5th African International Conference on Industrial Engineering and Operations Management, Johannesburg/Pretoria, South Africa, April 23 - 25, 2024
Publisher: IEOM Society International, USA
Published: April 23, 2024 DOI: 10.46254/AF05.20240217

Power Station Fly Ash Production System and Beneficiation Material Balance: A Case Study for the Cement Industry and the Need for Green Energy Production

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Abstract

The United Nations sustainable development goals call for responsible consumption and production. Coal is the dominate fuel used in most power stations worldwide and in South Africa where over twelve power stations are coal fired. The solid by-products associated with pulverized coal combustion at about 1200℃ in a power station furnace are splitted into 15% bottom ash and 85% fly ash. Bottom ash is collected at the bottom of the furnace through hoppers , while fly ash is collected from particulate matters found in flue gas leaving the combustion system, thereby being collected through utilization of electrostatic precipitators (ESP). ESP typically operates at about 99.80% fly ash collection efficiency from the flue gas stream passing the magnetic plates of the ESP, however, on average around 6 electricity generation units of a 3700MW coal fired power station, ESP efficiency of 99.83% has been achieved at a certain month. ESP efficiency of a 3700MW coal fired power station consumed 50 000 tons of pulverized coal per day across 6 electricity generation units. The coal consumed had 42.00% ash content. Total daily and monthly fly ash production at the power station was calculated through simplified material balances. The monthly calculations on the fly ash material balance were completed over three years period. The cement industry use fly ash for reduction of clinker substitution or clinker factor in the final cement being manufactured. The industry makes use of raw fly ash and fine fly ash that is produced from a raw fly ash classification process which is associated with fly ash rejects that needs to be disposed. The available fly ash at year 1 for extraction was 4.35 million tons compared to 1.10 million that was extracted for use by the cement industry which indicated that about 74.60% were left for further management. At year 2, 4.35 million tons was available for extraction, 0.84 million tons was extracted by the cement industry leaving 80.72% to be still managed by the power station. Meanwhile, at year 3, 4.35 million tons was available for extraction, 1.07 million tons was extracted by the cement industry leaving 75.71% to be still managed. Disposal of the excess fly ash to the accredited disposal site continues to pose environmental risks such as leaching and unavailability of the land for occupation and agricultural use by the growing population of South Africa. Although the Just Energy Transition strategy poses a long-term risk of fly ash availability out of this power station. Consideration of 50-year power generation lifespan of the power station, which was commissioned fully in 1980, is expected to end life , thus decommission date is between 2035 to 2040 which is staged per generation units. The expected growth in cement demand until between year 2030 and 2050 associated with clinker production thereby contributing to the greenhouse emissions can potentially be covered by the excess fly ash available for usage from the power station studied. This will further help reduce carbon footprint from the cement industry. To create a closed loop system, the annual fly ash rejects of 0.13 million tons, 0.10 million tons and 0.13 million tons at year 1, year 2 and year 3 respectively can be further managed through using ball mill to increase their surface area so value is added. This can assist in finding potential application of the fly ash rejects other disposal at dump fly ash site which is costly.

Furthermore, it was recommended that research on new application of fly ash to reduce the excess fly ash that needs to be disposed has potential to further reduce amount of fly ash that goes to disposal facility.

Keywords:
Ash, classification, flue gas, units and clinker

Introduction

Background

The cement industry in South Africa requires fly ash from coal fired power stations to manage clinker ratio in final cement being produced. Clinker substitution through utilization of supplementary cementitious materials such as fly ash, saves 0.87 ton of carbon dioxide (CO_2) for every 1 ton of clinker produced through calcination of limestone in rotary kiln of an integrated cement plant.

For this reason, fly ash from power stations is of strategic value to cement industry for manufacturing eco-cement. Its assessment for availability from power station operations is of great importance for the cement industry to plan their manufacturing strategies around it.
The value of fly ash to qualify it for utilization in various applications has thus far been through classification process in most countries such as India, Europe and South Africa. The classification process is associated with particle size separation to generate more fine fly ash product that conforms to South African National Standard 50450-1 or European Norms 50450-1. Figure 1 described such fly ash classification process of fly ash as outlined by (Barnes and Sear 2014).

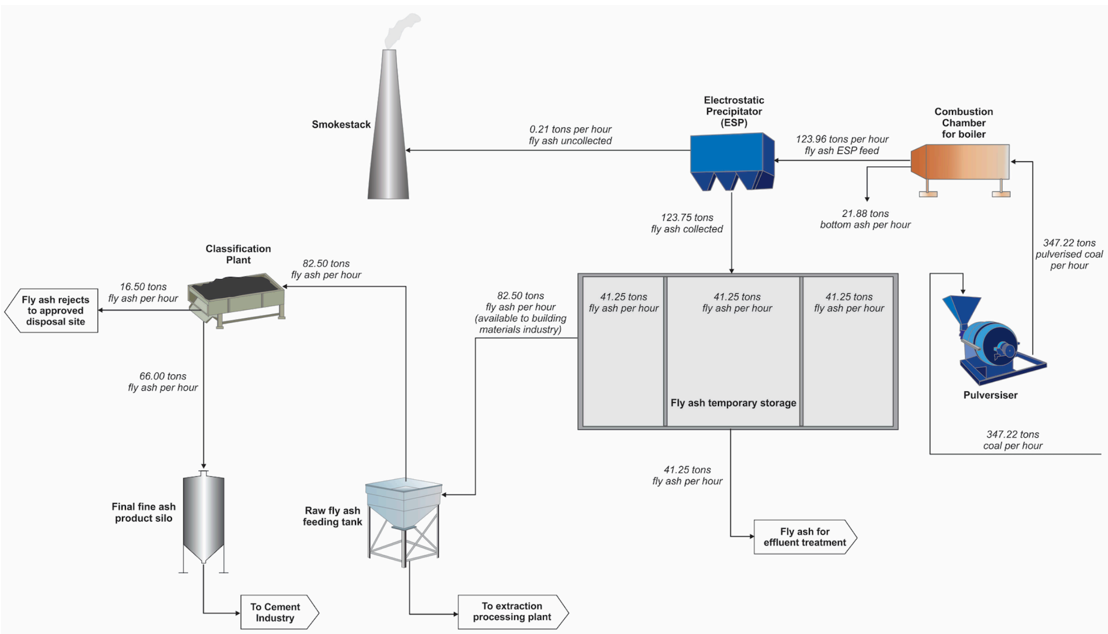

Figure 1. fly ash classification process of fly ash as outlined by (Barnes and Sear 2014).

