Coal and its Beneficiation Techniques: A Review

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Abstract

Crushing run-of-mine coal alters the proportion of particles in a given density class because of the coal's naturally occurring diversity in particle size and specific gravity. Because of this, the gravity-based coal washing process loses some of its effectiveness in terms of producing clean coal and maintaining high quality coal during the separation phase. The amount of 'near-gravity material' (material with a specific gravity within the range of 0.1) present in a normal coal at a given specific gravity makes washing the coal more challenging. Here, we employ two numerical indices—the 'near-gravity material index' and the 'index of washability'—to quantify the distribution of near-gravity material across density classes and to assess the degree of difficulty involved in the washing process. In order to remain competitive in the global coal market, India's coal businesses rely heavily on the process of beneficiating lower-grade coal, which presents significant obstacles.

Keywords

Coal beneficiation, wet and dry coal beneficiation, washability curve, near-gravity material, index of washability.

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1.0 Introduction

Coal characteristics mainly depend on the type of vegetation from which it was formed, the amount of decay that was allowed to occur, the pressure and temperature to which the decaying vegetation was subjected, and the foreign matter, whether wind or waterborne, that was deposited on the decaying vegetation while it was being converted into coal. Coal is a metamorphosed plant remains with infinite variations in consistency from brown coal to anthracite coal. Figure 1.1 summarizes the coal type's rank classification. The presence of mineral matter in coal can either take the form of segregation in the form of bands and lumps of varying sizes and thickness, or it can be present in a finely divided state and distributed uniformly throughout the coal (intrinsic/inherent mineral matter), depending on the coalification process.

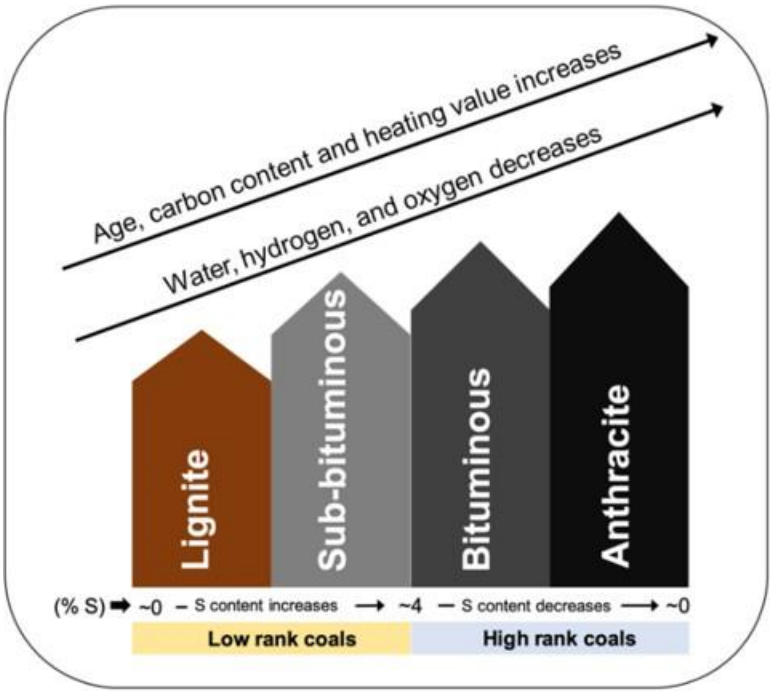

Figure 1. Coal types based on rank (Sondreal and Wiltsee, 1984, American Society for Testing and Materials, and Mochida et al., 2014)

- **Anthracite**: The highest rank of coal. It is a hard, brittle, and black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter.
- **Bituminous**: Bituminous coal is a middle rank coal between subbituminous and anthracite. Bituminous coal usually has a high heating (Btu) value and is used in electricity generation and steel making in the United States. Bituminous coal is blocky and appears shiny and smooth when you first see it, but look closer and you might see it has thin, alternating, shiny and dull layers.

- **Subbituminous**: Subbituminous coal is black in colour and is mainly dull (not shiny). Subbituminous coal has low-to-moderate heating values and is mainly used in electricity generation.
- **Lignite**: Lignite coal, aka brown coal, is the lowest grade coal with the least concentration of carbon. Lignite has a low heating value and a high moisture content and is mainly used in electricity generation.

Every continent in the world, including Antarctica, has coal reserves, however these are mostly concentrated in the Northern Hemisphere (Table 1). However, because various geological factors affect the thickness, continuity, quality, and mining conditions of coal, a large variety in coal characteristics has been documented throughout the world. According to quality, coal has been used as soft coke in residential hearths for burning bricks, creating industrial steam, cement manufacturing, railroad traction, producing thermal power, extracting various chemicals and byproducts, and in metallurgical industries, among other uses.

