Print ISSN : 0019-5537
Indian Journal of Power and River Valley Development
Contents available at: https://informaticsjournals.com/index.php/ijprvd

Technical Scientific Article

Coal Quality Change Due to Handling and Stockpiling in an Indian Power Plant: A Case Study (Part-1-The Preparation of Samples)

Jayanta Bhattacharya[1]*, Isha Medha[2], Subhash Chandra[3], Rishi Karan Singh Rathore[4] and Koushik Saha

[1]Department of Mining Engineering, School of Environmental Sciences and Engineering, Indian Institute of Technology, Kharagpur – 721302, West Bengal, India; jayantaism@gmail.com
[2]Research Scholar, Mining Engineering, Indian Institue of Technology, Kharagpur – 721302, West Bengal, India.
[3]Assistant Professor, Department of Civil Engineering, GITAM University, Visakhapatnam - 530045, Andhra Pradesh, India
[4]Environmental Sustainability, Associate Strategy and transaction at Ernst &Young

Abstract

Surface moisture in coal is an engineering problem that brings down the useful heat value. The Gross Calorific Value (GCV) when reduced, limits the maximum energy that can be extracted from a given mass of coal. This report discusses a study carried out over one year to understand how the openly brought coal, in wagons, undergoes changes in the open stockpile in terms of loss of total carbon both as a result of spontaneous combustion as well as retention of moisture due to occasional rains. The study was carried over from the wagon unloading to the point of use via the processes of coal handling; unloading, transport, stockpiling, redrawing from the stockpile and then use. The study finds that while open stockpiling reduces the GCV, the reduction in the size of the coal due to crushing, grinding and pulverizing before firing sort of compliments for the loss.

Keywords: Stockpiling, Coal Quality, Gross Calorific Value

1.0 Introduction

1.1 Sources of Coal at NTPC Farakka

NTPC Farakka receives coal supply from different organizations in line with the "Fuel Supply Agreement." In Table 1 coal supplies from different coal sources as well as their amount in million tons per annum are depicted. Figure 1 gives a bird's-eye view of the NTPC Farakka plant. Figure 2 provides the circuit diagram of the plant.

Table 1. Coal Sources at NTPC Farakka

Domestic Coal Supply Sources	Supplies in (million tons per annum)
M/S Eastern Coal Field Limited (ECL)	80.99 Lakhs
M/S Bharat Coaking Coal Limited (BCCL)	10.13 Lakhs
M/S North Eastern Coalfield Limited (NECL)	2.00 Lakhs
Imported Coal (Indonesia origin) through waterways	12.00 Lakhs

*Author for correspondence



Figure 1. An overview of the NTPC Farakka plant setup.

are facing acute fuel shortages and supply uncertainties. In the absence of or due to delayed policy measures, dependence on imported or domestic coal of any grade can be acceptable only after assessing its impact on power plants and the environment.

Fuel selection for power generation plays a key role in establishing advanced steam parameters; achieving the required gross heat rate and combustion efficiency of the plant; and identifying the best-suited equipment and pollution control systems. Thus, the success of a power plant depends on the source and quality of coal supplied. The following is a depiction of the impact of coal quality

