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Sampling and Analysis of Coal with Thermal and Chemical Methods for Quality Control Evaluation

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ABSTRACT- Coal is one of the huge consumed fossil fuels and has huge energy demands in various energy sectors especially in power generation sector and in industries. Coal is a common energy source in the cement and steel industry and in coming years India will rely heavily on the utilization of fossil fuels for its huge energy demands. As India is targeting to attain zero-carbon emission till 2070, there is pressing demand on efficient utilization of fossil fuels so as to minimize any harm to our ecosystem. In this paper we have performed thermal and chemical analysis on the quality of coal so as to determine the best quality of coal which can be utilized properly as well as graded for appropriate usage in various energy demanding sectors. We provided stage process test technique procedures for proximate analysis, ultimate analysis, mineral matter, physical and thermal characteristics, and so on. After having detailed analysis of coal samples, it is found that by increasing Sulfur content in coal, consumption of coal can be decreased significantly which will ultimately decrease the air pollution and less coal will be consumed in cement production.

KEYWORDS- Coal Analysis, Sampling, Sulphur determination, Coal quality

I. INTRODUCTION

In COP26 climate summit in Glasgow, Scotland (November 2021), India has announced three new targets including the promise to make India net-zero on emissions by the year 2070 [1]. The two other targets related to increasing India's non-fossil fuel installed capacity to 500 GW by 2030, and avoidance of at least 1 billion tons of emissions between now and 2030. As it has been included that until 2070, India will rely on fossil fuel for its huge energy demands in various energy sectors especially in power generation sector and in industry especially cement industry. So, until 2070 when India will attain zero carbon emission, we need to use fossil fuels very efficiently so that there will be less harm to our ecosystem. One of the huge consumed fossil fuels is coal. Our research is be based on using best available coal by using thermal and chemical analysis method so that we can determine the best quality of coal which can be utilized properly as well as graded so that by using proper grading we can use each quality of coal at various energy demanding sectors.

Coal is a popular energy source in the cement and steel industries. There are four varieties of coal: lignite, subbituminous coal, bituminous coal, and anthracite coal each type has varying amount of hydrogen, oxygen, nitrogen, sulfur, and carbon and as a result they have different uses. Mined coals need to be sorted, measured, analyzed, and blended to meet customer specifications. Table 1 discusses total coal imports in India since last six years.

Table 1: Total coal imports in India since last Six Years

Coal Import Year	2015 -16	2016 -17	2017 -18	2018 -19	2019 -20	2020-21
Total	203.9	191.0	208.2	235.3	248.5	215.2
Coal Imports (Million tons)	5	1	5	5	3	5

(Import up to November 2021 Source: - DGCI&S and CBIS's Website) [4]

India Imports 49% coal from Indonesia, Australia 20%, South Africa 16%, USA 5%, Russia 3% and other Countries 8%. Because of rising coal consumption, particularly from the power industry, India is becoming increasingly reliant on imports rather than indigenous supply [5].

A. *Coal feeding in cement manufacturing process*

Coal feeding is an important part of the cement making process in cement plants. With the help of a belt conveyor, coal is transferred from the coal yard to the coal hopper, where it is fed to the coal mills via a weigh feeder that controls the raw feed to the grinding mill. After feeding the coal to the mill, hot air from the kiln's grate cooler is sent to the mill to dry the coal. The mill is an air swept mill, which means that the pulverized material is swept out by a current of air as soon as it is formed, and the oversize partials are removed in an air separator (grid Separator) and returned to the mill via a conveyor, while the fine finished product is removed via a dust collector stored in a fine coal hopper thus the finished coal is ready to use or feed the Kiln Section.

When the coal is fed to the DDF counter (Calcine Counter), secondary coal firing occurs, resulting in a temperature of about 850 degrees Celsius for the raw meal (raw material consists of fine mixed powdered form of lime stone, Silica, Alumina, Iron, and other mixed aggregates materials) when it enters the kiln inlet, and calcinations achieved in the preheater of about 80-85 percent.