Table 1: Coal reserves around the world

Sl. No.	Country	Coal Researves in Million Tonnes (2021)	World Shares
1	United States	250,300	26.9
2	Russia	160,200	17.2
3	Australia	147,323	15.9
4	China	138,516	14.9
5	India	101,163	10.9
6	Germany	36,096	3.9
7	Ukraine	34,175	3.7
8	Poland	26,279	2.8
9	Kazakhastan	25,305	2.7
10	South Africa	9,888	1.1

While the demand for coal has been constantly rising, the global supply of high-quality coal is rapidly running out. Therefore, a significant degree of mechanization has been implemented to suit consumer demand, and the thinner, dirtier seams are mined. Raw coal may contain contaminants from the seam itself as well as from extraneous material removed during roof or floor mining. A higher percentage of top and bottom minerals are extracted during mining as a result of increased mechanization, which raises the impurities in raw coal. The increase in contaminants in the run-of-mine coal has also been heavily attributed to the effects of the 1969 Coal Mine Health and Safety Act on mining practices. For instance, excessive rock dusting adds other incombustibles to the run-of-mine coal whereas water sprays on continuous miners employed to disperse the dust at the face appear to increase significantly to the moisture content of the raw coal. The main impurities in coal include calcite, gypsum, kaolin, clay, sandstone, and shale.

The amount of these contaminants in coal greatly influences its physical characteristics. Shale, clay, and sandstone all have a specific gravity of roughly 2.6, however carbonaceous shale has a specific gravity that varies from 2.0 to 2.6 depending on how much carbonaceous material is contained in it. While pyrite has a specific gravity of roughly 5.0, other impurities including gypsum, kaolin, and calcite have specific gravities of 2.3, 2.6, and 2.7, respectively. Additionally, several values for the specific gravity of pure coal, ranging from 1.23 to 1.72, have been recorded in the literature (Nunenkamp, 1976). These variances result from the varying ash, moisture, and rank of various coals.

According to standard usage, "mineral matter" refers to all types of inorganic material connected to coal, including optically discernible mineral phases, complexed metals, and anions (Berkowitz, 1979). The sources of minerals vary, and they are consequently separated into two categories: syngenetic (inherent) and epigenetic (free) minerals (Lin et al., 1999). Syngenetic minerals typically form a close colloidal association with coal and are more challenging to remove during coal preparation. Even though epigenetic materials are frequently minute in size, crushing and washing activities make it easier to release and remove them.

According to the Reference Scenario of the International Energy Agency's (IEA) World Energy Outlook, from 2000 to 2030, the world's primary energy demand will rise by 1.7% year, reaching 15.3 billion tons of oil equivalent. The global energy supplies are sufficient to meet the anticipated rise in energy demand. At least until 2030, there will be sufficient global oil supplies, with unconventional oil likely taking up a sizable portion of those supplies. Additionally, there are sufficient reserves of natural gas and coal, and there will always be enough uranium to produce nuclear power through 2030.

Although there will be a 1.4% annual increase in demand (Table 2), coal's proportion of global primary consumption will only go down slightly, from 26% in 2000 to 24% in 2030. China, India, the United States, Australia, the European Union, Indonesia, Russia, South Africa, Germany, Poland, and Kazakhstan are the top 10 coal-producing nations. However, over three-quarters of the growth in coal consumption in developing nations and two-thirds of the growth in global coal demand may be attributed to India and China collectively. The majority of the increase in coal use will be for power production. An increase in the demand for coal in the electricity sector in Organization for Economic Co-operation and Development (OECD) nations will counteract a smaller drop in the usage of coal in end-use sectors. The industrial, residential, and commercial sectors in transitional economies and emerging nations will burn more coal, but the majority of the rise in overall coal consumption in both groups is driven by electricity generation. Nearly 90% of the growth in demand between 2000 and 2030 is accounted for by an increased concentration of coal use in power generation across all areas.