The classification process makes use of equipment such as classifier or air separators that operates on parameters such as feeding rate (i.e. 112.5 tons/hr), air flow rate (i.e. 750 m^3/hr) and power (i.e. 50kW) to produce fine fly ash product of at certain production capacity per hour (i.e. 27 to 45 tons/hr). This type of powder classification equipment is similar as used in the grinding systems of cement production lines. The operation of the classifier is dependent of centrifugal force that is generated when the material spreading plate rotates. Depending on the quality of the raw fly ash feed, the classification process typical splits the feed at 55%-45%,50%-50% split, 70%-30% split or 80%-20%, that is, fine fly ash product-fly ash rejects.

The South Africa cement industry is concerned about the availability of fly ash currently and into the future with the current power crises in South Africa which indicates low power availability. Thus, a material balance around a 3700MW power station with six units is required to quantity the availability of all types of ash at the power station operations. This is to quantity the risk exposure on ash availability to decarbonize the cement and concrete industry on the forecasted cement production between now and the year 20250. However, a typical 37008 MW old power station that contributes to fly ash availability within the cement industry have a generation units retirement/decommissioning plan as highlighted on Table 1 (Global Energy Monitor 2024).

Table 1. Power station electricity generation units retirement plan

Generation unit name	*Status*	*Fuel*	*Electricity generation capacity (MW)*	*Technology*	*Generation start year*	*Planned retirement year*
Unit 1	Operating	Coal-bituminous	618	Subcritical	1985	2035
Unit 2	Operating	Coal-bituminous	618	Subcritical	1986	2036
Unit 3	Operating	Coal-bituminous	618	Subcritical	1987	2037
Unit 4	Operating	Coal-bituminous	618	Subcritical	1987	2037
Unit 5	Operating	Coal-bituminous	618	Subcritical	1989	2039
Unit 6	Operating	Coal-bituminous	618	Subcritical	1990	2040

Due to the recent power crises in South Africa, the probability of a review of this generation unit's retirement plan is high. Furthermore, post 2040 the fly ash shortage to the cement industry because of this station can be supplemented by fly ash from other power station closer proximity to the point of usage.

Problem statement

The sustainable development goals call for responsible production, clean energy generation and climate action. Coal as a dominant source of fuel in most countries worldwide in power station operations is challenged. This is due to the waste streams it generates during combustion such as SOx and NOx, Carbon dioxide as gases and ash as solid. In South Africa, a typical 3700MW coal fired power station consumes 50 000 tons per day of coal thereby generating 20 000 tons of ash per day which needs to be managed. Ash management through disposal at authorized landfills has been practiced in most countries including South Africa. This requires a large hectare of land to be allocated for the duration of power station life which is typically between 50 and 60 years. As the population increases, the demand for land and power increases. A review of a typical power station ash production and management needs to be contacted to quantify current ash management strategy at the specific power station and qualify the need for clean energy solutions for future.

Objective

Overall objective

The main objective was to conduct fly ash material balance for a 3700MW power station for comparison on consumption by cement & concrete industry in comparison to amount of fly ash produced at 99.83% electrostatic precipitator fly ash efficiency.

Specific objective

1.1.1.1. Describe and calculate the ash production quantity in a system of a power station
1.1.1.2. Material balance on fly ash management through beneficiation to building material industry and disposal at accredited disposal facility over three years period

2. Literature review

Rhufyano et al. (2022) indicated that planning and control of supply of materials at a manufacturing company is vital for the support of a production process. Material Requirement Planning (MRP) through Economic Order Quantity (EOQ) technique are important decision making tools for material balance for profitability assessment of a manufacturing facility.

Khamai and Sopadang (2023) also indicated that material balances can be carried to reduce raw materials inventory costs of a manufacturing facility. The ABC classification method is a useful tool for raw material categorisation with respect to their level of sensitivity such as requirement for strict supervision and control to avoid stock-outs which can halt production lines. Sokolov et al. (2023) investigated the integration of indicators of performance to track the production development of lines of manufacturing. Performance indicators such as availability, efficiency, productivity, throughput, capacities, and changeovers were essential for determination of performance of support and main areas of manufacturing floor monitoring.

The implementation of Material Flow Cost Accounting (MFCA) analysis for determination of the optimal sample size and lot size in serial multi-stage processes was studied by (Supakulwattana & Chattinnawat, 2018). The study applied the MFCA technique to trace the material and energy used in terms of physical quantity and monetary units. This assisted with analysis of process efficiency and design of lot size and inspection of system with respect to quality. This further maximised the ratio of total positive cost of product to the total cost associated with MFCA concept.

Bhatia (2020) indicated that material balance also known as mass balance is an accounting principle of materials that enters and leave a system. It can be applied to any unit operation or process which an analogy that input streams (mass and energy) always balance with the output flow streams (mass and energy). Furthermore, Bhatia (2020) indicated that for the fact that energy or mass cannot be lost nor gained.

The importance of material balance in manufacturing facilities such as in Power station operations are of great importance for operational decision making processes. Tau et al. (2022) used based sheet-based modelling to calculate material balance around 4800W power generation capacity of Kusile coal fired power station around flue gas desulphurisation system. The material balance assisted with quantification of liquid (effluent), solid (ash production, gypsum) and gas (flue gas) streams within the desulphurisation plant. The material balance results where compared with real data from the plant which then demonstrated accepted level of accuracy in modelling operations. Heat balances in power station operations are of great importance also, simulation of heat balances of a 315 MW low rank coal-fired power station performance was evaluated by Suryo et al. (2021) for a power station in Indonesia. In 2017, coal consumption was about 83 million tons which was an indicative of dominance of coal as source of energy to run a power plant at about 65%. Furthermore, by year 2050, the share of coal consumption at a power station is expected to be about 73% which amounts to around 556 million tonnes. A typical thermodynamic model of Rankine cycle as shown by Figure 2 describes steam generation and its utilisation in a power plant as indicated by Michael and Howard (2016).

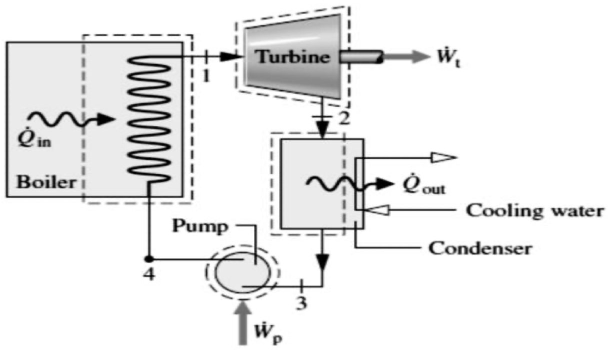

Figure 1. Rankine cycle thermodynamic model

Suryo et al. (2021) performed the heat balance simulation by Cycle-Tempo at different operating conditions of the power plant. The simulation results indicated that heat will increase 3.66% when all HPH are not on duty, while it increases by 2.63% in the case when all LPH are off duty. An increase in temperature of a superheater of 5℃ can potentially decrease the heat rate by 0.59% and by 0.39% when reheater temperature increase by 5℃ also.