The partially calcined material enters kiln inlet and the rest of calcinations that is dissociation of ($CaCO_3$) + ($MgCO_3$) is completed in the calcination zone of the kiln. And the formation of various phases known as tricalcium silicate, dicalcium silicate, and Tetra Calcium Alumina Ferrite in the burning zone takes place through a multi-channel burner pipe through which the coal enters in the Rotary Kiln burning zone with the result the temperature of calcined material reaches about 1300- 1400 Degree Celsius. This product is known as Clinker (In the shape of Noddle's). 4-5 % gypsum is added to the 95% of Clinker then feed to the grinding mill and hence cement is produced.

In this paper, additionally, we have included an introduction to coal creation which will aid in comprehending the difficulty of the organic percentage of coal as well as the complicated nature of the mineral element of coal. Overall, the paper will present a complete overview of coal analysis chemistry and technology that is required in the twenty-first century. The paper also includes information on how to test and analyze coal. It will also discuss the significance of test results and how they can be used to anticipate coal behavior and its associated ecological influence during usage.

It will be a valuable tool for analytical chemists, process chemists, professionals and engineers in the coal business, and other scholars interested in utilizing coal to minimize dependent on imported oil reserves and create efficient, better techniques of coal energy generation.

The remainder of the paper is presented: In the next part we will describe the project objectives of this work, followed by a related work section where we discuss some related works in the literature. Next, we present the methodology section in which we describe the experimental details for sample evaluation, and lastly, we present the results and discussion section and conclude the paper.

B. Project Objectives

The project objectives are as follows:

- Nomenclature, terminology, sampling, and analysis precision and accuracy all are addressed.
- Clarification of coal's performance in relation to its use, as well as the related ecological concerns.
- Standard testing and processes required are presented.
- Complete step-by-step instructions for test technique procedures for proximate, ultimate, mineral matter, physical, thermal characteristics.
- Providing a comprehensive study report in order to locate sulfur-rich coal in the market.

II. RELATED WORK

When the plants perished, their energy material remained buried in anaerobic, watery environs with (O) oxygen deprivation, preventing biomass reduction and carbon dioxide generation as reported in a study by Speight et al. [11] [13].

In today's terminology, coal is split into a series of kinds, all of which are the result of geographical development factors that have impact on the dead predecessors through time and are under suitable conditions [14] [17].

Salamony et. al [6], suggested the usage of alternative fuels is necessary to accomplish excellent combustion performance by reducing toxic chemical emissions (AFs). A one-of-a-kind waste disposal plan was developed at a cement mill to replace fossil fuels with a blend of rice husk and keep refusing fuel (RDF, 0%–5%). The impact of this substitution on clinker setting time and strength properties, as well as nitric oxide (NOx) and sulfuric oxide (SOx) emission levels, was evaluated. As per the results, coal consumption could be reduced by 17%, and the inclusion of RDF and rice husk mixed effectively reduced electrical energy consumption by 13%. NOx and SOx pollutants have also dropped. As a conclusion, these finding look at the effects of AFs on enhancing combustion, decreasing pollution, and creating financial growth sources.

Pyrite (Sulfur) plays a vital role in coal spontaneous combustion. Pyrite is an important component in coal spontaneous combustion. Pyrite has a third of the specific heat of coal, yet with the same heat immersion, the heat rise of pyrite is 3 times more than coal. According to the discoveries, increasing the sulfur content in coal by 5% will cut coal usage by 17 percent while also lowering NOx and SOx emissions.

These data indicate the effects of AFs on ignition efficiency, pollutants, and the development of economic health resources. Deng et al. [3] in their work present a study on effects of pyrites on coal combustion. Their study contributes to the optimization of renewable energy applications in the cement industry. They also stated that future studies should be done focusing on additional dropping emissions and addressing tests related with climate change.

