the chimneys, it is stopped by electrostatic precipitators or other particle filtration equipment.. It is primarily composed of Al(alumina), Si(silica), Ca(calcium) and Fe(iron), along with trace amounts of other elements.

Fly ash is proved to be a useful resource with a wide range of uses. The efficient deposition and use of fly ash has the potential to revolutionise numerous industries while minimising negative environmental effects, from construction materials to energy production. The current use cases, however, can be improved with technology and new materials because the existing are not very sustainable. Join us as we examine the intriguing potential of fly ash and how it can open the door to a more sustainable future.

- India – largest producer of coal in the world. According to the Ministry **of Coal GoI**, app. **778.19 million tons** of coal is produced in **2021-22** with a positive growth of **8.67% as compared to 2020-2021,** which results in the generation of more than <u>270 million tons of fly ash</u> annually.
- **According to the CPCB (**Central Pollution Control Board**) and MoEFCC (** Ministry of Environment, Forest and Climate Change**)**, about 95.95% of the fly ash generated in India is utilised, and the rest is stored in ash ponds, which can cause environmental issues.
- The Government of India has also launched various initiatives to promote the utilisation of fly ash, such as:

  <u>The Fly Ash Mission</u> which aims to increase the fly ash utilisation in India to 100%. The government has also <u>mandated the use of at least 25% of fly ash</u> in all construction projects nearby thermal power plants.

Different technologies have been adapted since 1994 under the Ministry of Science and Technology (GOI) for the safe and effective utilisation of fly ash, increasing its utilisation from 6.64 million tonnes in 1996–1997 to 168.40 million tonnes in 2018–19.

CLASSIFICATION OF FLY ASH

On the basis of type of coal used, the combustion temperature and procedure, as well as the manner of collection, fly ash is categorized based on its chemical and physical characteristics. Based on the quantity of calcium oxide (CaO) in the ash, the following categories are used to classify fly ash:

Fly Ash classification according to ASTM C618 (American Society for Testing and Materials):

1. **Class F Fly Ash**: Class F Fly Ash, commonly referred to as low-calcium fly ash, is created when bituminous or anthracite coal is burned. It is distinguished by its pozzolanic characteristics, high iron oxide, silica and alumina content, and a CaO concentration of less than 10%. It is often employed in the creation of concrete and other building supplies.
2. **Class C Fly Ash:** Class C Fly Ash, commonly called high-calcium fly ash, is created when sub-bituminous coal is burned. It is characterised by its self-cementing characteristics and has a CaO concentration of 15% to 30%. It can be used in the partial replacement of Portland cement in concrete mixes.

There are numerous forms of fly ash that can be created from the burning of various types of coal or by other collecting techniques, in addition to these two basic categories. These consist of:

3. **Class N Fly Ash:** It has a low CaO concentration and is created by burning lignite or sub-bituminous coal. It has characteristics with Class F fly ash.
4. **Class S Fly Ash:** It is created when sulfur-rich coal is burned, and it contains a lot of sulphur trioxide (SO_3). Usually, it's employed in the creation of high-performance concrete.

Fly Ash type according to IS Codes (IS 3812-1981):

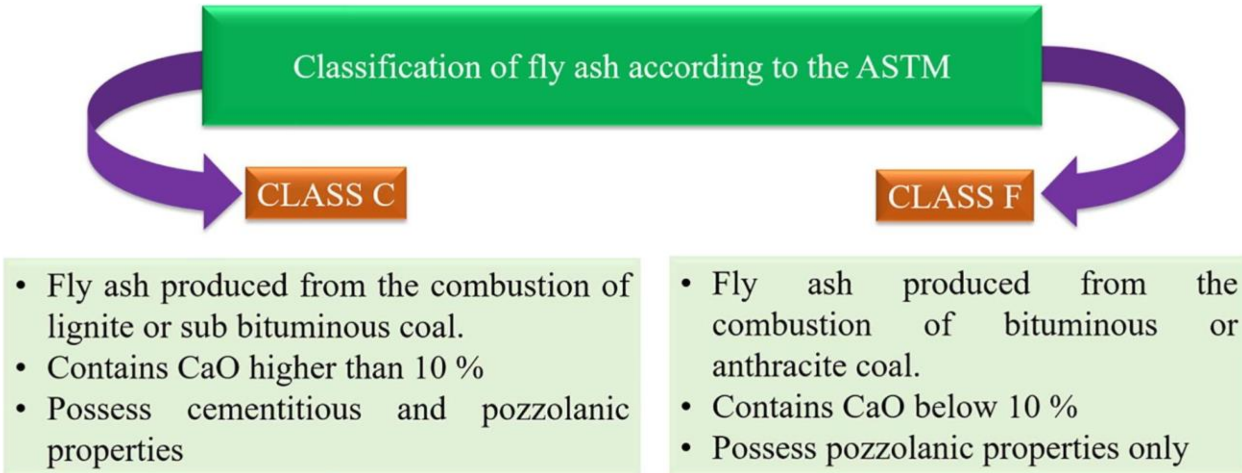
Grade I: It is made from bituminous coal with SiO_2, Al_2O_3, and Fe_2O_3 percentages that are more than 70%.

Grade II: It is made from lignite coal with SiO_2, Al_2O_3, and Fe_2O_3 percentages that are larger than 50%.

Depending on boiler operations, the kind of fly ash:

Low temperature (LT) Fly Ash: This is formed at low temperatures (LT) - at less than 900 °C temperature of combustion.

High temperatures (HT) Fly Ash: This is produced through combustion at temperatures lower than 1000 °C.



SOURCE: [Fly ash properties, characterization, and applications: A review - ScienceDirect]()

PROPERTIES OF FLY ASH

Physical properties: -

- **Particle size:** Fly ash is a fine, powdery substance, with the majority of the particles lying from 10 to 100 microns in size. The particle size distribution might change depending on the type of combustion technology employed and the collecting procedure.
- **Fineness of Fly Ash:** The average value of fineness modulus is around 2-2.5.
- **Colour:** Fly ash ranges from grey to black in colour, depending on the coal source, combustion conditions and chemical & mineral constituents: Lime content gives tan & light colours, whereas the presence of iron content imparts brownish colour.
- **Density:** Fly ash is a relatively low-density material, with a specific gravity typically ranging from 2.0 to 2.6, which makes it less dense than cement.
- **Porosity:** Fly ash has a high surface area and a large number of open pores which makes it a porous material.
- **Flowability:** Fly ash has good flowability, making it easy to transport and handle.
- **Electrical conductivity:** Fly ash is a good electrical insulator, but it can conduct electricity when exposed to moisture or other conductive materials.
- **Surface area:** Fly ash typically has a surface area of 300 to 600 square metres per kilogramme and is a very fine powder, which makes it an effective material for adsorption and catalysis.