Table 2: Sector wise coal consumption in India

Name of the Sector	Consumption (%)
Electricity sector	84.46%
Steel and Washery industry	6.65%
Paper industry	5.55%
Cement industry	2.18%
Textile industry	2.01%
Sponge iron industry	1.06%
Fertilizers and chemicals	0.19%

1.1 Indian coal

The major geological era in which coal was formed in India, dates back to about 280 to 225 million years ago to the Gondwana period when the major coalfields of Bihar, West Bengal, Orissa, Madhya Pradesh and Maharashtra were formed. The other major geological era of coal formation extends from 26 to 7 million years in the tertiary era, when the relatively newer coalfields of Assam and Jammu and Kashmir came into being (Wadehra, 1982). The total proved, inferred and indicated coal reserve of India amounting to 286 billion tonnes as on 1.4.2011 which representing seven per cent of the total world coal resources, ranks forth in terms of coal resources and is the third largest coal producer in the world with a production of 572.37 million tonnes in 2010-11. India's coal production has risen from 70 million tonnes in early 1970 (Ministry of Coal, 2011) to 692 million tonnes in 2016 (Wikipedia.org) with an average growth rate of around 5% (Figure 1.2). Out of the total coal, round 88% coal reserves come under non-coking coal category and power stations consume major chunk of non-coking coal. These non-coking coals are classified as grade A-G. While grades A-C represent the superior quality coal, grade D-G represent relatively inferior coal with higher levels of ash ranging from 35% to 45% that are used for power generation.

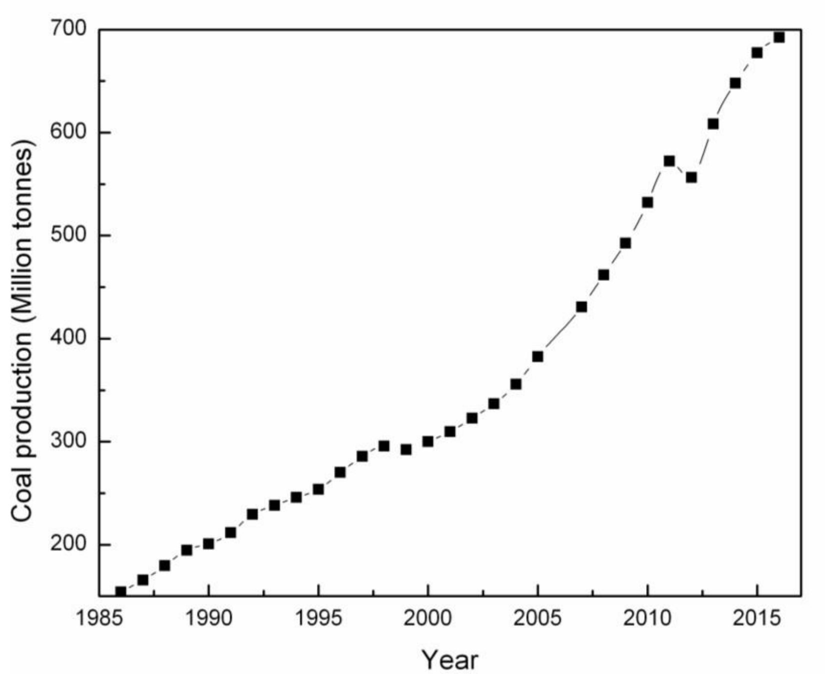

Figure 2. Year Wise Coal Production in India

Indian coals are of drift origin (Table 3) and have features that make them difficult to very difficult to wash (Biswal and Reddy, 1994; Choudhury, 1995; Biswal and Acharjee, 2003; Misra et al., 2003; Jena et al., 2008). They also have a high mineral matter content. The majority of the non-coking coal reserves are thick seam, which are naturally interbanded. It is exceedingly challenging to separate the bands while mining because they are thin and numerous. Because of these bands, the quality of the coaly material in these seams, which has a high ash percentage, deteriorates. The bands themselves are almost never made entirely of sandstones and are typically carbonaceous in composition (Mukherjee et al., 1982). As a result, the coal seams contain more near-gravity material and have substantially greater ash contents (40–45%). Another element contributing to the decline in raw coal quality is the coal seams' frail, fragile ceiling and floor. The percentage of vitrinite is also low and fluctuates greatly from seam to seam and inside the same seam in different locations at the same time (Biswal et al., 2002). This fluctuation in vitrinite content causes variations in the coals' surface features, which have an impact on the separation characteristics. Indian coal has typical washability features as a result of all of these elements, which are typically absent from coal from other regions of the world. being, the majority of the major industries require coals of a significantly higher quality than that of the coal being produced, which necessitates beneficiating the Indian coals.