Sulfur is an essential factor in coal consumption, and as a result. There has been a significant extent of printed/published work connected with the evolution of performances to increase the efficiency of the coal, and also the precision and accuracy of the assessment of sulfur accurately [15]. Coal has a wide range of Sulfur concentration, ranging from 0.5 to 5 percent weight/weight, which combines inorganic, organic Sulfur. Iron pyrite is most common type of inorganic Sulfur.

III. METHODOLOGY

A. Approximate analysis

The most frequent forms of analysis needed by the coal sector are moisture, ash, volatile matter, and fixed carbon, as well as ultimate analysis (carbon, hydrogen, sulfur, nitrogen, oxygen, and ash) [7].

B. Thermal analysis (Proximate Analysis)

Determination of Moisture (IS: 1350 PART I 1984)

The sample, which is manufactured in accordance with IS 436 (Part 1/sec1)-1964 and IS 436 (Part 2)-1965 [9], must be received in a sealed container and contain about 300 grams of raw coal that must pass through a 212 micron IS Sieve (coal had been crushed in laboratory crusher). Where the samples were prepared via air drying this operation's percent moisture loss must be indicated on the label as well. Maintain an oven temperature of 100 degrees Celsius +/- 2 degrees. Weigh an empty Petri dish record the reading. Set the weigh balance to zero and fill the Petra dish with 100 grams of sample. Put the Petri dish in the oven for 1 hour (Figure 1). After on hour cool down the Petra dish in discreet and weigh the Petra dish once again and note down the reading.

Moisture = W1 – W2

Where, W1 is the weight of the Petri dish before placed in oven and W2 is the weight of the Petri dish after oven.

C. Ash Determination

It was carried out according to the protocol IS 1350 (PART 1) 1984.

Materials required: Muffle furnace, silica or platinum crucible (10-15mm deep), weighing balance.

Weigh the empty silica or platinum crucible and record the reading W1. In the crucible, place 1 gram of fine coal (passed through a 212 micron IS Sieve). Place the crucible in the Muffle Furnace and heat it to 850 degrees Celsius +/- 10 (Figure 2). Keep the temperature at this level for one hour. Remove the crucible from the Muffle Furnace, allow it to cool, and then weigh it again W2.

ASH = W2 - W1 X 100

Total weight obtained will be the percentage of ash in coal.

D. Volatile Matter (VM)

The protocol was taken as per IS 1350 (PART 1) 1984.

Apparatus required: Muffle furnace, silica crucible or platinum crucible (10-15mm deep), weigh balance, Lid, Stop watch.

Procedure: Weigh the empty silica or Platinum crucible and note down the reading W1. Put 1gm of fine coal (passed in 212 microns IS Sieve) in crucible and cover Procedure: Weigh the empty silica or Platinum crucible and note down the reading W1. Put 1gm of fine coal (passed in 212 microns IS Sieve) in crucible and cover up the crucible with lid. Put the crucible in Muffle Furnace for 7 minutes and maintain the temperature up to 900degree Celsius +- 10 (Figure 3). Remove the crucible from Muffle furnace and cool down the crucible and weight the crucible once again W2.

Volatile Matter (VM)= W2 – W1 X 100

Total weight obtained will be the percentage of Volatile Matter (VM) present in the coal.

E. Determination of Sulfur

Protocol according to IS: 1350(PARTII) 1969: [8].