Chemical properties:-

- **Chemical composition:** Fly ash is primarily composed of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO), along with trace amounts of other elements such as magnesium, potassium, sodium, and titanium.
- **pH:** Fly ash is typically alkaline, having a pH range of 8 to 11.5.
- **Leaching behaviour:** Fly ash can leach out trace amounts of heavy metals such as arsenic, lead, and mercury depending on the condition of combustion and the source of coal in the power plant.

- **Pozzolanic activity:** Fly ash exhibits pozzolanic activity, which means it interacts with cement and water to produce a hardened substance. It forms calcium silicate hydrate (C-S-H), a key component of concrete, in the presence of water by reacting with calcium hydroxide. The reactivity of fly ash depends on its chemical makeup.
- **Mineralogical composition:** Fly ash's mineralogical makeup might change depending upon the combustion procedure and type of coal used. Fly ash contains the mineral phases quartz, mullite, hematite, magnetite, and calcium-silicate-hydrates (C-S-H).
- **Glass content:** A sizable portion of fly ash is made up of amorphous, glassy material. The fly ash's reactivity and potential for usage as a pozzolanic material can be influenced by the glass concentration.
- **Trace element content:** Fly ash may contain traces of several materials, including heavy metals and other substances found in coal. On the basis of the coal source and environment, these elements' concentrations can change.

FLY ASH COMPOSITION

The inorganic amorphous phase's crystalline and glass mineral constituents, along with partially or completely unburned black carbon, are the principal representatives of the FA's mineralogical composition. Fly ash is divided into primary, secondary, and tertiary stages based on the formation time. There is no change in the primary stages. Secondary stages including oxides and silicates are created during the burning of coal. Additionally, the transfer of fly ash made of portlandite and gypsum creates the tertiary phases. Trace elements, Si, Ca, C, Fe, O, Ti, H, K, Na, P, Al, N, Ba, and Mg are the main components of fly ash.

1. **Crystalline phases:** 5 to 50 percent of the bulk of fly ash is made up of crystalline components. There are 10 phases in the crystalline phases. Class C fly ash contains anhydrite (CuSO4), merwinite, periclase, and C3A. Mullite, melite, quartz, hematite (Fe2O3), magnetite (Fe3O4), and lime are other minerals. To distinguish between the reactive and stable crystal phases in FA, XRD is used to identify the crystal phases. C3A, anhydrite, and periclase are the reactive phases that are most susceptible to sulphate assault; stable phases are not produced in sulphate or hydration processes.

2. **Amorphous phases:** Circular particles in the amorphous phase, which are created by quenching particles and the chaos they cause, have a diameter size range of 1 to 5 m. This abnormality results in a lack of crystal structures, which makes them challenging to characterise. When parent coal has a low calcium percentage, aluminosilicate glass is created, but when parent coal has a high calcium concentration, calcium aluminosilicate glass is produced. Because Class C Fly Ash is more reactive than Class F Fly Ash, the latter is regarded as a known reactive phase.

3. **Black carbon (Unburned carbon):** Unburned carbon (UC) is a sign of ineffective combustion. The beneficial applications of Fly Ash among a variety of applications are hindered by UC. The primary factor in determining the kind, rank, circumstances of combustion, and coal feed size is coal-derived UC parameters.

Properties of Unburned Carbon:

(a) In the adsorption of organic substances such as petroleum components, phenols, polychlorinated biphenyls, and herbicides

(b) As the method for capturing valuable and hazardous elements, particularly flue gas mercury;

(c) As a low-cost supply of cokes and activated carbons which can be used in graphite manufacturing.

Chemical composition of Fly Ash:

Fly ash is made up of a variety of different substances, but all fly ash contains calcium oxide (CaO), aluminum oxide (Al2O3) and silica dioxide (SiO2) in substantial levels. Depending on where it comes from and how the power plant is operating, the characteristics of fly ash vary.

Component	Bituminous coal	Sub bituminous coal	Lignite coal
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO3	0-4	0-2	0-10
Na2O	0-4	0-2	0-6
K2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

SOURCE: What is Fly Ash? Physical and Chemical Properties of Fly Ash – Mastercivilengineer

<u>USES OF FLY ASH</u>

Fly ash has been used as an alternative to another industrial resource, process, or application for a number of reasons, such as the reduction of environmental pollution, cost and dumping area associated with disposal, substitution of more expensive resources, and financial benefit.
Following are some industries/area where coal fly ash is used widely:-

- **Concrete production:** In concrete production cement is partly replaced by flyash. It works as an admixture to improve the performance of concrete.

  As per IS:1489 (Part-I), we can substitute maximum 35% of OPC by mass with fly ash in concrete production.

  Mixing flyash with concrete lead to form a strong and durable material that is resistant to chemicals, abrasion, and fire. Also it improve workability, decreases water demand, lowering the cracking potential and reduce heat of hydration.

- **Cement production:** Flyash used widely in cement production as a raw material by cement industries at a large scale.

  Portland cement typically contains over 60% lime, some of which remains unreacted during hydration and can react chemically with fly ash silicates to form cementitious compounds. By incorporating fly ash into Portland cement, significant reductions can be achieved in bleeding, shrinkage, and heat of hydration, while also improving workability, durability, and ultimate strength. In addition to these benefits, the use of fly ash can also result in cost savings and a reduced environmental impact of cement production.

- **Brick and block production:** BIS (IS 3495: part 2 & IS 10077) has specified that up to 50% of the clay content in bricks and blocks can be replaced with fly ash. These bricks are cheap, durable, more compressive strength and highly fire resistant as compared to clay bricks. The fly ash based bricks are known to have higher compressive strength and are lightweight.

  <u>According to the CEA</u> (Central Electricity Authority) in 2018-19 9.96 % of the total fly ash generation is used in brick production.

- **Fly Ash for stabilization of expansive soils:** The mineral composition of certain soils makes them highly vulnerable to alterations in moisture levels, causing them to undergo changes in volume that can lead to the collapse of structures due to excessive settling. The extent to which a soil can undergo volume changes is primarily influenced by its plasticity, with soils possessing a higher plasticity index being more prone to such changes.

  When Fly Ash is mixed with these soil there is reduction in volume change and decrease in plasticity. This can be attributed to the change in soil grain size, specifically the transition from clay size to silt size, which occurs as a result of the presence of quick lime in Fly Ash.

- **Fly Ash in stabilized base course:** Fly Ash is greatly useful in road construction and embankments to improve its properties, such as strength, stability, and permeability. It can also reduce the amount of water needed to compact the soil, making it more cost-effective.

