NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

Department of Chemical Engineering

B.Tech Thesis On

Studies of Washing Characteristics of Low Grade Coal and Design of a Coal Washing Plant

Under the Guidance of

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Submitted By

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CERTIFICATE

This is to certify that the thesis entitled **"Studies of Washing Characteristics of Low Grade Coal and Design of a Coal Washing Plant"** submitted by **Shubhkant Kalsi** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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SHUBHKANT KALSI

DATE:

ABSTRACT

A low grade coal is a coal which contains impurities which on burning pollute the environment. It contains Sulphates, Calcite, Pyrite, Silica, $CaCO_3$, and Sulphates of $CaCO_,$ Sulphates from oxides which combine with silica to form complexes. It tends to form coal ash.Also, it contains sulphates which tends to decrease its Clinkering temperature.

All of the above lead to adopt various techniques to clean coal before using. One such method is Coal Washing. Various coal cleaning methods depending on the physical property difference, i.e. difference in their specific gravity or wetting characteristics. Specific graviy of pure coal is 1.2 to 1.7 and for impure coal is 1.7-4.9. In present work, an attempt has been made to study the different characteristics of coal washing by Float-and-Sink test. A design of a washing plant has been made with the help of data collected from this test.

The data collected simply shows the washing characteristics of washing of coal from which the coal can be varied from easy-to-wash to difficult-to-wash coal.

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1. **INTRODUCTION**

Coal is a brittle, firm, sedimentary, combustible rock derived from vegetable debris which has undergone many physical and chemical changes during the very long course of millions of years. It consists primarily of elemental carbon. The inorganic materials are found as admixtures. The quality of coal varies with rank from peat to lignite, from lignite to bituminous, from bituminous to semi-anthracite and from semi-anthracite to anthracite. About 67% of electricity produced in India is by combustion of coal. The total estimated reserves of coal in world are estimated to be 6,641,200 and for India the same is estimated to be 106,260 million tones. The consumption of coal is expected to increase at faster rate than it had been in the past because of the increase in the price of crude and natural gas. The demand of coal during the first half of last century remained more or less constant and now it is expected to increase in this century. It is estimated that coal can meet its demand for another 2300 years if used at present rate. It has the highest forward linkage effect with thermal power, railways locomotives, fertilizers industry, cement, steel, electric power and a number of other industries. India continues to be the sixth largest producer of coal with its annual production of nearly 100 million tones. The reserves of high ranking coal i.e. anthracite and coking bituminous coals are less as compared to the low ranking bituminous and lignite coals. On the other hand, the demand of high rank coals is more for metallurgical use and for use as fuel. [1]

The coal as it comes from mines consist of many impurities such as magnesium sulphate, sulphur in form of pyrites, slate and fire clay. These substances have higher specific gravity than pure coal which is 1.28 or 1.30. The fact that their specific gravity is higher than the pure coal makes the separation possible. Coal is purchased according to rather rigid specifications as to size, sulphur and ash content. Therefore, coal must be screened to size and it must be cleaned by jigging or by heavy-media separation. The International Energy Agency (IEA) predicts that world energy demand will grow around 60% over the next 30 years, most of it in developing countries. China and India are very large countries in terms of both population and land mass, and both have substantial quantities of coal reserves and hence they account for 70% of the projected increase in world coal consumption. Strong economic growth is projected for both countries (averaging 6% per year in China and 5.4% per year in India from 2003 to 2030), and much of the increase in their demand for energy, particularly in the industrial and electricity sectors, is expected to be met by using coal.