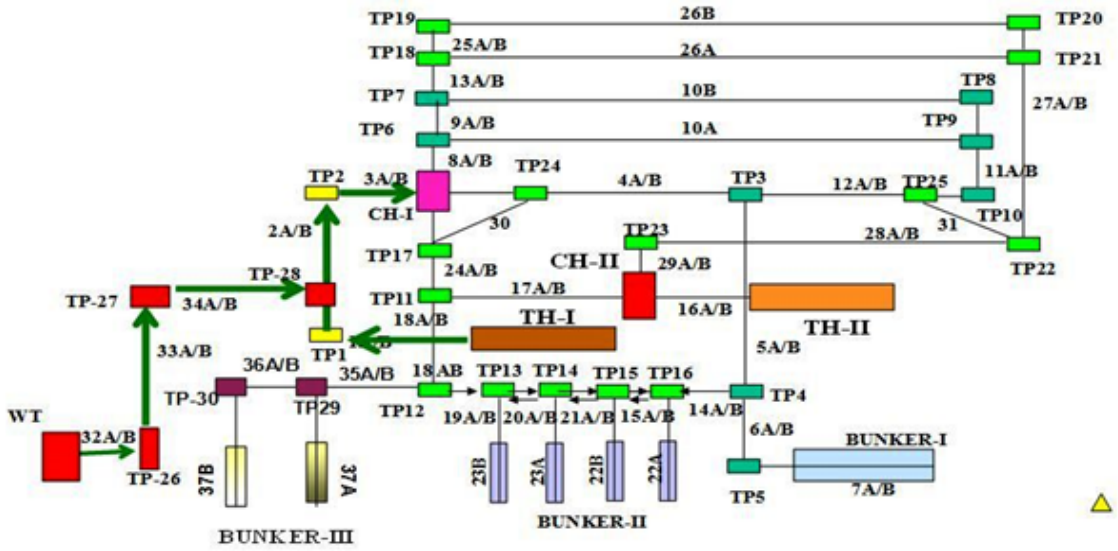


Figure 2. Circuit diagram of coal handling plant (CHP) at NTPC Farakka.

2.0 Background

2.1 Why Coal Quality is Important for Power Plants

For developing countries like India, coal-based thermal power generation is the main source of electricity as well as overall economic development. So, coal will continue to be the main source of power generation in the country for the years to come. However, coal is a fossil fuel and, therefore, it is important to address the concerns related to its consumption and quality at a time when power plants

variations on the selection of new boilers as well as the performance of existing plants and equipment.

2.1.1 High Moisture in Coal

- Effect on new boiler design and selection: This requires an increase in the furnace size and volume, large pulverizer size and high power availability. It also results in low boiler efficiency and high fuel requirement per MW of power generation.
- Effect on existing boilers: It makes it difficult to maintain steam and reheat temperatures.

Therefore, a high desuperheating flow would be required. High moisture content also results in low boiler efficiency, pulverizer capacity and outlet temperature.

2.1.2 High Ash Content in Coal

- Effect on new boiler design and selection: This requires an increase in furnace size and volume based on ash characteristics as well as large pulveriser size and high-power requirement. In addition, there is a higher fuel requirement per MW of power generation.
- Effect on existing boilers: This leads to an increase in the erosion of pressure parts, slagging and fouling of pressure parts, poor electrostatic (ESP) performance and overloading draught fans.
- Effect on ESP: ESP design parameters are dependent on fuel characteristics; therefore, the ESP size, performance and cost vary with a change in coal composition and ash characteristics.

2.1.3 Volatile Matter

- Effect on new boiler design and selection: If the volatile matter in coal used is low, special type down–shot burners are required. It also impacts the boiler turndown ratio and fuel residence time in the furnace.
- Effect on existing boilers: VM in coal helps in its combustion. Hence, a sudden reduction in VM results in issues in maintaining flame stability in the boiler and requires secondary fuel oil support to manage partial load operations.

2.1.4 Calorific Value of Coal

- Effect on new boiler design and selection: Low calorific value of coal has a cascading effect on the size and design of boilers, mills, ESP, draft fans, air and flue gases duct size, fuel handling and storage systems, ash handling and storage systems and auxiliary power consumption.
- Effect on existing boilers: If the calorific value of coal is reduced, there will be a need to fire additional coal into the boiler and for higher heat transfer in convective surfaces. Also, the requirement for de-superheating spray to maintain main steam temperatures would increase. It will also lead to low efficiency of boilers, mills and ESP; and erosion of pressure parts and draft fans.

2.1.5 Hard Grove Index

- Effect on new boiler design and selection: The Hard Grove Index (HGI) index is one of the important factors governing the selection and size of the pulveriser. A high HGI value indicates the ease with which coal can be ground in a mill.
- Effect on existing boilers: Coal fineness is severely affected if the HGI of the fired fuel is less than the desired value. This results in frequent mill maintenance and downtime and impact boilers efficiency and performance.