  Road bases made by partial use of flyash are strong, more durable, and cheap as compared to other base materials. It is important to exercise caution regarding seasonal fluctuations, and as a precautionary measure, proper sealing and protection with asphalt should be employed.

- **Agriculture:**

  Fly ash addition generally decreased the bulk density of soils, which in turn improved soil porosity and workability and enhanced water retention capacity The water holding capacity of sandy/loamy soils increased by 8% due to fly ash amendment, and accompanied an increase in hydraulic conductivity helped in reducing surface encrustation

  Fly ash increases the water retention capacity of soils because it causes structural and textural changes. The capacity of the soil to hold water is related to the surface area, pore space volume and continuity of pore space. This property is beneficial to soils, especially under rain-fed agriculture.

  Fly ash can be used in agriculture as a soil amendment to improve soil fertility and crop productivity. As it provides micro-nutrients like Fe, Zn, Cu and Boron. Some micronutrients like potassium (K), phosphorus (P) and calcium (Ca).

- **Fly Ash mix as a replacement for earthen/sand backfilling or land reclamation:**

  A well-proportioned mix of water, portland cement, fly ash if needed some coarse and fine aggregates also called as a flowable fill can be effective as a replacement for earthen backfills especially in small spaces like behind abutment walls, basement walls, retaining walls.

  The suitability of flowable fill in such cases is due to its self-compacting and self-leveling nature. This material is also called a lean mix backfill, flowable fly ash, controllable density fill.

  Considering the costs associated with transporting, placing, and compacting of earthen backfill materials, this method of using flowable fill not only provides an economical alternative but also increased strength and less maintenance.

  The strength of flowable fill directly depends on the quantity of cementitious material present. Typically, Flowable Fill made with Class C based Fly Ash possesses greater strength in comparison to Flowable Fill made with Class F based Fly Ash, as a result of the higher CaO content found in the Class C.

- **Others :** Used to melt ice on roads & parking lots.

Sustainability of the use cases of Fly Ash

Fly ash has many uses, but if it causes the depletion of natural resources or the destruction of ecosystems, its usage may not be sustainable.

It contains a variety of toxic and hazardous substances, including heavy metals like Pb,Hg,As, Cd,Ni,etc and radioactive elements like Th,U,Ra,Tc,Sr, etc which can leach into groundwater. Hence these metals pollute soil, groundwater as well as water bodies leading to risk of development of cancer and may cause many other hazards to human health & aquatic life.

Some of the examples are:

- In the case of using fly ash for **soil stabilization**, heavy metal present in fly ash can leach out to the groundwater, contaminating the soil and leading to a threat to the environment and hence its degradation.
- Also, in the case of **road construction**, heavy metal contamination can affect the nearby ecosystem and wildlife.
- Additionally, due to the scarcity of land and the adverse effects of **landfilling**, the use of landfills as a waste management solution is not sustainable.
- Using fly ash in **agriculture** can lead to the accumulation of heavy metals in crops which can pose a risk to the human health and animals.
- Fly ash can also be used for **environmental remediation** but depending on the concentration and type of contaminants present it’s effectiveness can vary making it an unsustainable and unpredictable solution.

Fly Ash a Threatening Problem

Fly ash is a byproduct of combustion of coal in power plants and other industrial facilities. It is a fine powder which is carried away from the combustion chamber by fuel gases and is collected by ESP or other particle filtration systems. Though fly ash can be used as a raw material in the cement and other construction materials production, it can also pose a threatening problem when it is not properly managed.

The production of fly ash results in the need for significant amounts of space for disposal and poses a threat to the environment.

This is due to the low quality of Indian coal, which has a high ash content (30-45%) compared to imported coal (10-15%). In 2018-19, 217.04 million tons of fly ash were generated.

If fly ash is not disposed of properly, it can harm local ecosystems by causing heavy metal pollution through erosion and leachate generation. Furthermore, fly ash can become airborne due to its weightlessness, contaminating the surrounding areas and affecting surface and groundwater, soils, and vegetation by releasing its hazardous metals.

One of the biggest threats associated with fly ash is its potential to contaminate air, water, and soil. The fine particles can become airborne and cause respiratory problems for humans and animals. If the particles settle on nearby water bodies, they can create toxic conditions that can harm aquatic life and make the water unfit for human consumption.

In addition to the health and environmental risks, fly ash can also pose a threat to infrastructure. If not properly stored, the fly ash can leach into the soil and cause ground stability issues. It can also corrode pipes and other metal structures, leading to costly repairs.

Furthermore, fly ash can also contain heavy metals and other pollutants that can pose a long-term risk to human health and the environment. These pollutants can accumulate in the food chain, potentially leading to health issues for those who consume these contaminated food.

In conclusion, fly ash is a potentially threatening problem if not properly managed. It is important for power plants and other industrial facilities to follow proper disposal and management procedures to minimize the risk of contamination and environmental harm.

So, there are two major constraints of coal-based thermal power plants, (1) land requirement for fly ash disposal, and (2) controlling the pollution, suspended particulate matter (SPM) as well as the movement of heavy metals into groundwater and food chain.

