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Quality Analysis of Ash from Lignite Coal and its Utilization at Thar Power Plant

Deepak Kumar
Shaheed Zulfikar Ali Bhutto Institute of Science and Technology, Hyderabad
E-mail: deepakdrathi@gmail.com

Bharat Lal
Department of Electronic Engineering, Mehran UET Jamshoro
E-mail: bharat.lal@faculty.muet.edu.pk

Mukesh Kumar
Department of Chemical Engineering, Mehran UET Jamshoro
E-mail: karmanimukesh44@gmail.com

Shanker Lal Meghwar
Department of Civil Engineering, Mehran UET Jamshoro
E-mail: shanker.lal@faculty.muet.edu.pk

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Abstract: Billion of tonnes lignite coal is deposited under the surface of Tharparkar zone had been started utilizing in its own mine mouth power plant. Tharparkar is rich in coal resource and have the potential to energize the Pakistan for at least 200 year with the deposited coal fuel of 175 Billion of tonnes. Thar coal further divided into 13 blocks; Block II (have 1% of 175 Billion of tonnes of coal has the capability of produce 5000 MW for 50 years) had just set its 2 units which is capable for 2x330 MW with coal consumption of 560 tons/hour. With the time, the increase in thermal power plant will results in increasing problems with the disposal of solid residues from combustion and off gas cleaning (Bottom ash and Fly ash). The properties of as fired coal is analyzed i.e, volatile matter, sulfur and nitrogen contents and solid residues from combustion and off gas cleaning (Bottom & Fly Ash) and it's found that as fired coal consists of 12% ash which is 5% greater than ash of design coal that is 7% and ranges from 4-12%. Large amount of ash produced by as fired coal reaches the almost upper range of ash in designed coal and yet it's not utilized or recycled, according to analysis it can be utilized in various forms i.e. CLC block, cements, road construction and agriculture, if it is not recycled in future then it will create bad impact to the environment like environment pollution, health concern to the human and wildlife and contaminant the under-ground water.

Index Terms: Ash, Coal, Thermal Power Plant, Quality Analysis.

1. Introduction

Coal based thermal power plants are still popular and cheap source of energy in many developing countries. Thermal power plants have been major source of power generation in Pakistan, for many years [1]. The energy crisis is increasing day by day and Pakistan government has planned to increase the power generation capacity up to 22000MW by 2035 through coal based thermal power plants [2]. The total coal reserves in Pakistan are estimated at 185 Billion tonnes, out of which 175 Billion tonnes are found in district Tharparkar under an area of 10,000 sq. km [2]. The coal is natural and cheap energy source and under developing countries moving towards, production of energy from coal [3]. Thar coal reserves have the capacity of producing energy of 100,000 MW by consumption of 536 Million tons of coal per year which is approximated to produce same amount of energy for more than 200 years [4]. The total coal reserves are greater than the summation of total oil reserves of Saudi Arabia and Iran together [5]. Not only coal thermal plants produce energy but at the same time they produce solid waste byproduct in bulk amount i.e. slag, bottom ash and fly ash. Disposal of solid waste from coal-fired power plants is becoming a serious challenge to the environmentalists [6]. In addition, it is found that emissions of gasses SOx, NOx, SPM, RSPM and other gases effects the surrounding environment badly [7-8]. The major drawback of coal based thermal power plants is disposal of waste product and emission of greenhouse gases [9]. However, nowadays the byproduct of coal is being recycled and used in manufacturing of bricks and partial replacement of cement in concrete [10].

The coal found in Tharparkar district is lignite type and as per design coal it consist of approximate 7-10% of ash. Thar coal reservoirs are divided in to 13 blocks. Currently, Block II (owned by Sindh Engro Coal Mining Company) is in operational. This block is capable of producing 5000 MW of electricity over the span of next 50 years which will consume 1.75 Billion tons of coal (i.e. 1% of total Thar coal reserves). The first thermal power plant has already started in July, 2019, and currently it is generating 660 MW of electricity with coal consumption of 13440 tons/day with full capacity and produces ash about 1344 tons/day. At the moment, this ash is being dumped which will cause serious problems, like respiratory diseases in those who are living nearby the coal plant in long term. The fly ash has cementitious properties and it can be used along with cement in concrete manufacturing. To use fly ash as secondary cementitious in concrete, it needs to be chemically analyzed to know the composition of different compounds present in ash. Thus, objective of this study is to analyze the quality of different types of Thar Coal Ash and discuss gaps and possibilities to dispose and recycle the ash at local level.