Even as demand grows, society expects cleaner energy with less pollution and an increasing emphasis on environmental sustainability. The coal industry recognizes it must meet the challenge of environmental sustainability and in particular it must reduce its greenhouse gas emissions if it is to remain a part of a sustainable energy future. The quality of coal need to be assessed only then it can be suitably used in different industries. [4]

The bed of coal is laid down in more or less distinct and separate layers or benches. Sometimes a layer of mineral matter is deposited in-between the benches of coal in the bed. Charcoal, the mother coal can almost always be noted as broken coal as a coating along the bedding planes. Sometimes charcoal is associated with clay and it constituents the ash forming or sulphur containing impurity. The main characteristics of charcoal in point of view of washability are its tendency to become easily reduced to fine powder. The structure of the coal bed particularly in the way the impurities are incorporated into the coal deposit has an important bearing on the washability of coal. Many of the coarse, removable particles of refuse in a raw coal, as crushed and prepared for washing, are broken fragments of veins of mineral matter, slate, or pyrite which occurs in some of the cracks of the coal bed. In general, impurities break irregularly into pieces of various sizes and shapes. A coal which is basically debris or can say which has very thin bands is difficult to wash than one which contains large proportion of bright coal. Dull coal breaks more irregularly than the bright coal. As it appears, the dull coal which is considered as the heterogeneous accumulation of finely divided plant-degradation products therefore contains more fine ash than the bright coal. “Inherent ash content” or “fixed ash content” of coal is the part of ash content of coal that is structurally a part of the coal itself and cannot be separated from it by any mechanical means. It is a purely a relative term , because it is possible in the laboratory by successively finer crushing to separate out more and more ash-forming constituents by float-and-sink method. As produced at mine, raw coal contains materials of all densities, from that of the lightest fragments of bright coal to that of the heaviest particles of shale and pyrite. Coals differ in the relative amount of material of different densities present and this is the factor that determines in large degree of amenability of a given coal to beneficiation by washing.

The ordinary coal-washing processes effect a separation between coal and impurity because of the difference in specific gravities of these components. In studying the possibilities of improving a coal by washing, it has therefore long been common practice to separate the raw coal mixture into coal and impurity by immersing it in a solution with specific gravity intermediate between that coal and impurity. The portion of the sample with specific gravity less than that of the solution floats and the portion with the specific gravity more than that of the solution sink. By the use of series of such solutions, each of successively higher specific gravity, a sample of coal may be separated into a number of portions, each made up of particles of restricted range of differences in specific gravity. Such a separation has been found most useful in coal-washing and has been called “specific-gravity analysis”. [6]

The separation into specific-gravity fractions by float-and-sink method is effected entirely by the differences in specific gravity of the particles and not because of the differences in the sizes and shapes of the particles present. The sizes and shapes are also the important factors in any coal washing process that involves hindered settling and stratification. For this reason, the float-and-sink method can be considers as an ideal or perfect separation that can be approached as a limit in practice by coal-washing machines. [6]

1.1. Advantages

Cleaning of coal has various advantages. Cleaning the coal at the mine site reduces the fixed carbon, volatile matter and ash content and traces of other elements like sulphur or phosphorus and some extraneous material like mud, clay dirt and parts of soft rock in the coal. By doing so,

- Transport and operating cost can be reduced as they are burden for carrying, handling and processing.
- The real content of coal i.e. the fixed carbon can be increased by reducing the ash content.
- There is a slowdown in process of metallurgical change and retard in the pace of chemical reaction due to the presence of such impurities.
- Process can be made efficient and pollution can be reduced.[11]

2. <u>LITERATURE RIVIEW</u>

The specific gravity at which a coal is to be cleaned is determined from the washability data and economic considerations. The ease of washing at this specific gravity may be judged from the amount of near gravity material (NMG) present in the coal. The amount of this material is defined as the percentage of the coal that will float in a range within ±0.10 specific gravity of the separation value. The presence of NGM causes misplacements of sinks in floats and floats in sinks. The larger the amount of NGM, more difficult will be the cleaning operation, and vice versa. [9]

2.1. INTERPRETATIONS FROM GRAPHS

- From curves 1 i.e. Total Float vs. Ash curve& curve 2 i.e. Total Sink vs. Ash curve, we can directly find out the yield and ash of the clean product & the heavy waste at a certain specific gravity of washing.
- If we want to know the specific gravity at which cleaning should be done to have maximum yield of clean coal within a certain upper limit of ash value, then Curve – 1 is consulted.
- Curve 3 i.e. Increment Curve shows how far it is possible to separate the dirt's from the clean coal by mechanical methods.
- For easily washable coal Curve 3 should have a sharp bend and a smooth line in case of difficult to wash coal. [12]