Nasrullah et al. (2014) conducted mass, energy, and material balances of SRF production process. The objective was for the analysis of material flows and their characteristics in various production streams of materials produced in MT based SRF production line are being analysed. The analysis are being analysed in the form of proximate and ultimate. The composition of the process streams was determined through manual sorting.

Methodology

Figure 3 depicts step by step flow of activities followed for the research study.

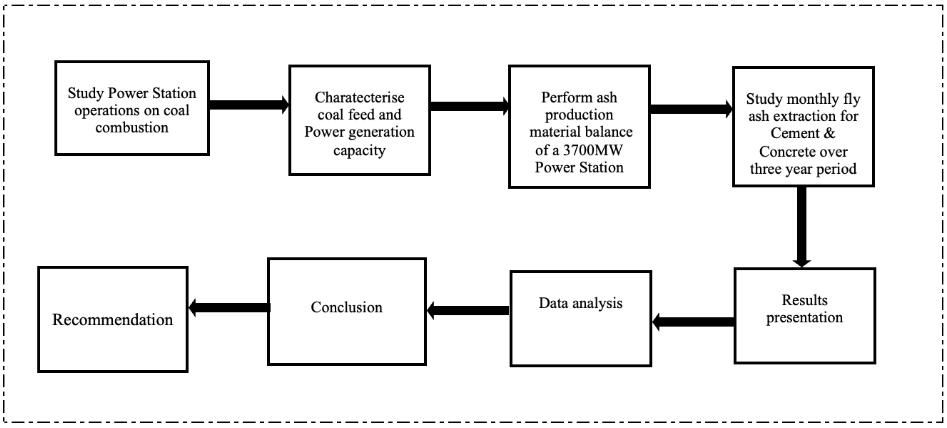

Figure 2. Research flow.

The following formulas were used to calculate Raw fly ash available at 6 Units post ESP (tons), raw fly ash extracted (tons), fine fly ash final product produced (tons), raw fly ash rejects generated to produce fine fly ash (tons), total fly ash extracted for use in cement and concrete industry (tons), excess fly ash not extracted (tons) and % excess to ash disposal site:

Raw fly ash available at 6 Units post ESP (tons) = Raw fly ash extraction time × coal combustion efficiency × Total number of Power generation units
Raw fly ash extracted (tons) = Quantities reported by despatch software (HODIM) in the period ,

Fine fly ash final product produced (tons) = Quantities reported by despatch software (HODIM) in the period = Raw fly ash extracted (tons) for feeding in fine fly ash production line × % split as product

Raw fly ash rejects generated to produce fine fly ash (tons) = Raw fly ash extracted (tons) for feeding in fine fly ash production line × % split as raw fly ash rejects
Total fly ash extracted for use in cement and concrete industry (tons) = Raw fly ash extracted (tons) + Fine fly ash final product produced (tons)

Excess fly ash not extracted (tons) = Raw fly ash available at 6 Units post ESP − Total fly ash extracted for use in cement and concrete industry

% excess to ash disposal site = (Raw fly ash rejects generated to produce fine fly ash + Excess fly ash not extracted)/ Raw fly ash available at 6 Units post-ESP

Results and discussion

Description and calculation of ash production quantity in a system of a 3700MW coal fired power station.

A power station consumed 50 000 tons of coal (Eskom 2021a), to produce a total of 3700MW of electricity using 6 generating units with each unit contributing about 616.67MW of electricity when on full load. The coal had the following characteristics:

Table 2. Typical characteristics of the accepted coal usage at a power station

Source: Eskom (2021b)

Parameter	***Unit of measure***	***Target***
Calorific value	MJ/Kg	16
Sulphur	%	0.6
Ash content	%	42.00

Rakgolela et al. (2023) indicated that the actual coal consumption and its characteristics used during the month of June 2023, were as outlined on Table 3.

Table 3. Actual coal consumption and characterised for June 2023 at a power station

Parameter	***Unit of measure***	***Actual***
Sulphur	%	0.67
Ash content	%	37.21

Source: Rakgolela et al. (2023)

The actual coal consumption was 1 298 323 tons versus 2 000 000 tons maximum permitted rate, meanwhile, the ash produced was 483 105.8 tons versus 770 000 tons maximum permitted production Rakgolela, et al. (2023). Furthermore, fly ash is part of the particulate matter emitted during coal combustion, by making use of electrostatic precipitators (ESP), the ESP is reported to have 99.8% removal efficiency of the fly ash present in the gases that are released through smokestacks at the power station (Eskom 2021b). For this reason, the six generation units had the following actual fly ash removal efficiency during the period of June 2023 as indicated by Rakgolela et al. (2023) on Table 4.

*T*able 4. Electrostatic precipitator efficiency as at June 2023 at a power station

Associated Unit/Stack	***Efficiency***	***Actual***
Generation Unit 1	%	99.95
Generation Unit 2	%	99.72
Generation Unit 3	%	99.79
Generation Unit 4	%	99.86
Generation Unit 5	%	99.80
Generation Unit 6	%	99.86
Average	**%**	**99.83**

It is known that a 3700MW coal fired power station consumes 50 000 tons per day on full load. Coal consumption per generation unit per day and the subsequent fly ash production per day is calculated as follows, with an assumption on equivalent efficiency on each generation unit:

Coal consumption per 616.67MW generation unit per day = $\frac{Total\ daily\ coal\ consumption\ for\ 3600MW\ electricity}{6}$

Coal consumption per 616.67MW generation unit per day = $\frac{50\ 000 tons\ per\ day}{6}$

Coal consumption per 616.67MW generation unit per day = $\frac{50\ 000 tons\ per\ day}{6}$

Coal consumption per 616.67MW generation unit per day = 8 333.33 tons per day

Ash production per 616.67MW generation unit per day = Ash content in coal × Coal consumption per 616.67MW generation unit per day
Ash production per 616.67MW generation unit per day = 42% × 8 333.33 tons per day
Ash production per 616.67MW generation unit per day = 3 500.00 tons per day

Ash is splitted into 85% fly ash and 15% bottom ash, therefore, fly ash and bottom ash per generation unit is calculated:

Fly ash production per 616.67MW generation unit per day = Ash production per 616.67MW generation unit per day × % Fly ash content in total ash
Fly ash production per 616.67MW generation unit per day = 3 500.00 tons per day × 85%
Fly ash production per 616.67MW generation unit per day = 2 975.00 tons per day
∴ Fly ash collected via ESP per 616.67MW generation unit per day = Fly ash production per 616.67MW generation unit per day × Average ESP efficiency

Fly ash collected via ESP per 616.67MW generation unit per day = 2 975.00 tons per day × 99.83%
Fly ash collected via ESP per 616.67MW generation unit per day = 2 969.94 tons per day