Table 3: State wise distribution and type of coal across India

State	Coal Reserves (Million tonnes)	Type Of Coal Field
Jharkhand	86.217	Gondwana
Odisha	84.878	Gondwana
West Bengal	73.424	Gondwana
Chattisgarh	33.092	Gondwana
Telengana	22.851	Gondwana
Maharastra	12.936	Gondwana
Bihar	3.464	Gondwana
Andhra Pradesh	2.247	Gondwana
Uttar Pradesh	1.062	Gondwana
Meghalaya	0.576	Tertiary
Assam	0.525	Tertiary

Nagaland	0.446	Tertiary
Sikkim	0.101	Tertiary
Arunachal Pradesh	0.09	Gondwana
Madhya Pradesh	30.217	Gondwana

1.2 Beneficiation of Indian coal

Systematic studies on the washability characteristics of the Indian coals were initiated in 1944 at the Indian School of Mines, Dhanbad, under the auspices of the Fuel Research Committee set up by the then Board of Scientific and Industrial Research (Sarkar and Bose, 1982). At that time, based on the washability study of several coals of different localities, the coal preparation scientists did not think coal washing was economically a feasible proposition. Therefore, coal beneficiation in India has evolved on different ways compared to other major coal producing countries. The early emphasis for coal washing in India was exclusively on beneficiation of coking coals to meet the rising demand of the iron and steel industries. The first coal washery was set up at West Bokaro in 1951 and the second one at Jamadoba in 1952 both by M/s. Tata Iron & Steel Co. Ltd (TISCO), followed by the third washery at Lodna by M/s. Turner Morrisin in 1955 (Wadehra, 1982). Success of these washeries and the general change in practice world over for preparation of raw coal for iron and steelmaking led the Indian steel plants to change their approach.

Because of its poor value or inability to cover the expense of the process, non-coking coal beneficiation in India was not given the attention it deserved until the last ten years. In order to burn heavy ash coal, power plants in India have adapted advanced combustion techniques. Although technology has advanced, many power plants are still unable to handle coal that is of lower quality, which only serves to increase the amount of greenhouse gases and other air pollutants that are released into the environment. Additionally, the Ministry of Environment and Forest (MoEF), Government of India, recently restricted the use of high ash coal (>34%) in a number of sensitive and severely contaminated areas. These have increased the difficulty of the coal preparation industry. The issue is exacerbated by the simple accessibility of imported coal of superior quality at affordable prices, which is a significant factor that negates the beneficiation consideration of Indian coal with high ash for power generation. Because of this, most power companies are still not persuaded of the financial advantages of implementing the washing process and are not willing to engage in this industry.

India currently produces 120 million tonnes of clean coal annually from 78 washeries as shown in Table 1. Since the technologies for these procedures are well known, the majority of these washeries use jigs, heavy medium separation, and chemical flotation to clean the run-of-mine coal. Water is used as a separating medium in several methods. Due to their lower efficiency, dry coal beneficiation processes are now less desirable than wet beneficiation. However, the dry beneficiation of coal is becoming more significant due to insufficient water resources, high slurries handling costs, and an increase in the moisture content of clean coal. Several dry beneficiation techniques are already available, however choosing the best one depends on the properties of the coal. Each dry process, like the wet one, has a unique spectrum of applications; no single process can handle all types of coals in all size ranges. To find an effective dry beneficiation process for treating high-ash Indian coal, a sizable research effort has been made (Sahu et al., 2009).

Table 4: Total number of washeries showing its capacity in India

Sl. No.	Name of washery	Capacity (Million Tonne per annum)	Subsidiary	State
1	Kusmunda	10.0	SECL	Chattisgarh
2	Baroud	5.0	SECL	Chattisgarh
3	Madhuband	5.0	BCCL	Jharkhand
4	Patherdih	5.0	BCCL	Jharkhand
5	Patherdih	2.5	BCCL	Jharkhand
6	Dahibari	1.6	BCCL	Jharkhand
7	Dugda	2.5	BCCL	Jharkhand
8	Bhojudih	2.0	BCCL	West Bengal
9	Ashoka	10.0	CCL	Jharkhand
10	Konar	3.5	CCL	Jharkhand
11	Karo	2.5	CCL	Jharkhand

12	Chitra	2.5	ECL	Jharkhand
13	Basundhara	10.0	MCL	Orissa
14	Jagannath	10.0	MCL	Orissa
15	Hingula	10.0	MCL	Orissa
16	Ib-Valley	10.0	MCL	Orissa
	Total	**92.10**		

CIL and its subsidiary companies already have 17 nos. of coal washeries in operation which are as shown in table 5.