2.2. EFFECT OF MOISTURE ON FLOAT-AND-SINK TEST

The moisture content of the sample affects the float-and-sink operation because of its dependence on specific gravity. The apparent specific gravity of the coal is defined as the specific gravity of the coal as tested, including the moisture and air held within the coal sample. This value varies with the moisture content, hence the moisture content will influence the results obtained by a float-and-sink test. Therefore, the float and sinks of each sample after float-and-sink test with each specific gravity is dried in sunlight to be complete moisture free. If clean coal and impurities take up in equal proportions, this would simply mean that a higher specific gravity must be used for the test when the saturated sample is used as than the air dried sample is used. [3]

2.3. ENTRAPMENT OF SINK PARTICLES BY FLOAT COAL

The principal cause of incomplete separation is the entrapment of sink particles by the float coal when the sample contains very small proportion of sink particles as compared with the float. The probability of this is minimized by treating small portion at a time, so that the layer of coal in the vessel is not more than three or four particles thick and by stirring the sample thoroughly after it is placed in the solution. In a series of float-and-tests, in case of incomplete separation, the float is retested in the same solution immediately after the first separation was completed. Sink removed from the float coal in this manner varies from four to five pieces. These particles recovered were slightly heavier than the test solution and comparatively low in ash content.

Refuse particles in the sink product that are only slight heavier than the liquid are much more difficult to remove by washing then the heavy clean refuse. Hence, more complete information on the specific gravity of the various components of coal is desirable. With the normal coals, it is most easily made by testing the samples on the solution with lower specific gravity of 1.30 first and then in the increasing order with difference of 0.10 specific gravity increments. The sink portion is then re-treated on successively heavier solutions; each solution gives one finished increment of specific gravity. For bituminous coals, the range of separation is generally from 1.40 to 1.70. [6]

3. OBJECTIVE

The objective of this project work is to analyze the washing characteristics of various coal samples collected from different mines. After studying the washing characteristics, the curves are to be drawn which are called "washability characteristics curves" from where it can be easily found out which coal sample is easy to wash and which one is difficult to wash and at what specific gravity we will get maximum yield of coal.

Designing of a coal washing plant is done with the help of washability characteristics curves we obtain. The designing is done on the basis of mass balance i.e. the quantity of media and water required for cleaning desired amount of raw coal.

4. MATERIALS AND METHODS

4.1. SAMPLE COLLECTION

Any sample, even the most simple, brings with it a cascade of possible errors, some of which are related to the structure of the ore, and some to its distribution and its texture, with still others resulting from the particular sampling technique used, from the way the technique is applied or from the sampling apparatus used. The word “sample” ordinarily denotes something that has been physically removed from its natural location to be tested in the laboratory. The experience of the professional, in sampling thousands of mines, provides a basis for deciding what the proper position and spacing should be; subject, of course, to modification for any individual mine after taking preliminary samples. This experience has developed methods, which eliminate, so far as possible, the personal element in selecting the material that is to constitute the sample. The standard methods of sampling include the use of various types of drills. The conventional method of doing this is by channel sampling. [7]

The samples were collected from the different mines of Orissa. Total eight samples were collected from the following mines in the month of December 2010:

1. Samleshwari open cast project, IB valley area, Brajrajnagar.
2. Basundhara Mines, Rampur-1
3. Basundhara Mines, Rampur-2
4. Belpahar open cast project, Lakhanpur Area, Jharsuguda
5. Lajkura open cast project, IB Valley Area, Brajrajnagar
6. Lilari open cast project, Lakhanpur Area, Jharsuguda
7. Lakhanpur open cast project, Lakhanpur District, Jharsuguda
8. Rampur undergroung mines, IB Valley Area, Brajrajnagar.

These samples were in the form of lumps, so crushing is done. The samples were crushed manually with the help of hammer. Two screens of size 2mm and 1 mm i.e. ASTM 10 and ASTM 18 respectively were used for screening the samples. The crushed sample is passed through both the screens. The sample retained in the 1mm screen i.e. (-2+1) is the required sample for further proceedings.