Fly ash production and utilization in India

Table 1: Fly ash generation and utilization during the year 2015 to 2021

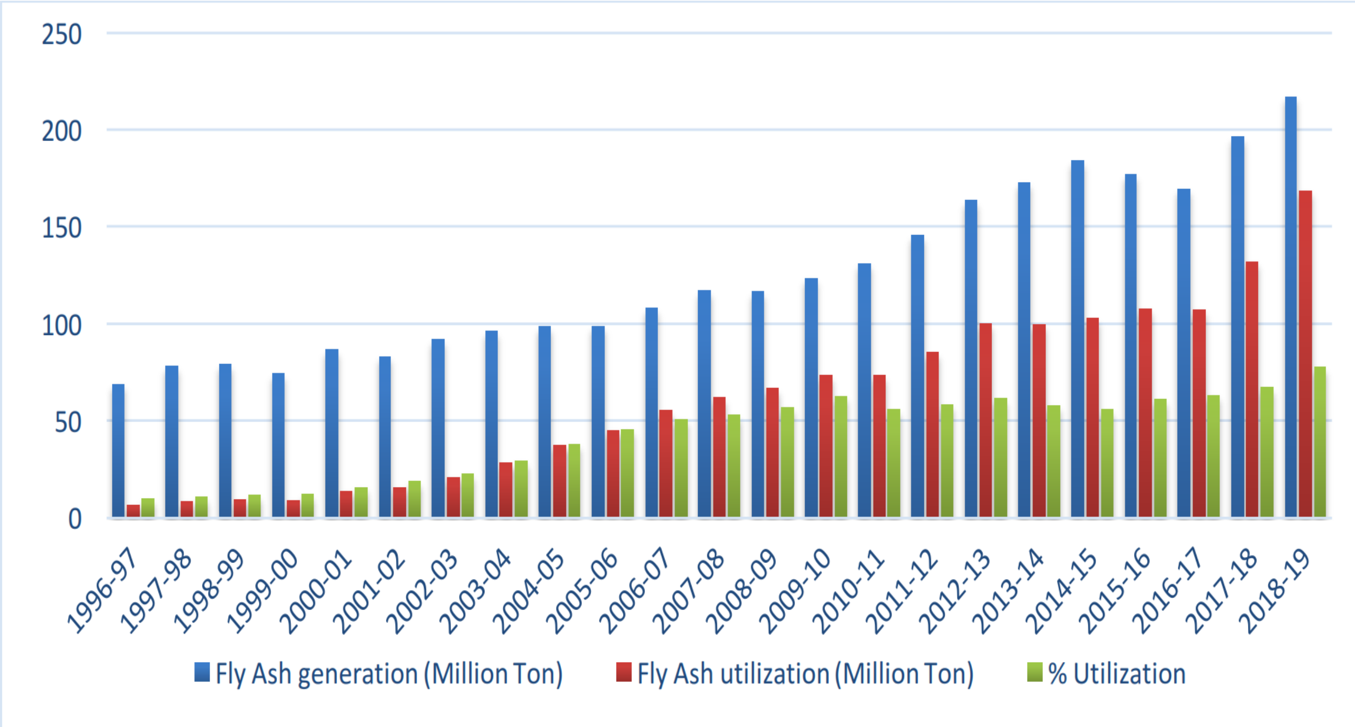
Description	2015-16	2016-17	2017-18	2018-19	2020-21
Number of Thermal Power Stations	151	155	167	195	202
Installed Capacity (MW)	145044.80	145044.80	177070.00	197966.50	209990.50
Coal Consumed (Million Tons)	536.64	536.4	624.88	667.43	686.34
Average Ash Content (%)	32.94	33.22	31.44	32.52	33.88
Fly Ash Generation (Million Tons)	176.74	169.25	196.44	217.04	232.56
Fly Ash Utilization (Million Tons)	107.77	107.10	131.87	168.40	214.91
% Utilization	60.97	63.28	67.13	77.59	92.41

Source: [CEA annual report 2021-22]

Table 2: Fly ash utilization during the year 2020-21

S.NO.	Mode of utilization	Utilization (Million tons)	% Utilization
1	Cement.	60.0229	25.81
2	Mine Filling	14.4187	6.20
3	Bricks and Tiles.	30.1832	12.98
4	Reclamation of Low Lying Area.	36.2463	15.59
5	Ash Dyke Raising	18.4722	7.94
6	Roads and Fly Over	34.9851	15.04
7	Agriculture.	0.0773	0.03
8	Concrete	1.9189	0.83
9	Hydro Power Sector	0.0611	0.03
10	Others.	18.5267	92.41
11	Unutilized Fly Ash	17.6469	7.59
	Total generated	232.5595	100.00

Source: CEA annual report 2021-22



Fly ash generation and utilization from 1996-2019

Experiments performed on fly ash in Lab:-

Specific Gravity:

The Specific Gravity (G) is the ratio of mass of given volume of solid in air to the weight of an equal volume of distilled water at STP. Here we used a specific gravity Bottle method for experiment. It is an important parameter for material identification, quality control and formulation of admixture and estimation of properties. Specific Gravity can be calculated using formula

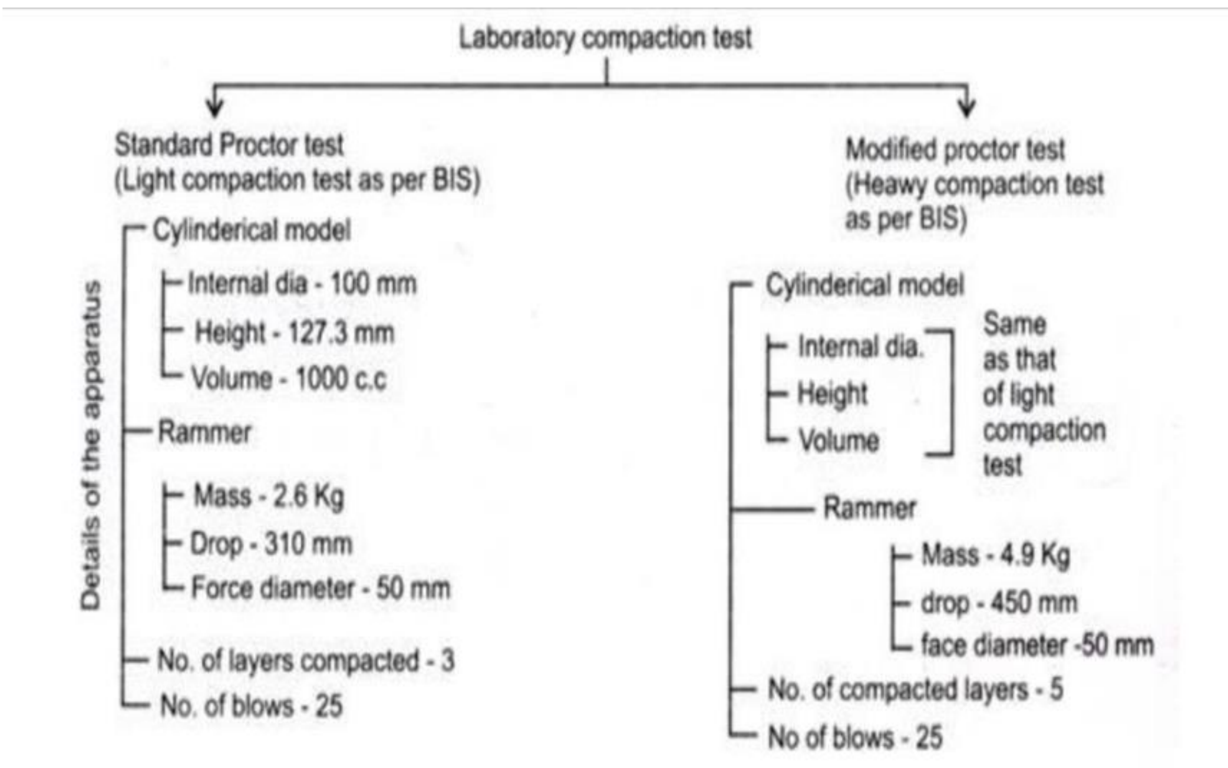
$$G = \frac{W2-W1}{(W4-W1)-(W3-W1)} \quad or \quad \frac{\text{dry density of fly ash}}{weight\ of\ distilled\ water\ of\ equal\ volume}$$