Table 5: CIL and its subsidiary washeries

Sl.no.	Name of coal Washery	Subsidiary company	Capacity (Million Tonne per annum)
1.	Dugda-ii	BCCL	2.00
2.	Bhojudih	BCCL	1.70
3.	Patherdih	BCCL	1.60
4.	Sudamdih	BCCL	1.60
5.	Moonidih	BCCL	1.60
6.	Mahuda	BCCL	0.63
7.	Madhuband	BCCL	2.50
8.	Kathara	CCL	3.00
9.	Swang	CCL	0.75
10.	Rajrappa	CCL	3.00
11.	Kedla	CCL	2.60

12.	Nandan	WCL	1.20
13.	Dugda-I	BCCL	1.00
14.	Gidi	CCL	2.50
15.	Piparwar	CCL	6.50
16.	Kargali	CCL	2.72
17.	Bina	NCL	4.50
	Total		**39.40**

A chain of coking coal washeries has expanded as a result of the initial task of washing Indian coals being successfully met. However, the Indian coal industries have faced new challenges and undergone significant changes in their approach to coal cleaning as a result of the rapid depletion of the reserves of excellent grade mineable coal, changes in mining patterns, stricter environmental restrictions, and the influx of imported coals. In the past, issues could be easily overlooked, but now they are significant issues. As a result, many coal users continue to express a general resistance to the commercial adoption of cleaning Indian coal. The price of clean coal, as well as the consistency and quality of the product delivery to Indian consumers, are of particular significance. It goes without saying that the cost of clean coal, which is on the higher side for Indian coal, has a direct or indirect impact on how well a washery performs.

It is clear from the literature that sometimes improperly choosing and operating coal washing equipment results in greater costs for cleaning Indian coals (Sarkar, 1984). The bulk of Indian coal washeries currently receive raw coal from a variety of mines with a wide range in each mine's unique features related to washability. Additionally, the quantity of coal sent from a specific mine to the washery fluctuates. These differences in feed coal quality make it challenging to choose and keep the coal washing systems running at their best (Mohanta et al., 2010). Additionally, there aren't many noticeable differences between coaly shale and shaly coal in terms of relative density because of the tight interaction and mixing of the coal and non-combustibles. As a result, according to Bhatnagar et al. (2013), the Washability Index of Indian coal ranges from 15 to 43, and the Near Gravity Material fluctuates between 35 and 50 percent. The higher concentration of Near Gravity Material in the feed coal results in more misplacement during the separation process, where clean coal is mistakenly moved to the reject coal stream and reject coal to the clean coal stream. Hence deteriorating the quality of clean coal.

Location-specific factors determine the optimal strategy for preparation in terms of maximum return. Each production team must determine the economics of preparation based on a number of factors, such as existing infrastructure, contract requirements, and the capacity to manufacture a product that satisfies those needs, predicted expenses, and the possibility of future changes in raw coal or final product. Over-preparation of the raw coal must be avoided and the clean coal quality criteria must be met if costly reject losses are to be avoided. It has been argued that the sooner we learn about these factors, the sooner we can start working to solve the issues.

1.3 Different Criteria for coal beneficiation process in India

Run-of-mines coal produced a high quantity of coal particles of various size and density due to the extensive automation and use of massive gear. Due to the liberation of the stones within the coal, not all of the fragments that result from a large coal particle breaking will report to the same density class as the parent particle. Thus, the comminuted coal's washability differs from that of the original coal. In this area, Kojovic and his colleagues have done extensive study through the Australian Coal Association study Program [15]. In an effort to quantify this, they present in Table 6 the probabilities that a comminuted coal particle will report to a higher or lower density class, or remain in the same density class as the parent particle. The progeny of a particle that splits in half (0.5) has a 2.1% probability of reporting to a higher density class, a 64.4% chance of reporting to the same density class as the parent, and a 33.5% chance of reporting to a lower density class.

Table 6: Density of comminuted coal particles compared to parent coal particle.

Ratio of progeny particle size to parent coal particle size	Chances of reporting to different density classes		
	Higher	Same	Lower
1		100	
0.5	0.3	59.8	39.9
0.25	2.1	64.4	33.5
0.13	11.1	63.8	25

0.06	31.7	50.6	17.7
0.03	45.6	45.7	8.6
0.02	40.1	40.9	19

Due to the variation in the density and as well as size of the run-of-mine coals after screening process, the coal beneficiation criteria are also changed because of the terminal settling velocity of the particles. Due to that, the criteria of density difference are not the only one for coal beneficiation. So along with that the beneficiation process also depends on the criteria of surface wettability and also criteria of initial acceleration of the particles which are listed beow:

- Difference in density (75%): Gravity Separator
- Difference in initial acceleration of the particles (15%): Jigging
- Surface properties (7%): Froth flotation
- Other (3%): Chemical