Various appearances of indications point to the assumption that sulphur in plant material is the Sieve 212 microns Weighing Balance Oven maintaining temp at 100oC Petri dish holding coal sample

Sieve 212 microns

Weighing Balance

Oven maintaining temp at 100ºC

Petri dish holding coal sample

Figure. 1: Determination of surface moisture

Silica crucible Weighing balance Silca Crucible With Coal Sample Muffle furnace

Coal Sample inside Muffle furnace Ash in Silca crucible

Silica crucible

Weighing balance

Silca Crucible With Coal Sample

Coal Sample inside Muffle furnace

Ash in Silca crucible

Muffle furnace

Figure. 2: Determination of Ash

Silca Crucible Weighing Balance Silca Crucible With Coal Sample covered with Lid Coal Sample inside Muffle furnace for 7 Min After removing sample from muffle furnace

Silca Crucible

Weighing Balance

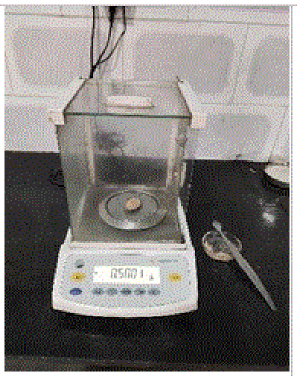
Silca Crucible With Coal

Coal Sample inside Muffle furnace for 7 Min

After removing samplefrom muffle furnace

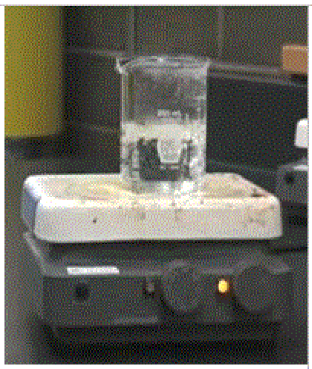
Sample covered with Lid

Figure 3: Determination of Volatile Matter (VM)



Weighing Balance weighting coal Ash

Beaker holding Coal Ash

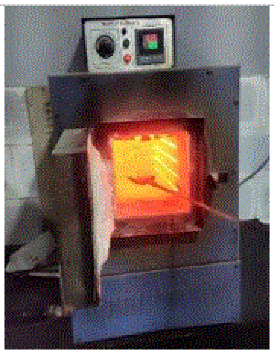


Beaker Boiling at Hot plate

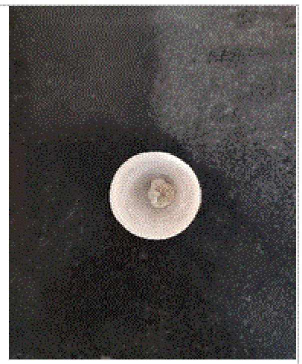
Filtered coal Ash Solution in 41filter Paper

Filtered Solution added with $BaCl_2$

Filtered solution filtered with 42 Filter Paper



42 filtered paper holded in Silca crucible and burned in Muffle furnace



Silca Crucible with Burnt 42 filter paper.

Figure. 4: Determination of Sulphur

primary foundation of sulphur in low-sulfur coals, while saltwater is also a major source of sulphur in moderate, great content sulfur coals [2].

"Pyritic" So3 is determined by extracting coal with dilute Hydrochloric acid and measuring Sulfur in the extract. Sulfur is insoluble in nHydro Chloric Acid, although dilute nitric acid dissolves it quantitatively under the conditions given. It's easiest to figure out using the indirect method, which involves calculating the quantity of Iron coupled ion pyratic state and the amount of Sulfur linked with it. “Organic” Sulfur is calculated by deducting the sum of %age of Sulfates and pyratic Sulfur from total Sulfur in the coal as determined by ESCHKA method.

Apparatus: Muffle furnace, air oven, 2 no Beaker, Platinum Crucible/silica crucible, Funnel, Glass Rod, Whatman Filter Paper 41 and 42, Weigh balance, clean cloth.

Reagents

- Concentrated Hydrochloric Acid HCl
- Dilute Hydrochloric Acid approx. 5N
- Dilute Hydrochloric Acid 0.5 N
- Barium Chloride Solution – 10%. Dissolve 100 grams of barium chloride di hydrate (Bacl2.2H2O) in water and make up the volume to 1000 ml.