2.1.6 Coal Constituents – Carbon, Hydrogen, Sulphur and Nitrogen

- Effect on new boiler design and selection: The ultimate analysis of coal is required to determine its carbon, hydrogen, sulphur and nitrogen content. This helps in calculating stoichiometric and excess air requirements for efficient combustion.
- Effect on existing boilers: A change in fuel constituents affects the combustion process.
- Super-critical and ultra-supercritical power plants can achieve efficiencies of 40 per cent and 45 per cent respectively. Coal characteristics can have a significant impact on the overall power plant performance and economics, and, therefore, understanding the effect of coal quality and their control is important.

3.0 Objectives

The objectives of the study were as follows:

- To prepare the coal samples from different locations of the coal handling plant of NTPC Farakka for proximate analysis and GCV profiling to determine their total moisture content and GCV respectively.
- To conduct a study of change in GCV in the stack yard due to stacking of coal for a longer duration.

4.0 Materials and Methods

4.1 Sample Collection

The coal samples were collected from seven different locations namely Wagon loading, Before crusher, After crusher, Before bunkering, Feeder Inlet, Pulverizer and Mill reject in 7 days from 14th December 2020 to 20th December 2021. All samples were collected as per the ASTM standard method for coal sampling from every above-mentioned location. Following are some pictures taken during the sample collection.



Figure 5. Collecting the coal samples from the location wagon loading.



Figure 3. Collecting the raw coal samples from the stack pile in plastic bags.



Figure 6. IIT team members during coal sampling at NTPC.



Figure 4. Separating the coal samples in different plastic bags according to their source location.



Figure 7. Crushing the big boulders into small-sized particles with a hammer.



Figure 8. Packing the processed coal samples in plastic zip bags for further lab observation.



Figure 10. Coning and Quartering of the coal samples at NTPC Farakka.



Figure 9. Collecting the coal samples from the stack pile in a plastic bag.



Figure 11. One part of the quarter was discarded as per the coning and quartering method.

4.2 Methods of Sample Preparation

4.2.1 Coning and Quartering

Coning and quartering is a method used by analytical chemists to reduce the sample size of a powder without creating a systematic bias. The technique involves pouring the sample so that it takes on a conical shape, and then flattening it out into a cake.

The coal samples were flattened in the form of cake and then divided into 4 quarters; two diagonally opposite quarters were randomly selected and discarded, while the other two were combined and constituted the reduced sample. The same process was continued until an appropriate sample size remained. All the coal samples after coning and quartering were brought to the site-based sample preparation laboratory to carry out further procedures of sample preparation.

4.2.2 Crushing

Crushing reduces the overall top size of the run-off mine coal so that it can be more easily handled and processed within the Coal Preparation Plant (CPP). Crushing requirements are an important part of CPP design and there are several different types of crushers. All the coal samples that were brought to the laboratory were crushed in a stage crusher, to reduce the coal size before its processing in the pulverizer unit.



(a) (b)

Figure 12. **(a-b).** Crusher units for coal sample preparation at NTPC Farakka.

4.2.3 Pulverizing

A pulverized coal-fired boiler is an industrial or utility boiler that generates thermal energy by burning pulverized coal (also known as powdered coal or coal dust since it is as fine as face powder in cosmetic makeup) that is blown into the firebox. All the coal samples after crushing were brought to the pulverizing unit to pulverize them to power form for final GCV and proximate analysis.



Figure 13. The pulverizing unit is used for pulverizing coal.

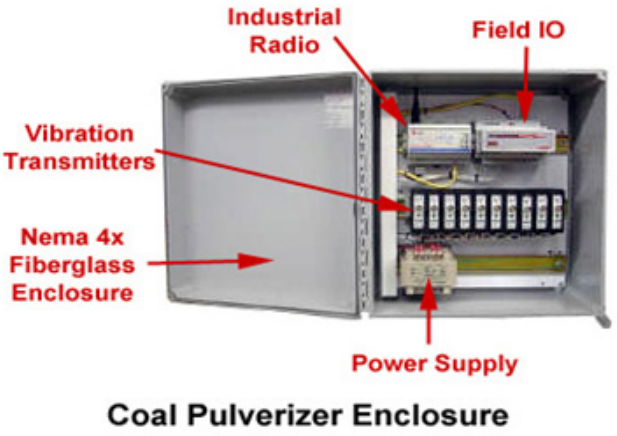


Figure 14. Coal pulverizer enclosure and its various components.