Fly ash uncollected via ESP per 616.67MW generation unit per day on gas stream = Fly ash production per 616.67MW generation unit per day × (100% – 99.83%)
Fly ash uncollected via ESP per 616.67MW generation unit per day on gas stream = 2 975.00 × 0.17%
Fly ash uncollected via ESP per 616.67MW generation unit per day on gas stream = 5.06 tons per day

Bottom ash production per 616.67MW generation unit per day = Ash production per 616.67MW generation unit per day − Fly ash production per 616.67MW generation unit per day
Bottom ash production per 616.67MW generation unit per day = 3 500.00 tons per day − 2 975.00 tons per day
Bottom ash production per 616.67MW generation unit per day = 525.00 tons per day

∴ Total fly ash production per 3700MW generation units = Fly ash production per 616.67MW generation unit per day × Total number of generation units
Total fly ash production per 3700MW generation units = 2 975.00 tons per day × 6
Total fly ash production per 3700MW generation units = 17 850.00 tons per day

∴ Fly ash collected via ESP per 3700MW generation units = Fly ash collected via ESP per 616.67MW generation unit per day × Total number of generation units
Fly ash collected via ESP per 3700MW generation units = 2 969.94 tons per day× 6
Fly ash collected via ESP per 3700MW generation units = 17 819.64 tons per day

Fly ash uncollected via ESP per 3700MW generation unit per day on gas stream = Total fly ash production per 3700MW generation units − Fly ash collected via ESP per 3700MW generation units

Fly ash uncollected via ESP per 3700MW generation unit per day on gas stream = 17 850.00 tons per day −17 819.64 tons per day
Fly ash uncollected via ESP per 3700MW generation unit per day on gas stream = 30.36 tons per day

∴ Total bottom ash production per 3700MW generation units = Bottom ash production per 616.67MW generation unit per day × Total number of generation units
Total bottom ash production per 3700MW generation units = 525.00 tons per day × 6
Total bottom ash production per 3700MW generation units = 3 150.00 tons per day

Figure 4 indicates the fly ash production process on overview based on above calculations. 347.22 tons of coal is combusted per hour, producing 295.14 tons per hour fly ash per hour where 294.64 tons per hour is collected via ESP with 0.50 tons per hour being uncollected by ESP based on 0.17% inefficiency. The fly ash drops in a temporary collection storage that has three compartments, with one compartment allocated for the power station to treat effluent resulting from activities such as cooling tower blow down. Thus, the total hourly fly ash input into the temporary storage is divided into three, with each compartment receiving 98.21 tons per hour. This is 18.71% allocated for extraction on effluent treatment and 81.29% available for extraction for use in other beneficiated industries such as the building materials industry (i.e. cement and concrete). The hourly bottom ash production per generation unit is 21.88 tons.

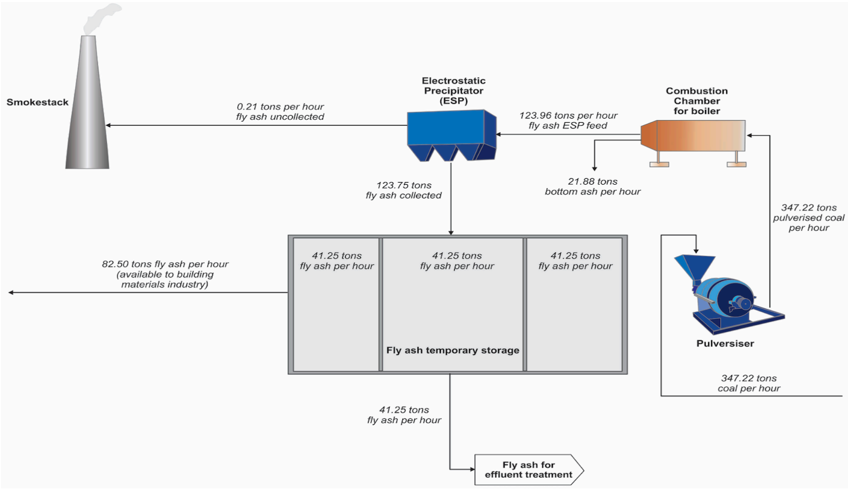

Figure 3. Fly ash and bottom ash material balance on 616.67MW generation unit

The fly ash collection system in the temporary storage post electrostatic precipitation is such that two generation units (1 233.34 MW) feeds into one temporary storage as outlined in Figure 5.
The fly ash collection system in the temporary storage post electrostatic precipitation is such that two generation units (1 233.34 MW) feeds equivalent fly ash input into one temporary storage as outlined in Figure 5.

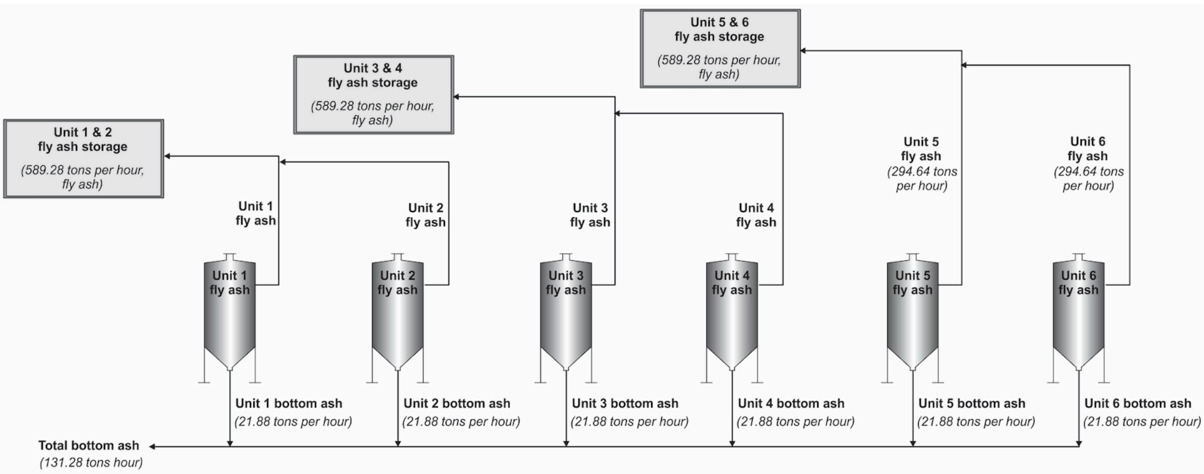

Figure 4. Fly ash and bottom ash material balance on a collection system of 3700MW power station

4.2. Calculation of material balance on ash management through beneficiation to building material industry and disposal at accredited disposal facility over three years period.