Procedure: Before beginning the analysis, thoroughly mix the Coal sample, which has been powdered to pass the 212 micron IS Sieve preferably with a mechanical laboratory mixer. Take a 1 gram sample of coal ash that has been accurately removed after it has been burned in a Muffle Furnace. Then, in a 250 mL beaker, heat with 50 mL dilutes Hydrochloric Acid until it is completely dissolved. Wash the filter paper thoroughly with distilled water.

Filter the mixture through a medium – washed filter paper (whatman Filter paper Number 41). Discard the Residue.

Add 15 to 20 ml of Barium Chloride (BaCl2) to the filtered solution in beaker. Boil the solution until the solution reaches to the boiling point. Rest the solution in a warm place near about 4 hrs. (For accurate results we can rest the solution for 24 Hrs.

Filter the mixture through a medium Whitman no. 42 filter paper. Wash the residue in filter paper thoroughly with Luke warm distilled water.

Put the remaining filtered material, along with the filter paper and funnel, in the oven for half an hour at 70 degrees Celsius, to evaporate all of the moisture in the filter paper. Place the filter paper in a Platinum Crucible and place the Platinum Crucible in a Muffle Furnace set to 800 degrees Celsius plus 25 degrees Celsius. Wait until all the filter paper present in platinum crucible gets burned and remove the crucible from the muffle furnace. Cool down the platinum crucible and weigh it in weigh balance and note down the reading (W1)

Now empty the crucible with a clean cloth and weigh again the platinum crucible and note down the reading (W2) (Figure 4).
Calculations:
SO_3 = W1- W2 x 100x 34.3 (which is the molecular ratio of SO_3 to $BaSO_4$)
Chemical reaction:
S + O_2 > SO_2
SO_2------> +½ O_2 = SO_3
SO_3+H_2O > H_2SO_4
H_2SO_4 + $BaCl_2$ --------□ $BaSO_4$+ 2HCl.
FILTER------□ DRY ---□ Weight of $BaSO_4$.

Results obtained are the content of Sulfur Tri Oxide present in coal. The total Sulfur Contents present in the coal samples vary from 1.1% to 11 % over all.

IV. RESULTS AND DISCUSSION

In this section we present a standard table that prescribes the methods of testing for Coal relating to Proximate Analysis including determination of Ash, Volatile matter and Moisture and Determination of Sulfur in Coal by Eschka method under different conditions.
All of the tables 2, 3 and 4 provide the exact results of coal sample tests. There are 10 samples in each table and the average / mean of the results has been calculated. As part of a daily supply of coal stock to a cement factory, all of these samples were analyzed for over a month. Each sample was taken from an unloaded vehicle (Lorry carry vehicle/transporter) that originated in Punjab, Madavpur. All of the aforesaid analyses were carried out in a laboratory of one of the top cement manufacturing plants in Kashmir.
These coal samples were primarily obtained from Indonesia, South African and Australian mines and were subsequently shipped by sea to Gujarat, Kadlaport after being unloaded. Coal is subsequently carried by train and lorry to Pathankot,
Madavpor Punjab, where it is delivered to India's Northern Regions, and then transported again in small or median loads to other destinations. Because of the hilly terrain in northern India, particularly in Jammu and Kashmir Trucks with payload capacities ranging from 11 to 50 metric tons are used. The majority of cement Plants in Kashmir acquire their coal from Madavpur, Punjab. Punjab is where the dealing and distribution takes place.

Table 2: Sampling Result

No. of samples	Ash Percentage/ 1 gram sample	VM(Volatile matter) Percentage /1 gram sample	Moisture Percentage/ 100 gram sample	Sulfur Percentage/1 gram Sample
Test Sample No 1	26.34	25.99	6.20	1.45
Test Sample No 2	26.40	24.29	6.0	1.41
Test Sample No 3	18.68	28.90	6.70	1.51
Test Sample No 4	25.38	29.50	6.80	1.53
Test Sample No 5	23.58	25.62	2.42	1.65
Test Sample No 6	22.90	24.79	3.49	1.54
Test Sample No 7	22.88	27.32	4.90	1.80
Test Sample No 8	21.66	26.20	4.80	1.89
Test Sample No 9	20.40	28.69	4.80	1.36
Test Sample No 10	22.34	25.46	5.60	1.48
TOTAL AVERAGE OF SAMPLES	20.69	26.67	5.17	1.56