The basic idea of a firing system using pulverized fuel is to use the whole volume of the furnace for the combustion of solid fuels. Coal is ground to the size of a fine grain, mixed with air and burned in the flue gas flow. Biomass and other materials can also be added to the mixture. Coal contains mineral matter which is converted to ash during combustion. The ash is removed as bottom ash and fly ash. The bottom ash is removed at the furnace bottom.

Pulverized coal provides the thermal energy which produces about 50% of the world's electric supply.

4.3 Sample Preparation

After the samples were collected from the 7 different locations and brought to the site-based laboratory of NTPC, sample preparation was done for GCV profiling. The sample preparation procedure is as follows:

S. No.	Sampling Point	Sampling Procedure
1.	Wagon Loading	From 7 randomly selected wagons of a particular rake, 350 kg samples from each wagon were collected. After coning and quartering of 7 wagon samples, one composite sample was prepared. After proper mixing and size reduction, the samples were taken to the laboratory for sample preparation. The coal samples were crushed by three three-stage crushers and were then left for 12 hours at room temperature for moisture reduction. Finally, the samples were obtained in the powdered form after processing by the pulverizer. From the obtained part, 2 numbers of final samples (-72 mesh) were prepared, 1st set for IIT Kharagpur and 2nd set for NTPC Farakka for further GCV and proximate analysis.
2.	Before Crusher	Samples were collected from the conveyor belts at 10 increments with 20-minute time intervals. From each increment, 350 kg of gross samples were collected. After coning and quartering of the samples, one composite sample was prepared. After proper mixing and size reduction, the samples were taken to the site-based laboratory for sample preparation. The coal samples were crushed by three stage crusher and were then left for 12 hours at room temperature for moisture reduction. Finally, the sample was obtained in the powdered form after processing by the pulverizer. From the obtained part, 2 nos. of final samples (-72 mesh) were prepared, 1st set for IIT Kharagpur and 2nd set for NTPC Farakka for further GCV and proximate analysis.
3.	After crusher	Samples were collected from the conveyor belts at 10 increments with 20-minute time intervals. From each increment, 75 kg of gross samples were collected. After coning & quartering the samples, one composite sample was prepared. After proper mixing and size reduction, the samples were taken to the site-based laboratory for sample preparation. The coal samples were crushed by three stage crusher and were then left for 12 hours at room temperature for moisture reduction. Finally, the sample was obtained in the powdered form after processing by the pulverizer. From the obtained part, 2 nos. of final samples (-72 mesh) were prepared, 1st set for IIT Kharagpur and 2nd set for NTPC Farakka for further GCV and proximate analysis.

4.	Before bunkering	Samples were collected from the conveyor belts at 10 increments with 20-minute time intervals. From each increment, 75kg of gross samples were collected. After coning & quartering the samples, one composite sample was prepared. After proper mixing and size reduction, the samples were taken to the site-based laboratory for sample preparation. The coal samples were crushed by three stage crusher and were then left for 12 hours at room temperature for moisture reduction. Finally, the sample was obtained in the powdered form after processing by the pulverizer. From the obtained part, 2 nos. of final samples (-72 mesh) were prepared, 1st set for IIT Kharagpur and 2nd set for NTPC Farakka for further GCV and proximate analysis.
5.	Coal Feeder Inlet	Samples were collected from the conveyor belts at 10 increments with 20 minutes time intervals. From each increment, 75 kg of gross samples were collected. After coning & quartering the samples, one composite sample was prepared. After proper mixing and size reduction, the samples were taken to the site-based laboratory for sample preparation. The coal samples were crushed by three stage crusher and were then left for 12 hours at room temperature for moisture reduction. Finally, the sample was obtained in the powdered form after processing by the pulverizer. From the obtained part, 2 nos. of final samples (-72 mesh) were prepared, 1st set for IIT Kharagpur and 2nd set for NTPC Farakka for further GCV and proximate analysis.
6.	After Pulverizer	Samples were collected from the conveyor belts at 10 increments with 20 minutes time intervals. From each increment, 2.5 kg of gross samples were collected. After coning & quartering the samples, one composite sample was prepared. After proper mixing and size reduction from one part, 2 nos. of final samples (-72 mesh) were prepared from the obtained part.
7.	Mill Reject	Samples were collected from the conveyor belts at 10 increments with 20 minutes time intervals. From each increment, 5 kg of gross samples were collected. After coning & quartering the samples, one composite sample was prepared. After proper mixing and size reduction from one part, 2 nos. of final samples (-72 mesh) were prepared from the obtained part.