Bottle No.	**1**	**2**	**3**	
Empty Weight of density bottle (W1), gm	38.16	37.23	39.52	
Weight of density bottle + Fly ash (W2), gm	73.52	71.33	72.66	
Weight of density bottle + Fly ash+ Water (W3), gm	159.88	160.55	158.92	
Weight of density bottle + Water (W4), gm	140.17	139.24	141.53	
specific gravity	2.2594	2.6661	2.1041	**Avg** =2.3415

We got the value of **specific gravity =2.3415**

COMPACTION

Compaction refers to the dynamic loading process, which involves rolling, tamping or vibration, used to densely pack fly ash particles together. This process reduces the amount of air voids without any significant changes to the water content of the fly ash. Essentially, compaction involves utilizing machinery to compress the fly ash into a smaller volume, which results in increased dry density and enhanced engineering properties. As solids and water are nearly incompressible, the reduction in the volume of air facilitates compaction.



Optimum Moisture Content (OMC):

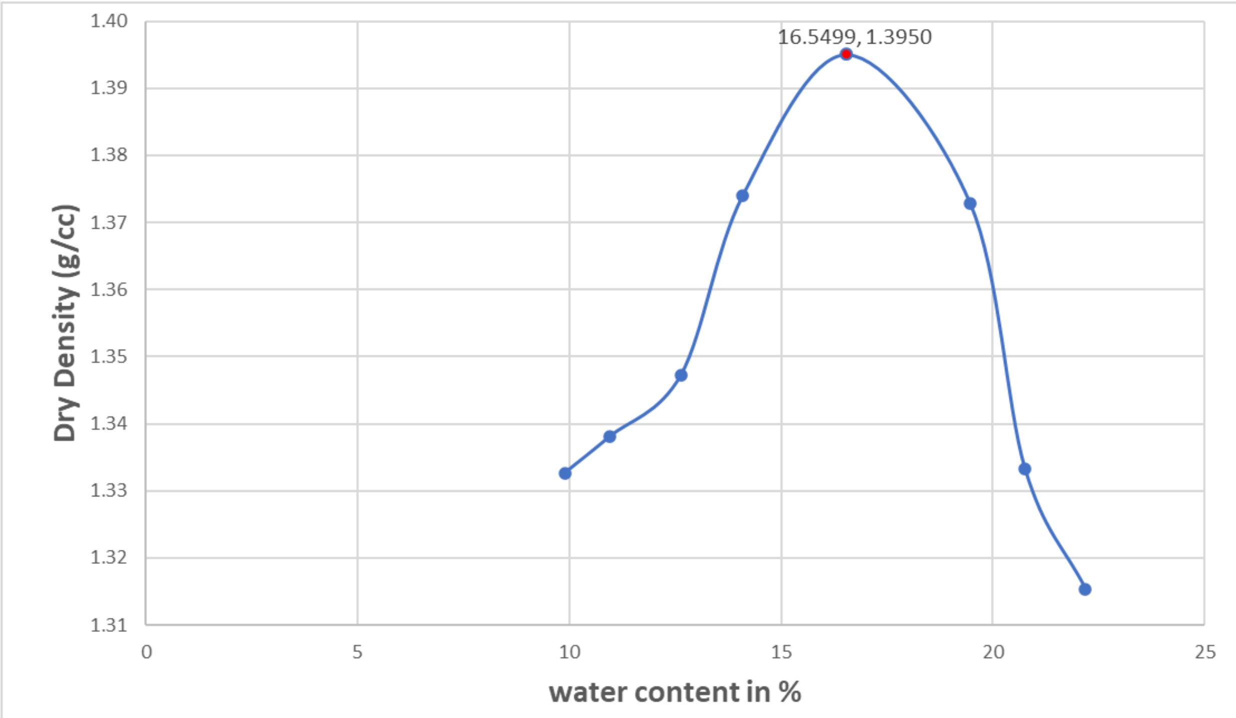
The water content or moisture content at which the flyash attains the maximum value of its dry density is maximum is known as optimum moisture content. It has an important role in compaction, strength and durability.

Following table shows the specification of apparatus used in experiment:-

Weight of empty mould (kg) W1	4.311
Height of mould (cm)	12.7
Internal Diameter of mould (cm)	10
Oven dry sample taken (kg)	3
Initial water content added (ml) (10% of dry sample taken)	300
Specific Gravity of fly ash	2.65
Volume of mould (cc)	997

Observations and calculation:

S.No.	1	2	3	4	5	6	7	8
Weight of mould + wet fly ash (kg)) W2	5.79	5.8	5.82	5.874	5.932	5.946	5.92	5.91
weight of wet fly ash (kg) W3	1.46	1.48	1.51	1.563	1.621	1.635	1.60	1.60
Bulk Density (g/cc) = W3 /V	1.46	1.48	1.52	1.5677	1.6259	1.6399	1.61	1.61
Weight of empty container (g) M1	16.39	16.45	13.57	16.25	15.28	16.62	16.67	16.26
Weight of container + wet fly ash (g) M2	22.28	23.75	21.86	27.26	28.59	31.85	42.8	47.39
Weight of container + dry fly ash (g) M3	21.75	23.03	20.93	25.9	26.7	29.37	38.31	41.74
Water content W = (M2-M3) /(M3-M1)	9.89	10.94	12.63	14.09	16.55	19.45	20.75	22.17
Dry Density (g/cc) = bulk density/(1+W)	1.330	1.340	1.347	1.374	1.395	1.373	1.333	1.315



From the above graph we can see that **OMC value =16.55%** and Maximum dry density at the OMC is 1.395 gm per cubic cm.

California bearing ratio test (CBR)

The California Bearing Ratio (CBR) test is a standard test method used to determine the load-bearing capacity of material and flexible pavement materials. It was developed by the California Division of Highways in the 1930s and has since become widely used worldwide.