Fly ash availability post electrostatic precipitators versus actual extracted fly ash at year 1

Table 4 indicates the availability of fly ash after 99.83% collection efficiency through ESP at year 1 where 80% of the quantity of both raw fly ash extracted and fine fly ash product produced by a fly ash extraction plant was sold to the cement and concrete industry. The production of fine fly ash product produces rejects streams that needs to be further managed, however, its handling is less complex than raw fly ash from the generation units. The annual fine fly ash production at year one as noted on Table 5 was 523179.3 tons (0.52Mt) which generated 130794.83 tons (0.13Mt) of fly ash rejects. This further indicated that the raw fly ash splited into 20% raw fly ash rejects and 80% fine fly ash product stream during the classification process. Meanwhile the total annual raw fly ash extracted was 581225.40 tons (0.58Mt) which was 13.37% of the total fly ash produced by the power station in year one. Figure 6 indicates the trend between quantity of raw fly ash available for extraction at 6 Units post ESP and total quantity of fly ash extracted for use in cement and concrete sector. Between the period of month of May and August, the amount of fly ash extracted was at peak compared to amount of raw fly ash available for extraction. This is attributed to the subsequent demand of cement and concrete in that season.

Table 5. Fly ash availability post ESP versus actual extracted fly ash for 80% usage in the cement and concrete industry at year 1

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash extraction time (hours)	744,00	672,00	744,00	720,00	744,00	720,00	744,00	744,00	744,00	744,00	720,00	744,00
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Raw fly ash extracted (tons)	41497,05	55657,35	45027,15	36007,65	48300,00	53187,75	60360,30	53777,85	52350,90	55886,25	52577,70	26595,45
Fine fly ash final product produced (tons)	36940,05	38090,85	40603,50	38468,85	53405,10	44944,20	48456,45	59516,10	39386,55	48293,70	45771,60	29302,35
Total (tons)	78437,10	93748,20	85630,65	74476,50	101705,10	98131,95	108816,75	113293,95	91737,45	104179,95	98349,30	55897,80
Raw fly ash rejects generated to produce fine fly ash (tons)	9235,01	9522,71	10150,88	9617,21	13351,28	11236,05	12114,11	14879,03	9846,64	12073,43	11442,90	7325,59

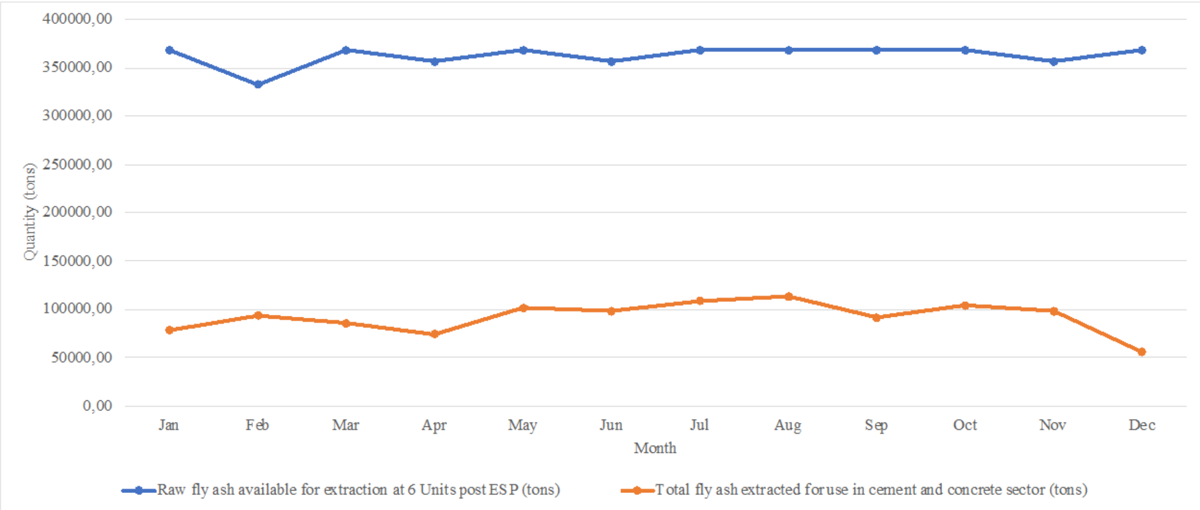

Figure 5. Raw fly ash available at 6 Units post ESP versus actual total fly ash extracted post ESP for usage with 80% in the cement and concrete industry at year 1

Fly ash availability post electrostatic precipitators versus actual extracted fly ash at year 2
Table 6 and Figure 7 indicated that the month of April was the lowest with respect to total fly ash extracted at 0.50%. The peak month of total fly ash extracted was in August which contributed 2.28% of the total quantity of raw fly ash available at 6 Units post ESP. Furthermore, the production of fine fly ash was 407896.12 tons (0.41 Mt) which was associated with 101974.03 tons (0.10Mt) of raw fly ash rejects. This quantity of raw fly ash rejects constituted 2.35% of the total quantity raw fly ash available at 6 Units post ESP for extraction.

Table 5. Fly ash availability post ESP versus actual extracted fly ash for 80% usage in the cement and concrete industry at year 2

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash extraction time (hours)	744,00	672,00	744,00	720,00	744,00	720,00	744,00	744,00	744,00	744,00	720,00	744,00
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Raw fly ash extracted (tons)	36947,01	25964,53	20548,27	2110,09	25403,48	34179,93	56629,46	53462,80	48326,02	45430,21	37378,22	44125,17
Fine fly ash final product produced (tons)	30322,83	32369,99	28446,40	19740,20	21656,64	39147,64	41009,37	45517,64	37712,39	39551,47	34867,01	37554,53
Total fly ash extracted (tons)	67269,85	58334,51	48994,67	21850,29	47060,12	73327,57	97638,83	98980,43	86038,41	84981,68	72245,23	81679,70
Raw fly ash rejects generated to produce fine fly ash (tons)	7580,71	8092,50	7111,60	4935,05	5414,16	9786,91	10252,34	11379,41	9428,10	9887,87	8716,75	9388,63

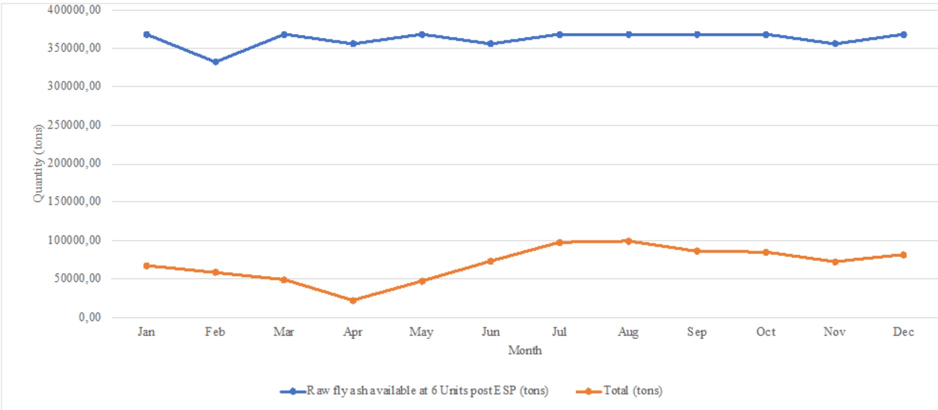

Figure 6. Raw fly ash available at 6 Units post ESP versus actual total fly ash extracted post ESP for usage with 80% in the cement and concrete industry at year *2*

4.2.3. Fly ash availability post electrostatic precipitators versus actual extracted fly ash at year 3

At year three, fly ash extraction started increasing from month of June to October as noted on Figure 8. The total annual fly ash that was available from 6 units running post-ESP was 4348080.00 tons with 1070903.20 tons extracted, thus constituting 24.63% of the fly ash that was not available as indicated by Figure 8.