(a) (b)

Figure 15. **(a-b).** Sample preparation in laboratories of NTPC Farakka.

After the sample preparation was done from the seven locations, stack sampling was done. The procedure followed is given as under.

1. A coal stack of a particular source was prepared with a height of 1.5 m.
2. Sampling was done by a hollow sampling pipe of 120 cm in length and 10 cm in diameter.
3. A sampling grid was drawn over the stack by 3/3 horizontal and vertical lines.
4. Each of the samples was to be collected from total intersecting grid points (total 12).
5. 10 kg of samples were collected from those selected 12 intersecting points.
6. After collection, proper mixing and size reduction (-72 mesh), 5 kg of two replicate samples were prepared.

4.4 Laboratory Analysis for GCV Profiling and Proximate Analysis

After the samples were collected and prepared at NTPC Farakka, they were brought to the IIT Kharagpur Laboratory in plastic zip bags. The coal samples were then analyzed in the laboratory to determine their Gross Calorific Value (GCV), Total Moisture content, volatile matter, Ash content as well as fixed carbon.

The instruments used for the laboratory analysis are as follows:

4.4.1 Bomb Calorimeter

A bomb calorimeter is a type of constant-volume calorimeter used to measure the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel burns, it will heat the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat the water outside the tube. The change in temperature of the water allows for calculating the calorie content of the fuel.

The calibration of an oxygen bomb calorimeter has traditionally been called standardization.

During the standardization process, a known amount of heat is introduced into the calorimeter by the combustion of benzoic acid. This standardization produces the energy equivalent of the calorimeter for a specific temperature rise.

4.4.2 Thermogravimetric Analysis System

Thermogravimetric analysis or Thermal Gravim Analysis (TGA) is a method of thermal analysis in which changes



(a) (b)

Figure 16. **(a-b).** Bomb Calorimeter setup used for GCV analysis of coal at IIT Kharagpur and bomb and its components, respectively.



Figure 17. TGA was used for proximate analysis at IIT Kharagpur.

in physical and chemical properties of materials are measured as a function of increasing temperature (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss).

Thermogravimetric analysis (TGA) relies on a high degree of precision in three measurements: mass change, temperature, and temperature change. Therefore, the basic instrumental requirements for TGA are a precision balance with a pan loaded with the sample and a programmable furnace. The furnace can be programmed either for a constant heating rate or for heating to acquire a constant mass loss with time.

Two different types of analysis were done on the coal samples which were:

(i) Proximate Analysis: Proximate coal analysis is mainly done to determine coal's energy value. Because so much depends on coal's heating ability, proximate analysis provides invaluable information about chemical composition. Proximate analysis parameters include sulphur, moisture content, volatile matter, ash content and fixed carbon.