2. Quality Analysis of Ash and Coal

A. Analysis of Coal

In this research different samples of as fired coal was taken on daily basis for one week and tests was performed in Chemical Laboratory of EPTL (Engro Powergen Thar Pvt. Ltd.). The LC-233 ESPEC equipment was used for total moisture. Quick Intelligence Sulfur determination device was used for finding the total sulfur, and Automatic Bomb Calorimeter was used for calorific value of coal. The coal Proximate Analysis is shown in Table 1. It is clear from chemical composition of coal that average ash includes in as fired coal is 10.41%.

Table 1. As fired coal- lab report analysis (proximate composition)

Parameters	Total Moisture	Ash	Volatile	Sulfur	Fixed Carbon	Net calorific value	Net calorific value
Sample No.	(%)	(%)	(%)	(%)	(%)	KJ/KG	Cal/g
1	44.42	11.48	25.67	1.98	18.61	10956	2620
2	47.13	7.83	26.42	1.5	18.63	11436	2735
3	45.34	11.29	25.7	1.08	17.67	10670	2552
4	30.75	12.55	35.35	0.99	21.35	15031	3595
5	27.39	12.5	36.41	1.08	23.7	15960	3817
6	47.06	8.29	27.12	0.79	17.54	11161	2669
7	42.38	8.9	29.82	0.86	18.9	12598	3012
Average Values	40.64	10.41	29.50	1.18	19.49	12544.57	3000.00

B. Analysis of Ash

After the combustion of coal in boiler's furnace, two by products are generated first is Bottom Ash and second is Flue Gases. The bottom Ash or Slag is discharge through the bottom of furnace and remaining flue gases are passed through the heat recovery zone (Back Pass of Boiler). It flows through the Electrostatic Precipitator ESP (ESP is equipment used to clean the off-gas through the electro static charges and extract it into the fly ash and clean gas). The Fly Ash is conveyed through pneumatic lines and collected into the ash silos. In terms of economic the total ash is approximate 10 % of its coal value.

The ash sample was collected from different taps and test was performed at EPTL Chemical Lab on SPECTRO XRD equipment.

C. Bottom Ash

The Bottom Ash or Slag discharges from the bottom of Boiler's Furnace. It is composed of coarse and granular, incombustible by-products. To remove the bottom ash, it is kept in molten state and tapped off in liquid passing through the slag discharge ash cooler (which are also used for heat recovery medium) and put off through conveyors to Silo. Bottom ash from Lignite Coal type contains approximate 35% of Silicon di Oxide, 18% of Calcium Oxide and 15 kJ/Kg of Ferric Oxide. The oxides analysis and particles size analysis results are given in Table 2 and 3.

Table 2. Bottom ash XRF analysis

Oxides in Ash	Units	Sample 1	Sample 2
Sodium oxide Na2O	(%)	3.93	3.94
Magnesium oxide MgO	(%)	<0	<0
Aluminum oxide Al2O3	(%)	17.04	17.91
Silicon oxide SiO2	(%)	35.49	35.2
Phosphorus oxide P2O5	(%)	0.12	0.11
Sulfur oxide SO3	(%)	8.28	7.49
Potassium oxide K2O	(%)	0.16	0.16
Calcium oxide CaO	(%)	18.59	16.41
Titanium oxide TiO2	(%)	2.01	2.1
Iron oxide Fe2O3	KJ/KG	15.82	16.82
Concentration Summation		101.45	100.15

Table 3. Bottom Ash particles size distribution

Particle Size (mm)	Std. Unit	Sample 1	Sample 2
＞20	(%)	0	0
20-10.0	(%)	1.7	0
10.0-5.6	(%)	1.65	0.59
5.6-3.35	(%)	1.43	0.91
3.35-1.0	(%)	5.51	4.58
1.0-0.5	(%)	10.19	9.87
0.5-0.25	(%)	24.97	27.88
0.25-0.106	(%)	/	/
0.106-0.075	(%)	52.62	54.23
＜0.075	(%)	1.84	1.86
Dmax	mm	16	9