1.3 Major equipment's used in Indian coal washeries

As can be seen in Figure 1.3, contemporary beneficiation techniques can be broken down into four categories: physical, chemical, physicochemical, and bio-beneficiation. Separation by magnetic or gravitational fields is an example of a physical technique. Chemical processes include acid or alkaline leaching, whereas physicochemical processes include flotation and oil agglomeration. Bacteria play a key role in bio-beneficiation processes. It is not uncommon for a beneficiation process to need the use of many technologies. Various coal washing technologies, including the dense media bath, heavy media cyclone, jig, water-only cyclone, barrel washer, spiral concentrator, and flotation units, saw heavy use in India's coal industry.

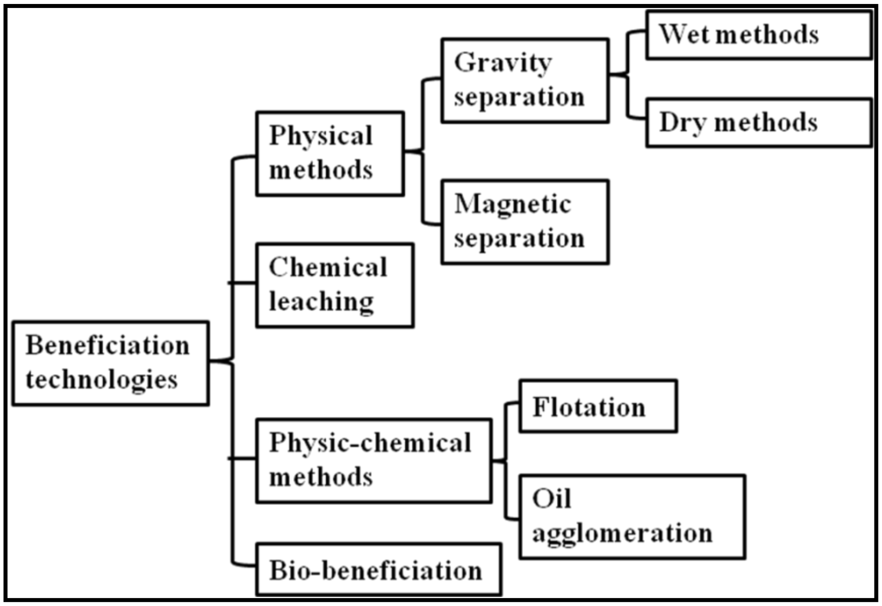

Figure 3. Classification of beneficiation technologies

1.3.1 Physical methods

1.3.1.1 Gravity separation

Wet and dry density-based separation techniques are used in gravity separation. Dense media baths, heavy media cyclones, water-only cyclones, barrel washers, shaking tables, spiral concentrators, multi-gravity separators, Knelson concentrators, and Falcon concentrators are examples of wet density-based separation technologies. On the other hand, dry density-based separation techniques include air jigs, air tables, air dense medium fluidized beds, and dry vibration fluidized beds.

Dense media bath

Essentially, the dense media bath is a tank filled with heavy media into which consistently and softly fed coarse coal is introduced. As heavy media, the fine magnetite powder suspended in water slurry is employed. The density of the suspension is changed to a value that is somewhere between the density of the related mineral materials and the density of the coal. As a result, the heavy coal particles sink while the light coal particles float. The floating coal is extracted by a scraper conveyor and hauled up over a stationary screen after floating the whole length of the bath. The majority of this thick medium passes through the still object and is then recirculated back into the bath. The lower strand of the same conveyor transports the heavy waste in the opposite direction as it sinks to the bottom of the bath. The two items leave the vessel at its opposing ends. For medium removal and subsequent recovery, the float coal and the trash separately travel past the drain-and-rinse screen. The size range and the quantity of sink materials in the raw coal feed affect the density media bath's capacity. For different feed qualities, modifications or alterations to the vessel can be made fast and simply. Compared to typical heavy medium vessels, this equipment uses less recirculating medium. The medium handling circuit's maintenance requirements and horsepower are subsequently reduced.