The annual production of fine fly ash generated raw fly ash rejects of 125035.05 tons relative to 500140.20 tons fine fly ash produced as indicated by Table 7. The slow demand for cement and concrete impeded the performance of fly ash extraction at the power station for utilization.

Table 6. Fly ash availability post-ESP versus extracted fly ash for 80% usage in the cement and concrete industry at year 3

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash extraction time (hours)	744,00	672,00	744,00	720,00	744,00	720,00	744,00	744,00	744,00	744,00	720,00	744,00
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Raw fly ash extracted (tons)	49515,00	37200,00	41419,00	42232,00	46599,00	45263,00	49057,00	53040,00	53192,00	61428,00	52604,00	39214,00
Fine fly ash final product produced (tons)	35792,40	35535,15	43270,50	33806,85	43797,60	43967,70	45146,85	44068,50	48768,30	43979,25	43749,30	38257,80
Total (tons)	85307,40	72735,15	84689,50	76038,85	90396,60	89230,70	94203,85	97108,50	101960,30	105407,25	96353,30	77471,80
Raw fly ash rejects generated to produce fine fly ash (tons)	8948,10	8883,79	10817,63	8451,71	10949,40	10991,93	11286,71	11017,13	12192,08	10994,81	10937,33	9564,45

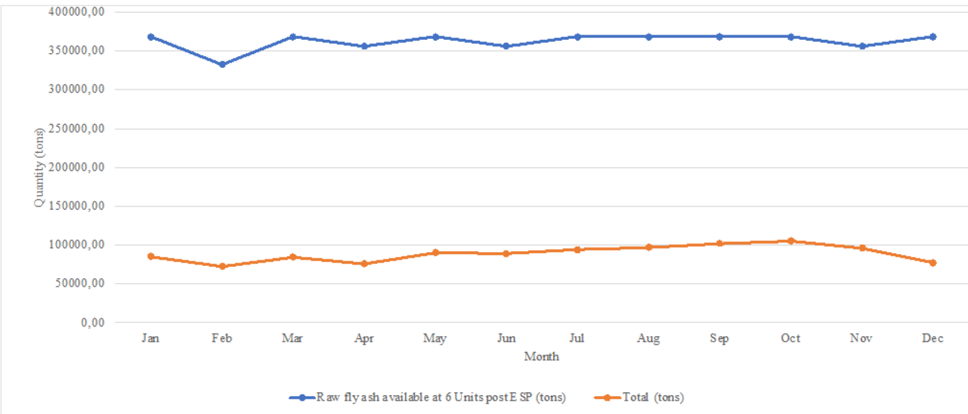

Figure 7. Raw fly ash available at 6 Units post ESP versus actual total fly ash extracted post ESP for usage with 80% in the cement and concrete industry at year 3

Quantification of excess fly ash dumped at the disposal site over a years period.

The excess fly ash that is dumped at the disposal site near the power station is dependent of amount of fly ash produced across the generation six units with an assumption that all operate under equivalent pulverized coal combustion efficiencies, thus with equal fly production. Together with the amount fly ash extracted for use in the cement and concrete industry. Figure 9 depicts the simplified fly ash material balance flow within the power station fly ash collection system. Demonstration has been through using January month of year one.

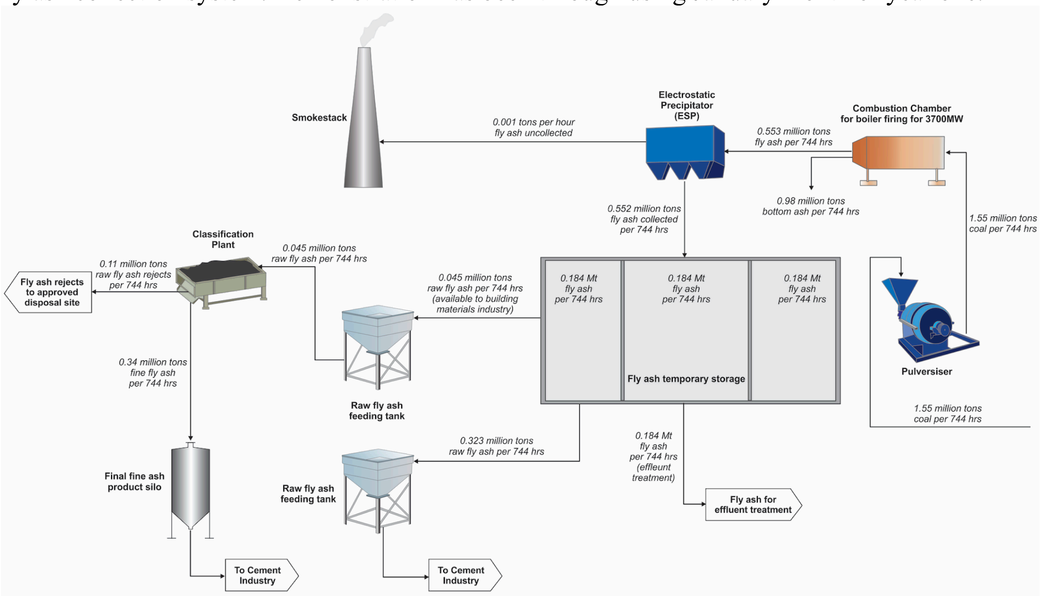

Figure 8. Simplified fly ash material flow within the power station fly ash collection system for January, year 1

Similar calculations were made for all months at year one, year two and year three as summarized by Figure 10 and Table 8 for year one, Figure 11 and Table 9 for year two, Figure 12 and Table 10 for year three.

It was noted that the monthly fly ash production at year one was significantly higher than the consumption by the cement and concrete industry which added to a full year fly ash production of 4348080.00 tons (4.35Mt; 100%) versus 1104404.7 tons (1.10Mt; 25.40%) used by the cement and concrete industry, thereby leaving an excess of 3243675.30 tons (3.24Mt; 74.60%) as shown by Figure 10 and Table 8. The month of August has been a better performing month as 26.72% was used by the cement and concrete industry which was the highest relative to what was produced, thereby disposing 73.28% at the disposal site which was the lowest. The month of December was the lowest in terms of fly ash utilization by the cement and concrete industry at 13.19% usage of the produced fly ash with 86.81% being disposed.