D. Fly Ash

Fly ash is recovered from flue gas through the off-gas cleaning method using ESP after passing through the heat recovery zone. The fine particles are ionized and extracted by field on plate. The collected particles are continuously hammered and disposed through the vessels. The vessel convey it to the Ash Silos through Pneumatic medium. Fly ash consists of silt-sized particles which are generally spherical, typically ranging in size between 10 and 100 micron. It consists primarily of oxides of Silicon, Aluminum, Iron, Sulfur and Calcium as given in Table 4. The fly ash at Thar power plant contains around 16% of Calcium oxide (CaO), thus it is classified as “Class C” according to ASTM C618-19.

Table 4. Fly ash XRF analysis

Oxides in Ash	Units	Sample 1	Sample 2
Sodium oxide Na2O	(%)	1.67	1.63
Magnesium oxide MgO	(%)	3.57	3.47
Aluminum oxide Al2O3	(%)	13.25	14.98
Silicon oxide SiO2	(%)	37.03	37.18
Phosphorus oxide P2O5	(%)	0.08	0.08
Sulfur oxide SO3	(%)	10.57	9.45
Potassium oxide K2O	(%)	0.1	0.11
Calcium oxide CaO	(%)	16.39	14.92
Titanium oxide TiO2	(%)	1.93	1.99
Iron oxide Fe2O3	KJ/KG	16.3	17.39
Concentration Summation		100.91	101.21

3. Ash Disposal

Generally, disposal of ash is one of the major problems for coal-based thermal power plants. When lignite coal type is burnt it produces approximately 69.3% of fly ash and 30.7% of bottom ash. Currently, the fly ash produced at Thar Coal Power plant is about 24502.6 tones/month, and bottom ash is about 10851.6 tones/month. The ash occupies around 120,000 sq. meter of land with four meter in-depth of ash disposal pond. However, it is expected that the ash disposal is going to soar at around 212,128.8 tons per year. Ash disposal on daily basis for fifteen days (i.e., 1st Sept. 2019 to 15th Sept. 2019) is shown in Table 5.

Table 5. Fortnightly ash disposal report

Day	Fly Ash Disposed (In tons)	Bottom Ash Disposed (in tons)
1	826.44	499.88
2	1005.68	480.58
3	943.62	460.88
4	956.66	407.98
5	958.8	357.84
6	924.88	288.1
7	876.72	429.96
8	906.18	245.1
9	1039.06	409.34
10	1137.12	362.48
11	1048.26	313.14
12	1058.94	259.16
13	1112.34	318.76
14	991.96	502.26
15	1027.62	447.78
Total Ash	14814.28	5783.24

4. Coal Consumption and Energy Generation

Table 6 shows fifteen days coal consumption in two units (i.e., 330MW of each). The average coal consumption of Unit 1 is 82541.126 tons and 80761.27 tons for Unit 2. While Figure 1 shows trend of coal consumption in fifteen days.

Table 6. Coal consumption table for fifteen days

Day	Unit 1 coal consumption (in tons)	Unit 2 coal consumption (in tons)	Total coal consumption in tons
Day 1	5786.86	6163.55	11950.41
Day 2	5199.73	6249.28	11449.01
Day 3	5797.25	5667.88	11465.13
Day 4	5815.4	4669.7	10485.1
Day 5	4729.605	4156.4	8886.005
Day 6	5300.695	4528.62	9829.315
Day 7	5551.8	4292.22	9844.02
Day 8	5830.1	4997.7	10827.8
Day 9	5603.61	5138.8	10742.41
Day 10	5430.9	5543.1	10974
Day 11	5536.9	5495.55	11032.45
Day 12	5170.5	5500	10670.5
Day 13	5378.08	5833.25	11211.33
Day 14	5580.318	6108.17	11688.488
Day 15	5829.378	6417.05	12246.428
Total Consumption per 15 days	82541.126	80761.27	163302.396