Heavy media cyclone

The Heavy media cyclones are used to separate the dispersed phase from a continuous phase by utilizing centrifugal force and when the continuous phase is an aqueous suspension of ultrafine particles, the cyclone is known as heavy media cyclone. A conventional hydro cyclone consists of a cylindrical section attached to a conical section as shown in Figure 1.4. An inlet tube is attached to the cylindrical section and the discharge tubes are fitted at the top and bottom of the column. The feed is injected tangentially at the top of the cylindrical section of the hydro cyclone causes swirling and thus generate centrifugal force within the device. The separation is brought on by this centrifugal force. Heavy medium cyclones are straightforward and durable mechanically and metallurgically speaking, although separation efficiency is rarely as great as anticipated. This is due to the fact that coal preparation plants aren't always run in accordance with the design criteria, such as the original cyclone dimensions, medium density, viscosity, ideal feed rate, feed size distribution, and feed coal's range in washability. The heavy medium cyclone's key benefits are its ability to handle huge loads, effectively handle even fine coal, improve separation sharpness even when the feed contains a significant amount of near-gravity material, and have no moving parts.

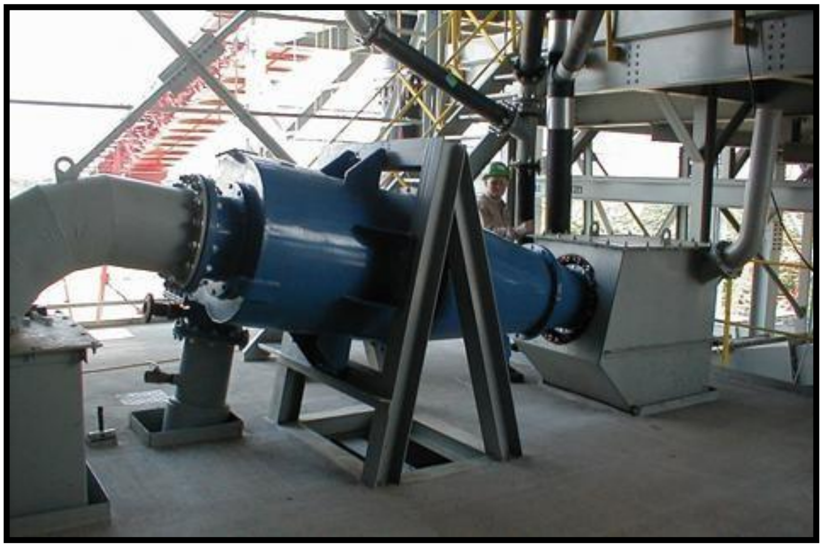

Figure 4. Photograph of Heavy media cyclone

Jig

Jigging is a technique where water and particles are moved repeatedly with pulsed air, causing the particles to stratify based on their relative densities, sizes, and shapes. Inside the water medium, the feed particles reorganize and progressively move to the strata that correspond to their qualities (Figure 1.5). This happens as a result of fluid flow that pulses vertically, which causes a bed of particles to alternately expand and compact. In terms of relative density, particles are distributed in layers, with the layer with the lowest relative density being at the top, the layer with the highest relative density being at the bottom, and the layer with a higher relative density but smaller particle size or a lower relative density but larger particle size being at the layer below. Therefore, the stratification and movement of the particles in a jig are influenced by the motion of the water.

Jigs have taken on new forms in the coal preparation sectors as a result of the application of new ideas and the usage of new manufacturing and control technologies. It is demonstrated that the performance of the under-bed pulsated Batac jig is superior to that of the Baum type, which substitutes a mechanical plunger for compressed air. As opposed to the Baum jig, which generates the water current required for the jigging action in a separate air chamber alongside the jig bed, the Batac jig generates it in air chambers that are situated beneath the jig bed. The

ROMJIG entered the market to treat the feed coal particle size range of 350-40mm by also utilizing the moving bed principle.

Figure 5. Photograph of Jig

Barrel washer

A solid cylindrical drum called a barrel washer has sink lifters attached to the interior of the revolving shell. There are four possible geometries that can be used: single gravity for two-product separation; single gravity for handling two different sizes; two gravity, three products with one media reclaiming circuit; and two gravity, four products with two separate media reclaiming circuits. For cleaning coal, a four-product system is now in use. At one end of the drum, raw coal and medium are introduced. At the discharge end, clean coal floats and flows over a weir before reaching a drain and rinse screen. By lifters fastened to the interior of the drum shell, the sinks are raised from the medium pool's bottom. This product is discharged into a central, suspended trough, where a medium stream empties the waste into a drain and rinse screen.