4.2. FLOAT-AND-SINK TEST

Several testing methods have been devised for treating raw coal to obtain separation of coal and dirt particles present in particular sample, more or less analogous to the separation made by washery with the object of finding an approximate measure of the washability of coal by an inexpensive measure. The raw coal contains impurities after its primary sizing operations. It contains the minerals matter with which it was associated underground and some other materials getting mined up during handling.The properties which are used in coal cleaning are specific gravity, shape and size of the particles, friction, resilience, surface tension etc.the specific gravity of raw coal varies directly as the ash content, the higher ash material will be concentrated in the part that sinks and the clean coal will gather in the part that floats. [2]

Cleaning process generally depends upon differences in density between clean coal and its impurities. They suitably remove the free dirt but not the inherent dirt present in coal paricles. The extent of removal of free dirt on the amenability of a coal to improvement in quality is more commonly known as the “washability” of coal and is more commonly indicated by the “float and sink” analysis of coal samples. These washability investigations are conducted before average proposal for installation of a new coal washery is to be considered.

4.2.1. Experimental Procedure

A coal sample of (-2+1) size is taken and of which about100g is weighed. Liquids of different specific gravity varying from 1.3 to 1.8 are prepared using CCl4, benzene and bromoform in different concentrations. The liquids are taken in fuel jars and arranged in the order of increasing specific gravities (1.3, 1.4 … and so on). The sample is first placed in the lowest specific gravity liquid. The fraction higher than the liquid floats and heavier ore sinks. The portion which floats on a particular specific gravity and the portion which sinks are known as sink fraction. Then the sinks are placed in next higher specific gravity and the float and sink fractions separated. In this way, the float and sink fractions of different specific gravities are collected and weighed, taking care that no coal particles are lost. Determination of the ash content of coal of the float and sink fractions are carried out and the results are tabulated. The washability curves are plotted taking total floats vs. ash, total sinks vs. ash and the washability characteristic curves on instantaneous ash curve. [2]

4.3. DETERMINATION OF ASH CONTENT

Ash content of coal is the non-combustible residue left after coal is burnt. It represents the bulk mineral matter after carbon, oxygen, sulfur and water (including from clays) has been driven off during combustion. Analysis is fairly straightforward, with the coal thoroughly burnt and the ash material expressed as a percentage of the original weight. [7]

Each fraction of float-and-sink test is crushed to fine powder so as to screen through ASTM-70 mesh screen. One gram of each sample is taken in air dried silica crucible and is weighed. The muffle furnace is heated to a temperature of 750˚C. The crucible along with the sample is placed in muffle furnace. The sample was heated for 90 minutes at a temperature of (750±25˚C). The crucible was then taken out and is cooled in desiccators to avoid any moisture content with the sample. The crucible after cooling is again weighed and the reading were noted.

The following calculations were made during the determination of ash content of coal:

X = Weight of empty crucible,

Y = Weight of crucible + Weight of sample (before heating),

Z = Weight of crucible + weight of sample (after heating).

% Ash content of the sample = $\frac{Z-X}{Y-X} \times 100$

The representation of the washability curves are as follows:

Curve 1: Total Float – Ash curve

Curve 2: Total Sink – Ash curve

Curve 3: Instantaneous Ash curve or Increment curve. [9]