Table 3: Sampling Result

No. of samples	Ash Percentage/ 1 gram sample	VM(Volatile matter) Percentage /1 gram sample	Moisture Percentage/ 100 gram sample	Sulfur Percentage/ 1 gram Sample
Test Sample No 11	21.30	27.56	5.20	1.90

Test Sample No 12	22.50	28.0	4.96	1.54
Test Sample No 13	21.60	27.46	5.30	1.62
Test Sample No 14	23.0	27.19	6.0	1.89
Test Sample No 15	27.19	27.96	6.80	1.38
Test Sample No 16	18.74	21.93	5.20	1.66
Test Sample No 17	21.72	24.10	5.0	1.89
Test Sample No 18	20.66	24.77	6.30	1.69
Test Sample No 19	20.88	25.59	5.64	2.05
Test Sample No 20	24.58	28.52	5.20	1.56
TOTAL AVERAGE OF SAMPLES	22.21	26.30	5.56	1.71

Table 4: Sampling Result

No. of samples	Ash Percentage/ 1 gram sample	VM(Volatile matter) Percentage /1 gram sample	Moisture Percentage/ 100 gram sample	Sulfur Percentage/ 1 gram Sample
Test Sample No 21	17.18	25.76	7.80	1.53
Test Sample No 22	16.0	31.50	7.0	1.56
Test Sample No 23	14.50	32.20	9.20	1.82
Test Sample No 24	21.0	31.80	7.90	2.04
Test Sample No 25	19.78	31.73	7.90	1.55
Test Sample No 26	20.40	34.60	7.50	1.36
Test Sample No 27	19.2	32.19	8.0	1.78
Test Sample No 28	22.78	30.40	12.76	1.65
Test Sample No 29	23.24	27.65	6.5	1.79
Test Sample No 30	18.54	30.39	6.4	1.54
TOTAL AVERAGE OF SAMPLES	19.26	30.82	8.09	1.66

V. CONCLUSION

To meet the goal of bringing India zero- emissions by 2070 and increasing non- fossil fuel capacity factor to 500 GW by 2030, along with avoidance of at least 1 billion tons of carbon emissions from now till 2030, it is concluded that India will rely on fossil fuels until 2070. Fossil fuels will cater to its huge energy demands in various energy sectors especially in power generation sector and in industries especially the cement industry. In order to attain zero carbon emission, the available fossil fuels need to be utilized in a very efficient manner so that there will be minimal harm to our ecosystem.

As coal is the most consumed fossil fuel, our research presented in this paper is based on using best available coal by using thermal and chemical analysis methods, in order to determine the best quality of coal. We presented some analysis on the ways to achieve good quality coals which can be utilized properly as well as graded so that by proper grading we can utilize the appropriate quality of coal at various energy demanding sectors. After having detailed analysis of coal samples, it is found that by increasing Sulfur content in coal, consumption of coal can be decreased significantly which will ultimately decrease the air pollution and less coal will be consumed in cement production.

The major contributions of this paper are:

- We presented a detailed coverage of nomenclature, terminology, sampling, and accuracy and precision of analysis.
- We provided a detailed discussion of coal activities in response to its use, and also the related environmental concerns.
- We supported our coal analytic methods with the performance of required standard tests and procedures.
- We demonstrated step-by-step test methodology procedures for proximate analysis, ultimate analysis, inorganic material, physical, and thermal properties.
- The thorough data in table 2,3 and 4 aid us in identifying the finest sulfur-rich coal, allowing us to increase output while reducing coal consumption and, as a result, lowering environmental impact.

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