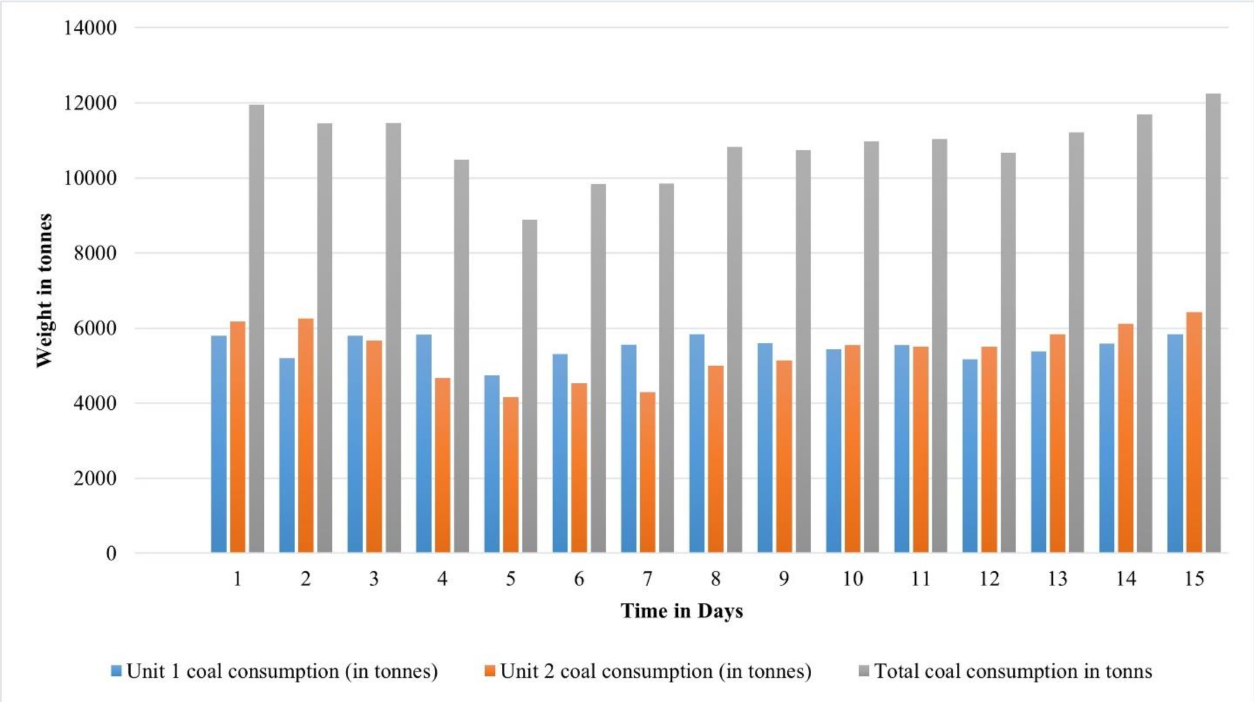

Fig.1. Total coal consumption chart for fifteen days

Table 7 and Figure 2 shows the net Ash (fly ash and bottom ash) disposal for fifteen days and corresponding total coal consumption for both the units. According to chemical analysis as given in Table 1 the average ash contents in coal is 10.41% but from 15 days report on coal consumption and ash disposal, the ash production is about 12.6% which is slightly higher.

Table 7. Coal consumption and ash production in tons for fifteen days

S.No	Day	Coal Consumption	Net Ash Disposal
1	Day 1	11950.41	1326.32
2	Day 2	11449.01	1486.26
3	Day 3	11465.13	1404.5
4	Day 4	10485.1	1364.64
5	Day 5	8886.005	1316.64
6	Day 6	9829.315	1212.98
7	Day 7	9844.02	1306.68
8	Day 8	10827.8	1151.28
9	Day 9	10742.41	1448.4
10	Day 10	10974	1499.6
11	Day 11	11032.45	1361.4
12	Day 12	10670.5	1318.1
13	Day 13	11211.33	1431.1
14	Day 14	11688.488	1494.22
15	Day 15	12246.428	1475.4
Total Consumption per 15 days		163302.396	20597.52