ASTM Standard Method Used for Proximate Analysis

The determination of moisture, followed by volatile matter followed by ash was carried out in the following sequence using the same test specimen.

a. After the instrument setup was verified for the preparation of the apparatus, the crucibles were loaded and tared.
b. Approximately 1 g of coal or coke was added to the crucible in the balance position and it was weighed immediately before advancing to the

next crucible. The test specimen was transferred from the sample bag to the crucible quickly to minimize the exposure of the test specimen to the atmosphere during the initial weighing process.

c. For moisture determinations, the weighed test specimens were heated in the crucibles without the covers at 107 +3°C for 1 h. A drying gas flow rate of 0.4 to 1.4 furnace volume changes per minute was used. The instrument was programmed to terminate the test when the test specimens and crucibles had reached a constant mass.

d. For volatile matter determinations following the moisture analysis, covers were placed on the crucibles in the TGA. The instrument was programmed to reweigh the crucibles, with specimens inside, and covers in place before initiating the volatile matter part of the cycle. To provide an inert atmosphere, nitrogen or argon was used with a flow rate of 0.7 to 1.4 furnace volume changes per minute to sweep away the volatile components. The furnace temperature was raised at a rate such that the temperature was raised from 107°C to 950 + 20°C in a 26-30 min period. The instrument was programmed to be held at that temperature for 7 min. The TGA weighed the covered crucibles at regular intervals while the temperature of the furnace was raised. The weights of the crucibles and covers at the end of the 7-minute hold period were used in the calculation of the volatile matter.

e. For ash determinations following the volatile matter determinations program, the furnace was required to be cooled from 950 to 600°C. And for that, the crucible covers were removed. The furnace atmosphere was changed to oxygen or air. For coals, the temperature was raised at such a rate that a final temperature of 750 + 15°C was reached at the end of 1 h. If the oxidizing gas was oxygen, the flow rate was adjusted to 0.4 to 0.5 furnace volume changes per minute. The instrument was programmed to terminate the test when the test specimens and crucibles had reached a constant weight.

f. For fixed carbon determinations, it was calculated using the following formulae:

FC = 100 - (TM+VM+AC),

where,

FC = Fixed carbon (%)

TM = Total moisture content (%)

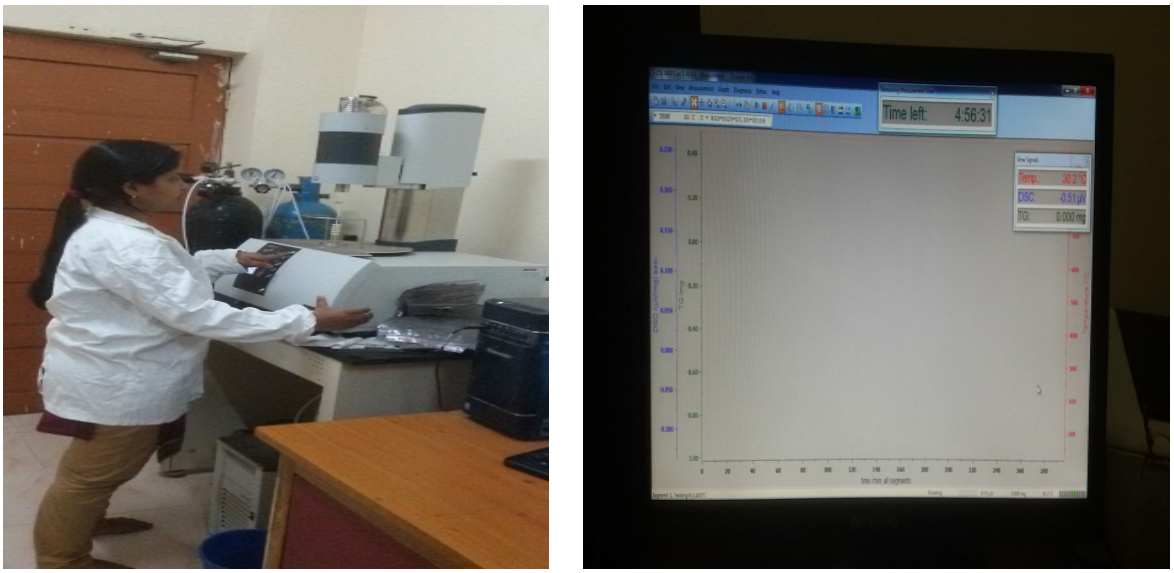
VM = Volatile matter (%)

AC = Ash content (%)



(a) (b)

Figure 18. **(a-b)** The furnace moved up to place the sample and the crucible was placed on the pan filled with sample, respectively.