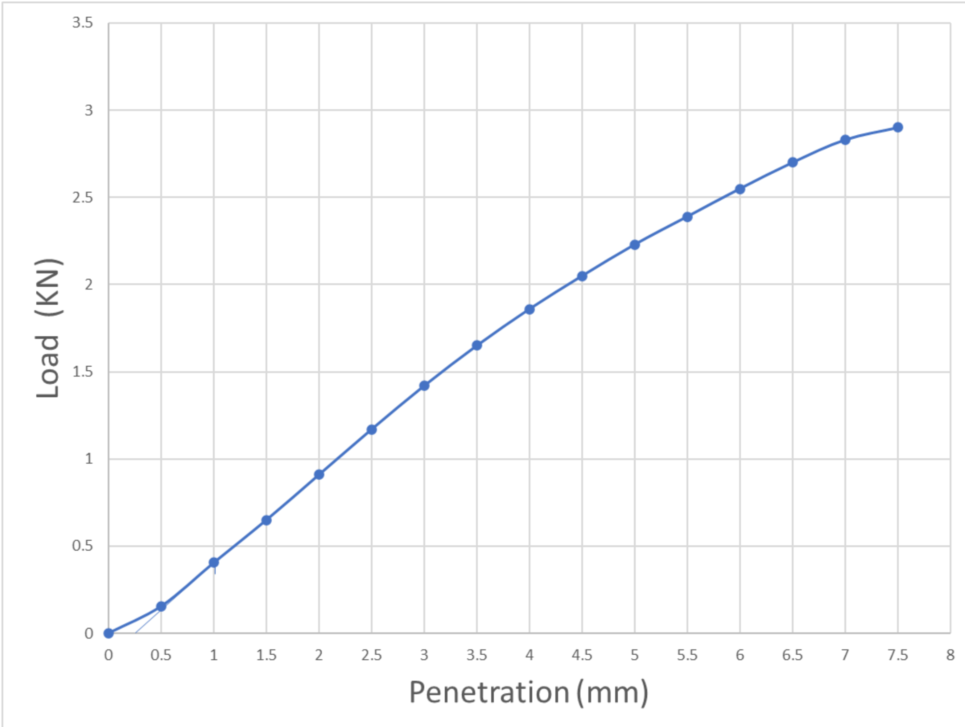
The CBR test involves measuring the penetration resistance of a flyash sample under controlled conditions. The test is typically performed in a laboratory, although it can also be done in the field. A cylindrical flyash sample is compacted into a mold at a specific moisture content and density, and a standardized piston is then pressed into the soil at a specific rate of penetration. The load required to achieve a specific depth of penetration is recorded, and the CBR value is calculated as the ratio of the load required to penetrate the flyash to a certain depth to the load required to achieve the same penetration in a standard material, typically crushed limestone.

The CBR value is an important parameter in designing and evaluating the performance of flexible pavements, such as asphalt or concrete, and in selecting suitable subgrade materials. A higher CBR value indicates a stronger and more resilient soil or pavement material that can withstand heavier loads without excessive deformation or rutting. The CBR test is also used to determine the thickness of the pavement layers required for a given traffic loading and soil conditions.

The table given below shows the observations and the specifications of the apparatus & CBR testing machine.

Observation	
Weight of dry fly ash (g)	4000
Weight of empty mould (g)	3662
Weight of wet fly ash+ mould (g)	7360
Weight of wet fly ash (g)	4660
Diameter of mould (cm)	15
Height of mould (cm)	17.5
Height of spacer disk (cm)	4.8
Volume of mould (cm3)	3092.51
Bulk Density of fly ash (Vs)	1.6259
Area of plunger (cm2)	19.625
Rate of base plate (mm/minutes)	1.25

Dial Gauge (mm)	Proving Ring Reading (divisions)	Load (Applied Force) (kN)	Load (kg)	Pt, Load on piston (kg/cm2)
0	0	0	0	0
0.5	15.5	0.155	15.800	0.8051
1	40.5	0.405	41.284	2.1037
1.5	65	0.65	66.259	3.3763
2	91	0.91	92.762	4.7268
2.5	117	1.17	119.266	6.0773
3	142	1.42	144.750	7.3758
3.5	165	1.65	168.196	8.5705
4	186	1.86	189.602	9.6613
4.5	205	2.05	208.970	10.6482
5	223	2.23	227.319	11.5831
5.5	239	2.39	243.629	12.4142
6	255	2.55	259.939	13.2453
6.5	270	2.7	275.229	14.0244
7	283	2.83	288.481	14.6997
7.5	290	2.9	295.617	15.0633



In the above graph we made a straight line/tangent at the point where concavity of graph changes (i.e, point (1,0.45)) and get Corrected zero is **0.2 mm**. So to find load value at 2.5mm and 5mm, add the correction value of 0.2mm in it {i.e, find load in above graph at 2.5+0.2 =2.7mm and 5+0.2=5.2 mm penetration).

Calculate the CBR value using following formula:

$$CBR\% = \frac{Corrected\ Load\ Value}{Standard\ Load} \times 100\%$$

Penetration depth (mm)	Pt (kN) (corrected Load)	Ps (kg/cm2) standard	Ps (in kN)	CBR
2.5	1.27	**70**	13.44	9.45
5	2.294	**105**	20.15	11.38

<u>pH Test:</u>

This test is performed to check the nature of ashes whether they are acidic, basic or salts.

Material	**pH_1**	**pH_2**	**Average**
Fly ash	8.23	8.45	8.34

From the pH test it is concluded that the flyash is **basic** in nature.

Results of all the above Lab test

Name of Experiment	Value obtained from experiment
Specific Gravity	2.34
Optimum Moisture Content	16.55%
Mamimum Dry Density	1.395 g/cc
CBR value (2.5mm Penetration)	9.45
CBR value (5.0mm Penetration)	11.38
pH test	8.34 (Basic in nature)

Flyash Testing and Characteristic Techniques

1. **X-ray Diffraction (XRD):**

   The fly ash crystalline phases are qualitatively identified using XRD. By striking the solid sample with electrons, XRD causes it to produce x-rays. Different x-ray behavior after colliding with a crystal structure can be studied. Some x-rays diffract according to how crystalline the structure is, while others will pierce deep through the material and eventually collide with a crystal. The X-ray equipment creates a pattern by scanning the angles of scattered and diffracted patterns and measuring their intensities. By graphing the generated patterns to connect diffraction angle to diffracted intensity, a diffractogram is created.

2. **X-ray fluorescence (XRF):** All varieties of fly ash are evaluated for their bulk oxide contents using XRF. Additionally, XRF is routinely used to determine the composition of the amorphous phase. FA is stimulated by high-energy x-rays that produce secondary or fluorescence x-rays. Secondary x-rays were used to identify the FA oxide concentrations both quantitatively and subjectively.

Target Area - Bathinda Region of Punjab

⇒ As per CEA statistics, the Punjab state is one of the most fly ash producing states in the country in FY 21-22.

⇒ Thermal power facilities in the Bhatinda district of Punjab yearly create more than a million tonnes of fly ash.

⇒Major fly ash producing Thermal Power Plants in the region are Guru Nanak Dev Thermal Power Plant (460 MW) , Guru Hargobind Thermal Plant (920 MW), Talwandi Sabo Power Plant (1980 MW), Rajpura Thermal Power Plant (1400 MW).