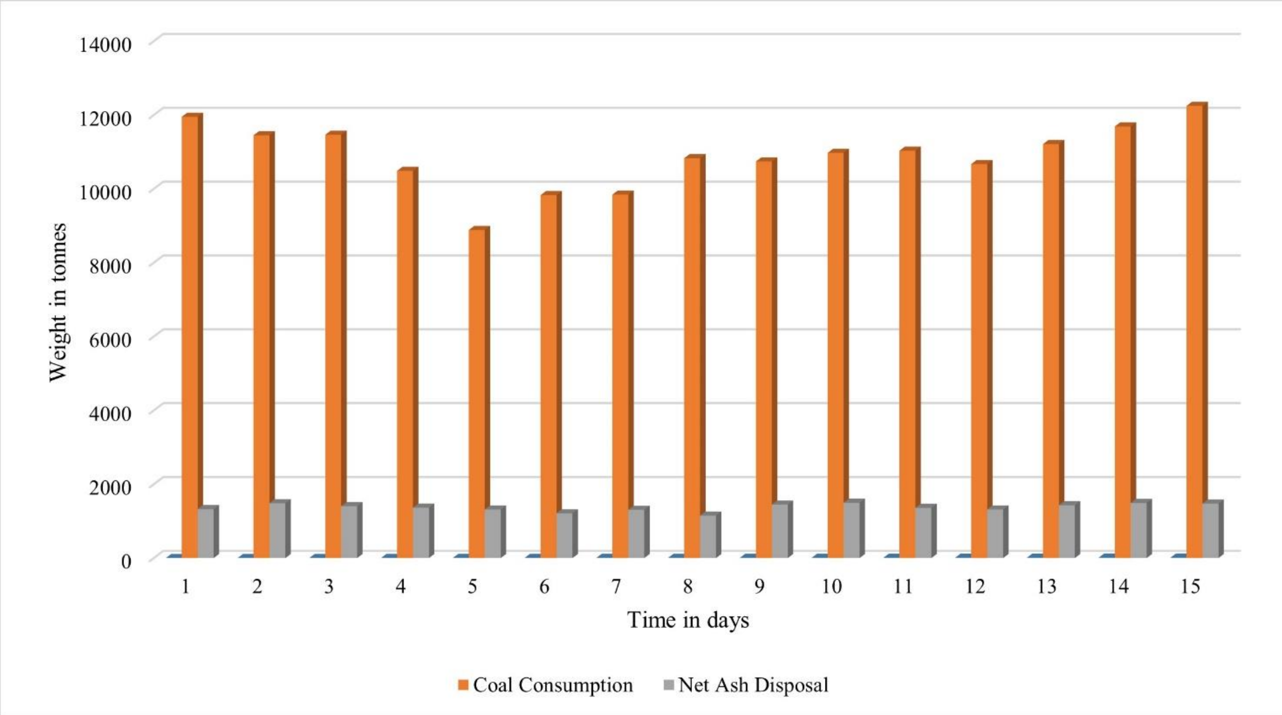

Fig.2. Total coal consumption and ash production for fifteen days

Table 8 and Figure 3 shows the 15 days report of power generation, coal consumption, fly ash production, bottom ash production and net ash production.

Table 8. Coal consumption, fly ash and bottom production and net power generation for fifteen days

S. No	Day	Generation (MWh)	Coal Consumption (in tons)	Fly Ash production (in tons)	Bottom Ash production (in tons)	Net Ash production (in tons)
1	Day 1	13537.6	11950.41	826.44	499.88	1326.32
2	Day 2	14523	11449.01	1005.68	480.58	1486.26
3	Day 3	13275.8	11465.13	943.62	460.88	1404.5
4	Day 4	12131.9	10485.1	956.66	407.98	1364.64
5	Day 5	11346.4	8886.005	958.8	357.84	1316.64
6	Day 6	11751.6	9829.315	924.88	288.1	1212.98
7	Day 7	11704.3	9844.02	876.72	429.96	1306.68
8	Day 8	11715.2	10827.8	906.18	245.1	1151.28
9	Day 9	12961	10742.41	1039.06	409.34	1448.4
10	Day 10	13260.1	10974	1137.12	362.48	1499.6
11	Day 11	13160.8	11032.45	1048.26	313.14	1361.4
12	Day 12	13159.4	10670.5	1058.94	259.16	1318.1
13	Day 13	13742	11211.33	1112.34	318.76	1431.1
14	Day 14	14595.4	11688.488	991.96	502.26	1494.22
15	Day 15	14594.6	12246.428	1027.62	447.78	1475.4
Total Production		195459.1	163302.396	14814.28	5783.24	20597.52