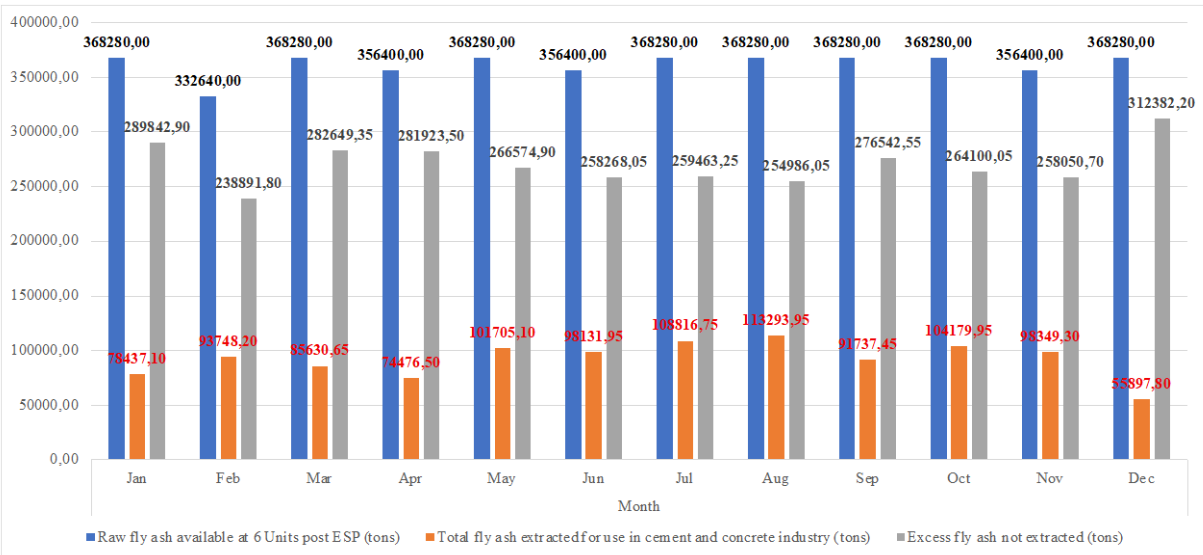

Figure 9. Monthly excess fly ash to dump site at year 1

Table 7. Monthly percentage excess fly ash dumped to ash disposal site at year 1

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Total fly ash extracted for use in cement and concrete industry (tons)	78437,10	93748,20	85630,65	74476,50	101705,10	98131,95	108816,75	113293,95	91737,45	104179,95	98349,30	55897,80
Raw fly ash rejects generated to produce fine fly ash (tons)	9235,01	9522,71	10150,88	9617,21	13351,28	11236,05	12114,11	14879,03	9846,64	12073,43	11442,90	7325,59
Excess fly ash not extracted (tons)	289842,90	238891,80	282649,35	281923,50	266574,90	258268,05	259463,25	254986,05	276542,55	264100,05	258050,70	312382,20
% excess to ash disposal site	81,21	74,68	79,50	81,80	76,01	75,62	73,74	73,28	77,76	74,99	75,62	86,81

During year two as indicated by Figure 11 and Table 9 , the monthly total fly ash extracted for use in cement and concrete industry has been relatively low compared to year one. The extraction of fly ash is a function of cement and industry demand. Lower construction projects reduced the fly ash consumption. The total annual fly ash production was 4348080.00 tons (4.35Mt; 100%), while the total annual extraction was at 838401.29 tons (0.838Mt; 19.28%) and 3509678.71 tons (3.51Mt; 80.72%) that was in excess and needs further management. The month of July was the peak month with 23.73% fly ash extracted and used in the cement and concrete industry, 76.27% was disposed. Meanwhile April was the worst performing month with 95.25% of fly ash produced disposed. This was due to Covid-19 pandemic having affected fly ash users business operations due to unforeseen trading restrictions.

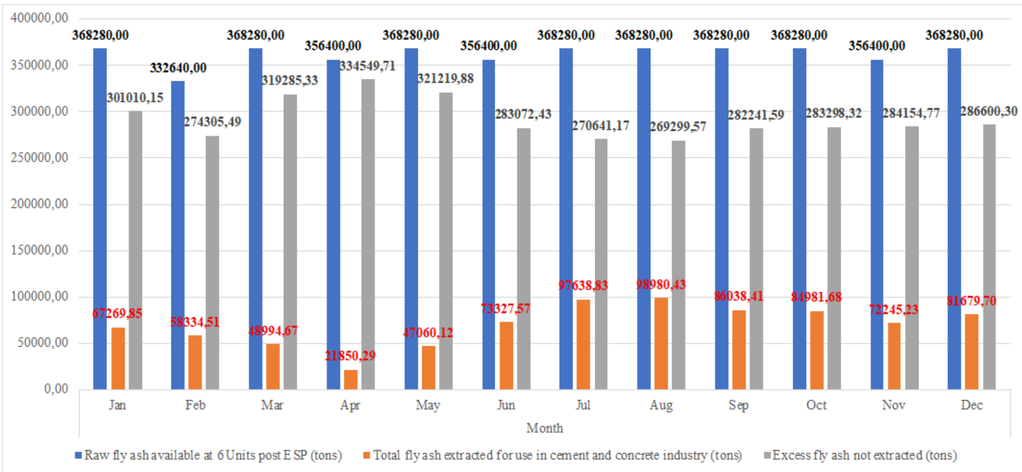

Figure 10. Monthly percentage of excess fly ash dumped to ash disposal site at year 2

Furthermore, the trend of fly ash usage in year three has been better in comparison to year one and similar performance in comparison to year two. These is with respect to per-centage contribution on what was produced as the power station combust the coal versus what was extracted for usage by the cement and concrete industry

Table 8: Monthly percentage of excess fly ash dumped to the ash disposal site at year 2

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Total fly ash extracted for use in cement and concrete industry (tons)	67269,85	58334,51	48994,67	21850,29	47060,12	73327,57	97638,83	98980,43	86038,41	84981,68	72245,23	81679,70
Raw fly ash rejects generated to produce fine fly ash (tons)	7580,71	8092,50	7111,60	4935,05	5414,16	9786,91	10252,34	11379,41	9428,10	9887,87	8716,75	9388,63
Excess fly ash not extracted (tons)	301010,15	274305,49	319285,33	334549,71	321219,88	283072,43	270641,17	269299,57	282241,59	283298,32	284154,77	286600,30
% excess to ash disposal site	83,79	84,90	88,63	95,25	88,69	82,17	76,27	76,21	79,20	79,61	82,17	80,37

. On full year, 4348080.00 tons (4.35Mt; 100%) was produced, 1070903.20 tons (1.07Mt; 24.63%) extracted for use and 3277176.80 tons (3.78Mt; 75.37%) was in excess with a requirement for further management initiatives. Disposal at accredited disposal has been the option partaken. These has been noted on Figure 12 and Table 10.