Determination of Concentration of Ur and Cs in Fly Ash (GNDPT, Bathinda)

Place	Mean Value of Norm Concentration	
	Uranium(mg/Kg)	Cesium(mg/Kg)
Inside Thermal Power PLant	1.6±0.04	0.3±0.011
Ash Dyekeria	1.42±0.02	0.17±0.011
Outside the Plant (5Km)	1.62±0.127	0.26±0.005
Outside the Plant (10Km)	1.62±0.127	0.3±0.017
Outside the Plant (15Km)	1.45±0.02	0.17±0.011

Guru Nanak Dev Thermal Power Plant, Bathinda
Source: https://in.pinterest.com/pin/463026405413825819/

Rajpura Thermal Power Station, Rajpura
Souce: https://www.babushahi.com/upload/image/NPL1.JPG

FlyAsh Percolation Causes Groundwater Pollution

As per MOEF standards and the literature analysis it is evident that the mixing of fly ash with concrete to create embankments is the primary use of fly ash.

As per our analysis, we know that Fly ash is a byproduct of coal combustion, and it contains several contaminants, including heavy metals like arsenic, cadmium, tin, lead, and mercury. When fly ash is disposed of in landfills or ponds without proper containment or if it rains it can react with these hazardous heavy metals and can leach into the groundwater, contaminating it and posing a risk to human health and the environment.The degree of contamination being the highest under the dumping sites and mining sites which has the highest concentration of fly ash dumped in the ground.By placing the layer over these sites, it serves as a means of entrapment of contaminants and prevent them to reach to the groundwater or other reaching sensitive receptors like wells, streams or wetlands.

SOLUTION

One main solution is to use **G**eopolymer **S**ynthetic **C**lay **L**iners. Geopolymer Synthetic Polymer sheets are thin liners that can be used as a means of entrapment of the bottom ash or the contaminants from reaching groundwater.

Clay liners have low permeability, which means they can effectively contain the fly ash and prevent it from leaching into the groundwater(immobilization of toxic metal materials).

What is a Geo-Polymer Synthetic Clay Liner?

⇒ Geopolymers are a class of inorganic, non-metallic materials that are formed through a chemical reaction between a source of aluminosilicate material and an alkaline solution. They are a type of "cement alternative" that can be used in construction and other applications.

Unlike traditional Portland cement, which requires high-temperature firing of limestone and clay, geopolymers can be formed at much lower temperatures, and without the need for carbon-intensive processes. They are also known for their high strength and durability, as well as their resistance to fire, acid, and other types of damage.

Geopolymers can be made from a variety of materials, including fly ash, blast furnace slag, and metakaolin (a type of clay mineral). They have a wide range of attainable uses, such as in coatings and adhesives, the manufacturing of lightweight building materials, and as a binding agent for concrete. They are also being studied for use in environmental remediation, such as the solidification and stabilisation of hazardous waste.

Reaction involved in formation of Geopolymer synthetics:

Aluminosilicate Geopolymer matrix source (Fly Ash)	+	Alkaline activating solution	$\Longrightarrow$	Flowable cementitious paste	$\Longrightarrow$	Geopolymer matrix

- Aluminosilicate cementitious (Inorganic polymeric framework), amorphous or partially crystalline.
- Innovate and alternate material to conventional bentonite clay.
- General formula for these geo-polymer is $M_n[-(SiO_2)_z\text{-}AlO_2]_n.wH_2O$

  M= monovalent cation (Na+, K+), and n= the degree of polymerisation and z=1,2,3 or higher.

Source:https://ars.els-cdn.com/content/image/1-s2.0-S0959652616300798-fx1_lrg.jpg.

Why GeoSynthetic Polymer over Bentonite Clay Liners?

Bentonite Clay liners have been traditionally used as a barrier material due to their low permeability and ability to retain moisture. These polymers finds greater edge over Bentonite Clay liners:

- Geosynthetic polymers are more flexible than clay liners, which can be beneficial in situations where the liner may experience **differential settlement** or other movements.
- Geosynthetic liners can be designed to be highly resistant to chemical attack, making them suitable for use in **harsh chemical environments**.

In general, the initial cost of geosynthetic liners may be higher than that of clay liners, but they can offer long-term cost savings due to their durability and resistance to degradation.

Analytical Approach

We computed a short case study based on some relevant facts and costs associated with the materials and processings.

⇒ **Here's an example cost-benefit analysis comparing geopolymer synthetic liners to traditional bentonite clay liners for a hypothetical landfill application:**

Assumptions:

- The landfill is expected to operate for 20 years.
- Area of the dumping site is 10000 sq. meters.
- The cost of materials and installation for a geopolymer synthetic liner is Rs. 50 per square meter, and the cost of materials and installation for a bentonite clay liner is Rs. 35 per square meter.
- The expected maintenance and monitoring costs for the geopolymer synthetic liner are Rs. 20,000 per year, and the expected maintenance and monitoring costs for the bentonite clay liner are Rs. 30,000 per year.

- The benefit associated with the reduced health risk of the environment from contaminants, improved public health and increased regulatory compliance is Rs. 1,00,000 per year for geopolymer synthetic and Rs. 6,0,000 per year for bentonite clay liners.

The discount rate used for this analysis is 7%.

Solution-

For Bentonite Clay Liners:

Initial investment (1st-year cost)= 350000

Subsequent maintenance costs (annual)= 30000

Annual benefits received as a result of the investment= 60000

Discount rate to be used for the calculation= 7%

The number of years over which you want to calculate the NPV= 20

Total Net Present Value⇒ $\sum_{i=0}^{20} Values\ corredpong\ to\ ith\ year$

Plugging in the given values, the NPV can be calculated as:

NPV ⇒ (-350000) + (60000 - 30000) / (1 + 0.07) + (60000 - 30000) / (1 + 0.07) ^ 2 + ... + (60000 - 30000) / (1 + 0.07) ^ 20

NPV ⇒ -350000 + 8316.08 + 7744.28 + ... + 768.64

NPV ⇒ 119083.53

For Geopolymer synthetic Clay Liners:

Initial investment (1st-year cost)= 500000 Rs.

Subsequent maintenance costs (annual)= 20000 Rs.

Annual benefits received as a result of the investment= 100000 Rs.