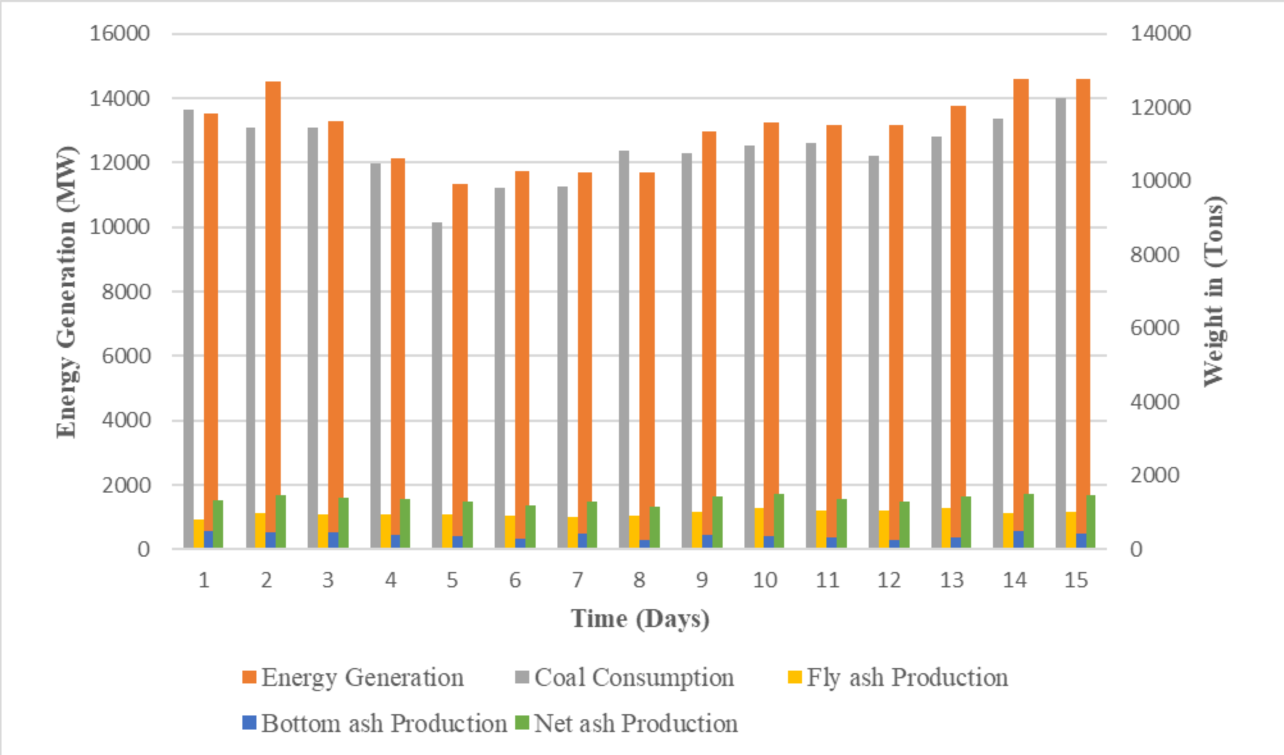

Fig.3. Total coal consumption, ash production (in tons) and net power generation (in MW) chart for fifteen days

5. Impacts of Ash on Environment

The particle size of fly ash is ranging from 0.5 to 300 micron in diameter, being light weight, have potential to get airborne easily and pollute the environment [13]. If it is not managed properly than it can causes serious health concern for human and wild life in long time. Additionally, ash contaminates the under-ground water and fresh water resources with traces of toxic metals present in fly ash. In addition, it requires large part of land to dispose or landfill. Indirectly ash also contributes to climate change and global warming. As coal power plants emits lots of greenhouse gases in environment with huge proportion of carbon di oxide.