(a) (b)

Figure 19. **(a-b)** The furnace moved down after placing the sample in the pan and the software program of TGA showing the analysis has started, respectively.

(ii) GCV Analysis: GCV of a substance can be defined as the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic of each substance. It is measured in units of energy per unit of the substance, usually mass, such as kJ/kg, kJ/mol, kcal/kg, and Btu/lb. Heating value is commonly determined by the use of a bomb calorimeter.

ASTM Standard Method Used (ASTM, 2019) for GCV Determination

a) Calibrating the Instrument with Benzoic Acid

For the calibration or standardization of the bomb calorimeter, benzoic acid was selected because of its desirable properties according to the ASTM standards. The benzoic acid quantity was measured and taken to be approximately 1 g. After conducting all the steps mentioned below for different benzoic acid cubes, the GCV was noted. In all the readings, the one data was selected to be the standard which repeated the most.

b) Prepare the Sample in the Bomb

The coal sample was put in the crucible. The standard sample size should be 1 g. A known length of fuse wire was passed through the sample with both ends of the wire being attached to the two electrodes of the bomb.

c) Closing the Bomb

Care was taken not to disturb the sample when moving the bomb head to the bomb cylinder. The sealing ring was checked to be sure that it was in good condition and it was moistened with a bit of water so that it would slide freely into the cylinder; then the head was slid into the cylinder and was pushed down as far as it would go. For easy insertion, the head was pushed straight down without twisting and the gas release valve was left open during this operation. The screw cap was set on the cylinder and it was turned down firmly by hand to a solid stop. When properly closed, no threads on the cylinder were to be exposed.

d) Filling the Bomb

The oxygen supply was connected to the bomb and the gas release valve was closed. The filling connection control valve slowly opened and the gauge was watched as the bomb pressure rose to the desired filling pressure (usually 30 atm., but never more than 40 atm.); then the control valve was closed. Then, with the help of a touch pen, the FILL option was selected on the instrument

touch screen. The oxygen filled in the bomb for 1 min and stopped automatically.

e) Fill the Calorimeter Bucket

The bomb was placed inside the calorimeter bucket by attaching the lifting handle to the screw cap and the bomb was lowered with its feet spanning the circular boss in the bottom of the bucket. The bomb was handled carefully during this operation so that the sample would not be disturbed. The lifting handle was removed and 2 l of water was added to the bucket.

f) Final Settings

The power source was connected to the bomb and the thermometer was put inside the bucket. The cover was set on the jacket and the stirrer was started by selecting the START option on the touch screen. The other necessary details were filled like Bomb ID, Spike weight, Sample name, Sample size etc.

g) It was required to stand 10 m back from the calorimeter while the bomb was fired to assure the user's safety.

h) Recording GCV (Gross Calorific Value)

The bucket temperature started to rise within 30 seconds after firing. This rise was rapid during the first few minutes; then it became slower as the temperature approached a stable maximum. Usually, the temperature would reach a maximum; then drop very slowly. But this was not always true since a low starting temperature might result in a slow continuous rise without reaching a maximum. Finally, the GCV reading should be noted appearing on the screen after the completion of the test automatically.

i) Opening the Bomb

After the GCV reading was taken and the stirrer was stopped, the cover was lifted from the calorimeter. The bomb was lifted out of the bucket and the gas release valve was opened on the bomb head to release the gas pressure before attempting to remove the cap. After all pressure had been released, the cap was unscrewed and the head was lifted out of the cylinder. The interior of the bomb was examined for soot or other evidence of incomplete combustion. If such evidence was found, the test would be discarded.

j) Fuse Wire Burnt

All unburned pieces of fuse wire were removed from the bomb electrodes, the crucible was cleaned and the bomb was made ready for the next sample test.



Figure 20. Oxygen filling in the bomb through the nozzle and the bucket filled with water in the bomb calorimeter setup respectively for GCV analysis.



(a) (b)

Figure 21. **(a-b)** Placing the bomb inside the bucket with the help of lifting handle and Setting of the program on the touch screen of the bomb calorimeter setup, respectively.