Discount rate to be used for the calculation= 7%

The number of years over which you want to calculate the NPV= 20

Plugging in the given values, the NPV can be calculated as:

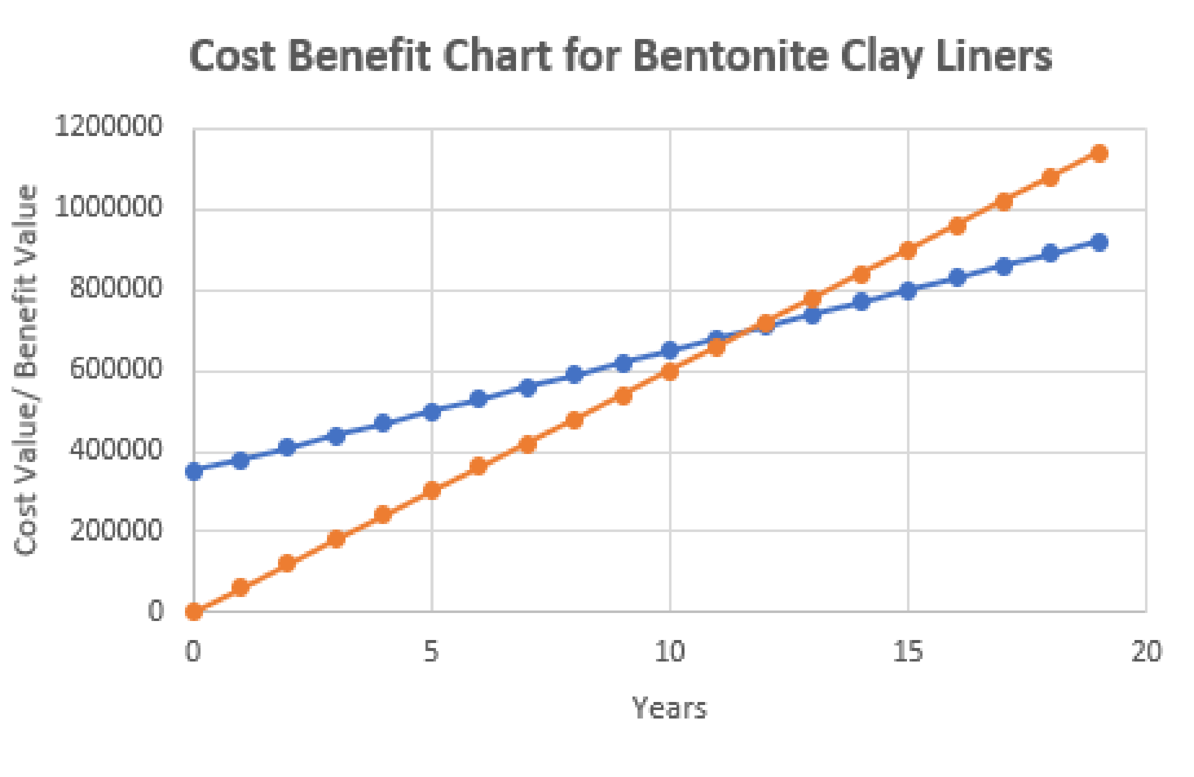
NPV ⇒ (-500000) + (100000 - 20000) / (1 + 0.07) + (100000 - 20000) / (1 + 0.07) ^ 2 + ... + (100000 - 20000) / (1 + 0.07) ^ 20

NPV ⇒ -500000 + 7082.63 + 6609.67 + ... + 656.39

NPV ⇒ 173465.07

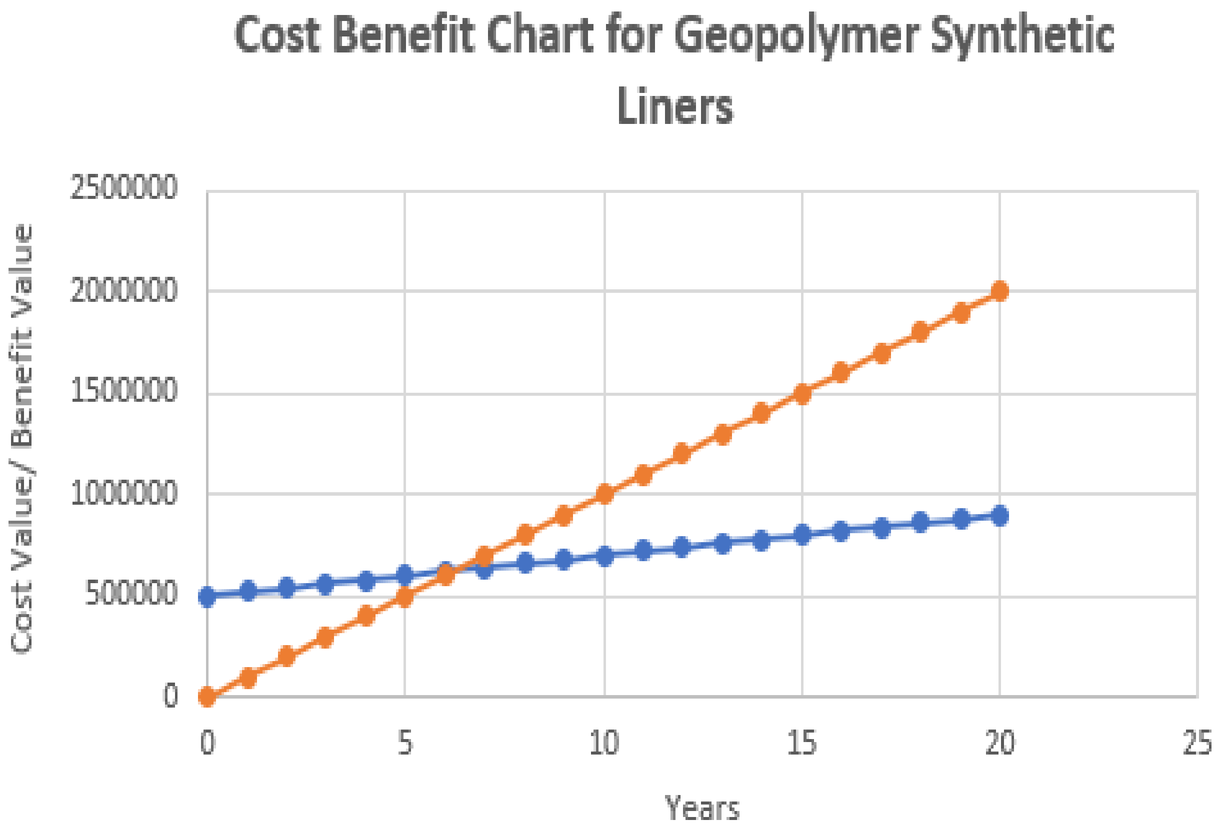
The results clearly show that the NPV value of Geopolymer synthetic liners is more than Bentonite Clay Liners.

The points where the value of benefits from the projects becomes equal or greater than the cost is **Break Even point**.



After 11 years, the Project would be profitable, i.e the benefit value exceeds the cost-

Break Even Point ⇒11 years.



After 6 years, the Project would be profitable, i.e the benefit value exceeds the cost-

Break Even Point ⇒ 6 years.

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