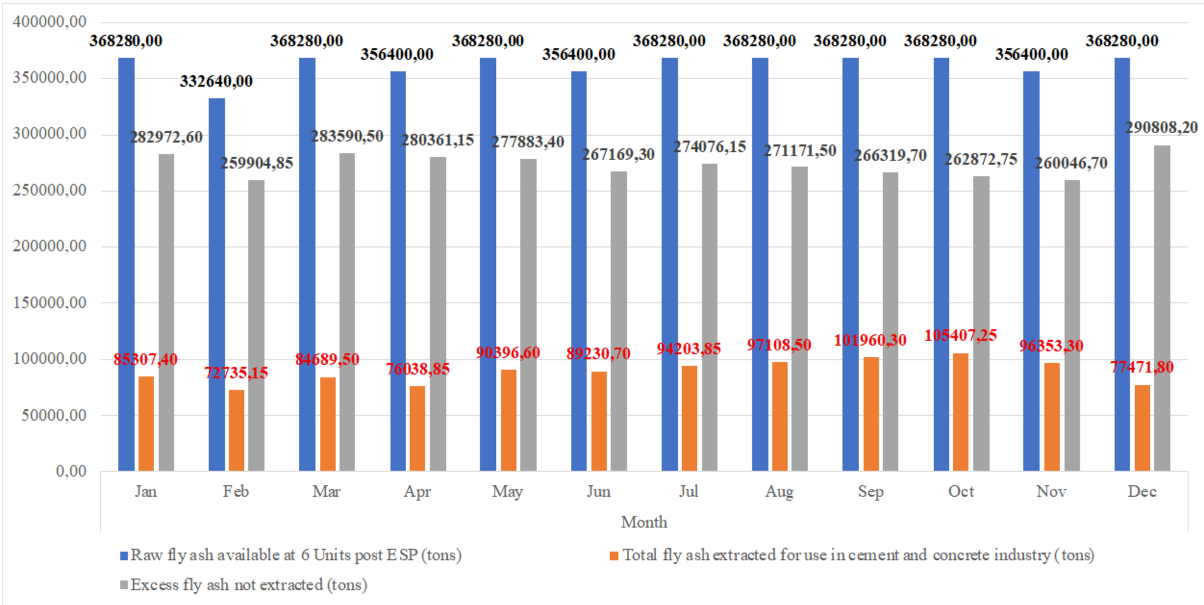

Figure 11. Monthly excess fly ash to dump site at year 3

Table 9. Monthly percentage excess fly ash dumped to ash disposal site at year 3

	Month											
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Raw fly ash available at 6 Units post ESP (tons)	368280,00	332640,00	368280,00	356400,00	368280,00	356400,00	368280,00	368280,00	368280,00	368280,00	356400,00	368280,00
Total fly ash extracted for use in cement and concrete industry (tons)	85307,40	72735,15	84689,50	76038,85	90396,60	89230,70	94203,85	97108,50	101960,30	105407,25	96353,30	77471,80
Raw fly ash rejects generated to produce fine fly ash (tons)	8948,10	8883,79	10817,63	8451,71	10949,40	10991,93	11286,71	11017,13	12192,08	10994,81	10937,33	9564,45
Excess fly ash not extracted (tons)	282972,60	259904,85	283590,50	280361,15	277883,40	267169,30	274076,15	271171,50	266319,70	262872,75	260046,70	290808,20
% excess to ash disposal site	79,27	80,80	79,94	81,04	78,43	78,05	77,49	76,62	75,63	74,36	76,03	81,56

Conclusion

Production of electricity at a 3700MW generation capacity required 50 000 tons coal per day across six generation units each at 616.67MW which ash content of 42.00%. The 21 000 tons total ash production per day has been splitted at 17 850.00 tons (85%) fly ash per day and 3 150.00 tons per day (15%). The fly ash is most beneficiated in the cement and concrete industry for clinker factor reduction or clinker substitution in finished manufactured cement. This reduces carbon dioxide as emission associated with cement being manufactured. Electrostatic Separators (ESP) are used to collect the fly ash from the off gas stream from coal combustion at 99.83% average collection efficiency amongst the six generation units. The daily total fly ash collection rate from the flue gas stream as part of particulate matter was 17 819.66 tons, with 30.34 tons uncollected from the flue gas stream daily. The total annual collected fly ash through ESP was 4.35 million tons. Material balance on collected fly ash over three years period was analysed. It was noted cement and concrete industry consumed 1.10 million tons, 0.84 million tons and 1.07 million tons at year one, two and three respectively. This consumption rate was a function on the market cement and concrete demand coupled with the product formulation with respect fly ash utilisation. This further indicated that excess fly ash was available at 74.71%, 80.69% and 75.40% at year one, year two and year three respectively. This excess fly ash production within the three period assessed indicated the potential room to cater for spite in fly ash demand as a strategic raw material in cement production for contribution on decarbonisation strategy. The risk exposure on fly ash availability was at the perspective of Just Energy Transition strategy by the power generation electric utility which calls for phasing out reliability of coal as the only sole source of heat content for power generation. Furthermore, the end of life power station generation units retirement plan with early commissioned generation unit expected to retire in year 2035 and late commissioned generation unit expected to retire in year 2040. The power crises in South Africa pose a probability of the generation units retirement plan for revision in order to keep up with the energy demand.

Recommendations

The assessed fly ash consumption of 25.71% , 19.31% and 24.60% for year one, year two and year three by the cement industry can be increased based on the forecasted cement demand until year 2050. This poses an advantage for decarbonised cement produced, with less greenhouse gas emissions affecting climate change.

Research and commercialization of other alternative applications of fly ash can aid in increasing the utilization which substituent reduces disposal at approved disposal. Disposal is not a preferred method of fly ash management as it pollutes the environment.

Furthermore, the production of fine fly ash as part of beneficiation requirements for value addition of the fly ash to improve its applicability was associated with the annual production of fly ash rejects of 0.13 million tons, 0.10 tons and 0.13 million tons at year one, year two and year three respectively.. These quantities was send as part of excess fly ash that was disposed of. Re-engineering of fly ash classification plant through retrofitting of grinding mills for these fly ash rejects can potentially help with creation of a close loop system for avoidance of fly ash rejects disposal.

The South Africa power generation mix is constituted by twelve coal-fired power stations that can also reviewed with respect to fly ash management strategy. These further aid in fly ash availability assessment to the cement industry from the various coal fired power stations for decarbonisation of the cement manufacturing process. These subsequently assist in managing the change in climate due to greenhouse gases as contributed by the cement sector.

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Biographies

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