6. Utilization of Ash

Fly Ash is being economically utilized in building structures for example, bricks, roads, stabilization of embankments etc. It is additionally utilized as raw material in agricultural and wasteland development programs. Through research development and application of recycling, fly ash has shifted from “Waste Material” category to “Resource Material” category. Some of the innovative and commonly manufactured ecofriendly building material utilizing fly ash is covered below.

A. Cellular Light Weight Concrete (CLC) Blocks

CLC blocks can substitute to conventional bricks and concrete blocks in building with density varying from 400 kg/m^3 to 1800 kg/m^3 [11]. Further foamed concrete is manufactured by mixing Portland cement, sand, fly ash, water and preformed foam in varied proportions. CLC blocks have more performance benefits than conventional bricks like lightweight, fire resistance, thermal insulation, sound absorption and acoustical insulation. These blocks are cost-efficient as well.

B. Fly Ash based new Bio-Composites Material as Wood Substitute

The fly ash-based composites have been developed with Human Hair and composite plates. These composite plates were developing by using CY-230 resin. These bio composite material have good mechanical performance, low-cost, high toughness, and bio-durability. Fly ash based composite has been successfully used for many decades for all engineering applications.

C. Usage of fly ash in cement

Fly ash possesses pozzolonic properties and it can be used as binding material. For many years fly ash is used as secondry cementitious material along with Portland cement. American Society of Testing Materials categorizes fly ash into different types based on CaO content. Standards allow maximum 30% replacement of fly ash as partial replacement of cement in concrete which gives adequate performance of concrete. However, according to J. Alam and M.N Akhtar [11], up to 35% of suitable fly ash can directly be substituted for cement as blending material [11]. Fly ash improves the quality and durability characteristics of concrete and contributes to lower amount of cement usage which results in economical concrete.

D. Fly Ash in Road Construction

Fly ash utilization as construction material for enhancing the engineering properties of soil reduces the demand of disposal and hence controls the source of pollution and protects the environment.

E. Use of fly ash in Agriculture

Element of fly ash like Magnesium, Sulphur, Phosphorus, Potassium improve soil's fertility, physical and chemical properties which results in an increase of crop yields. Further, it improves the water holding capacity of soil and crop grown on fly ash amended soil are safe for human use.

7. Conclusions

The aim of this research was to know the quality of Thar Coal fly ash, its production and possible usage. From experimental data it was observed that the Thar coal type is lignite and ash produced is Type C. The coal consumption for energy produces 12% fly ash which is dumped nearby power plant. The ash disposal can pose serious environmental impact and health hazards if not handled properly.

Possible ways to use fly ash as potential abundant material has also discussed to highlight the recycling of this byproduct. As this study is only based on single power plant but there are twelve more plants which are not in operational condition at this point. However, in future they will be functional to produce energy and fly ash as well. Thus, there is huge availability of fly ash to recycle for different purposes.

For research and development, this ash needs further experimental investigation in different industries like construction. The investigation may include suitability of the ash as secondary cementitious material in concrete, making bricks by replacing ordinary clay in different proportions etc. These researches will open many possibilities to recycle this byproduct efficiently, economically and environmental friendly.

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Authors’ Profiles

Deepak Kumar is electronics engineer and work as assistant manager in Jamshoro power company limited. The author has research interest in utilization of waste ash in the different useful products. He has also interest to do research in the field of instrumentation and control.

Bharat Lal is Lecturer at Electronic Engineering department at Mehran University of Engineering and Technology, Pakistan. Author has research interest in smart cities, Automation and control, Recycling of waste material, Machine Learning, Artificial Intelligence and Embedded Systems

Mukesh Kumar is chemical engineer and work as assistant manager in a power generation company. He has research interest in recycling and reuse of waste material coming from burning of coal. Also has research interest in the field of water treatment technologies to increase the efficiency and reduce the waste production.

Shanker Lal Meghwar is Lecturer at Civil Engineering in Mehran UET Jamshoro. The author has research interest in secondary cementitious materials, recycling of waste as potential material for concrete and numerical analysis to mimic the behaviour of structural concrete.

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