Spiral concentrator

According to Wills (1992), the spiral concentrator is made up of an open trough that spirals vertically downward in a helix pattern around a central axis. With a solids content ranging from 15 to 45% by weight, feed is injected at the top of the spiral and allowed to flow downward. The stratification of particles is influenced by a number of intricate mechanisms, such as the combined effects of various forces, varied particle settling speeds, interstitial trickling, and potentially impeded settling (Mills, 1978). In general, the lower density material reports to the spiral's upper wall, whereas the higher density material reports to the spiral's inner edge. Classification can also take place, typically pushing the high-density, small particles to the spiral's outside border. Middling feed material is located in the spiral trough's center. It is widely utilized in a variety of circuit configurations for processing coals due to its relative simplicity, high efficiency, ruggedness, compactness, cost effectiveness, and environmental friendliness. Spirals are now a typical method for concentration of 0.1mm to 2mm coal because of the increased interest in recovering coal fines since the 1980s. Spirals can handle material that is too coarse for flotation and too fine for dense-medium separation while still maintaining high combustible recoveries.

Figure 6. Photograph of Spiral concentrator

1.3.1.2 Magnetic separation

The difference in magnetism between coal and gangue particles is the basis for magnetic separation. Magnetic separation is typically utilized in the process of beneficiating dry coal. Magnetic separation should come before the dry processing of raw coal. Pyritic sulfur's surface oxidation to FexOy (T 4000C) and decomposition to FeS (T > 4000C) during the heat treatment boost the material's magnetic characteristics. A dry permanent magnetic roll separator could successfully separate the pre-heated coals. Organic and total sulfur could also be rejected into the tailings. Deep coal cleaning is not an economically viable option for Indian coals, hence Indian washeries do not use the magnetic separation method.

1.3.2 Chemical leaching

Coal desulfurization and de-ashing use chemical leaching. Coal is burned or mixed with acid or alkali to remove the sulfur. Pyrite is the main inorganic sulfur component found in coal, and it is typically recovered using an acidic direct leaching process. The most efficient way to remove sulfur from lignite is through chemical leaching. It is not utilized in industrial settings; rather, it is primarily used in experimental settings.

1.3.3 Physic-chemical method

Flotation unit

The most popular beneficiation method used for Indian coking coal fines less than 0.5 mm is froth flotation. Hydrophobic particles are attracted to air bubbles, which cause them to rise to the top of the pulp zone (Figure 1.7) and eventually report to the froth product, whereas hydrophilic particles stay in the pulp and are discharged as tailings. This process is a physical separation. The coal surface is made even more hydrophobic during this process, which increases the likelihood that the particles of the coal flotation concentrate will agglomerate. Only when there is floatable material in the feed does the froth begin to develop as concentrate. Additionally, the foam carries some freed fine gangue and a percentage of medium particles. As soon as there is no more material that can be collected by flotation, the froth stops forming. These factors highlight how interconnected the floatable material, water, and other gangue reporting to the froth are.

It is well known that this method outperforms and is more affordable than other methods for separating fine coal particles. But variations in feed qualities, machine design, and operating circumstances can drastically affect this process. In order to achieve the best yield at the required ash content of clean coal, plant operators must regulate the process. Additionally, the flotation performance is not entirely suitable for coal particles that are ultra-fine and moderately coarse. It is now understood that the low flotation efficiency of ultrafine particles results primarily from the low probability of bubble-particle collision, whereas the high probability of particle detachment from the bubble surface accounts for the low flotation recovery of coarse particles (Ralston and Dukhin, 1999; Yoon, 2000; Tao, 2004).

Figure 7. Photograph of Flotation unit

Oil agglomeration

Oil forms oil bridges between coal particles because oil rapidly displaces water from the organic components' surfaces rather than the surfaces of the ash-forming minerals because the organic components tend to be more hydrophobic and oleophilic than the inorganic minerals. A collection of such agglomerates is easily isolated from the suspension of un-agglomerated minerals by sieving, floating, or skimming when several coal particles are linked together to create one compact, spherical agglomeration under the right circumstances. Fuel oil, diesel oil, kerosene, and vegetable oils can all be used in the agglomeration process. Surfactants are occasionally required in the production of oil agglomerates. Kerosene can be emulsified using surfactants to reduce the size of the droplets and the amount of kerosene used in the oil agglomeration.

1.3.4 Bio-beneficiation

Coal contains both organic (mainly in the form of dibenzothiophenes and benzothiophenes) and inorganic (FeS2) forms of sulfur. Up to 90% of inorganic sulfur can be removed using microbial cultures (such Thiobacillus ferrooxidans), however it is challenging to extract organic sulfur. In the demineralization and desulfurization of coal, fungus is used. Although one environmentally beneficial way for cleaning coal is bio-beneficiation, the procedure is extremely sluggish and can even take several days. In order to speed up the process, some more potent fungi should be found.

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