5. RESULTS AND DISCUSSION

5.1. SPECIFIC GRAVITY ANALYSIS

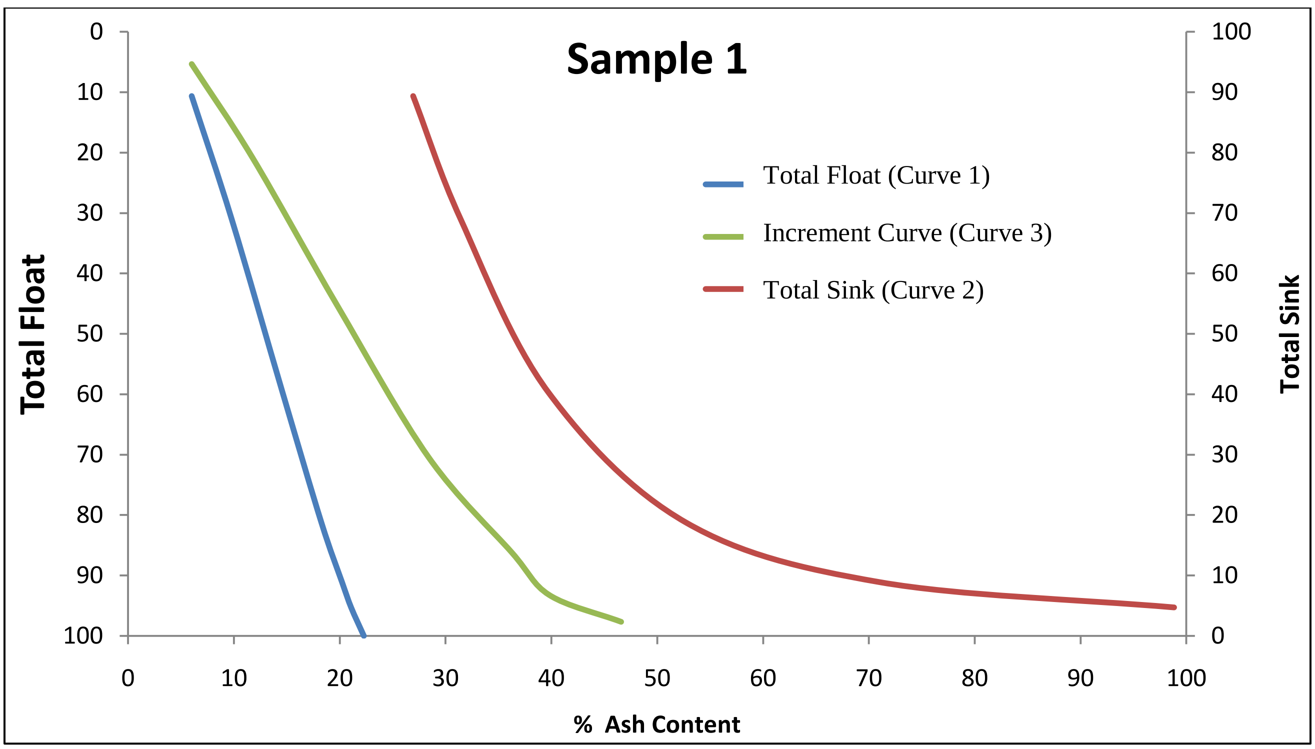
The primary reason for incomplete separation and uncertain separation in the washing process is the great variation in density of sink. Refuse particles in the sink that are only slightly heavier than the liquid are much more difficult to remove by washing than the heavy clean refuse.A succession of float-and-sink tests using the liquids of different specific gravities supplies the required data. Such a series of tests are called the “specific-gravity analysis” of the sample. Ordinarily, it is sufficient to cover 0.10 increments in specific gravity. With normal coals, it is most easily made by testing the coal sample on the solution with lowest specific gravity of 1.30 or 1.35. [8]

5.2. FLOAT AND SINK TEST RESULTS

5.2.1 Sample 1

Float and Sink test results for sample 1:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield up toMiddle of Fraction (%)
1.3	10.622	6	0.637	0.637	10.623	6	89.377	24.083	26.95	5.31109
1.4	20.467	11.76	2.408	3.0453	31.091	9.794	68.908	21.675	31.45	20.85662
1.5	28.625	19.8	5.668	8.7130	59.716	14.591	40.283	16.007	39.73	45.403537
1.6	21.552	28.43	6.128	14.840	81.268	18.261	18.732	9.8796	52.75	70.492281
1.7	9.851	36.27	3.573	18.413	91.119	20.208	8.8806	6.3063	71.01	86.193956
1.8	4.186	39.81	1.666	20.079	95.306	21.069	4.6948	4.6402	98.84	93.212266
>1.8	4.695	46.6	2.188	22.267	100	22.267	0	2.4523	-	97.652582



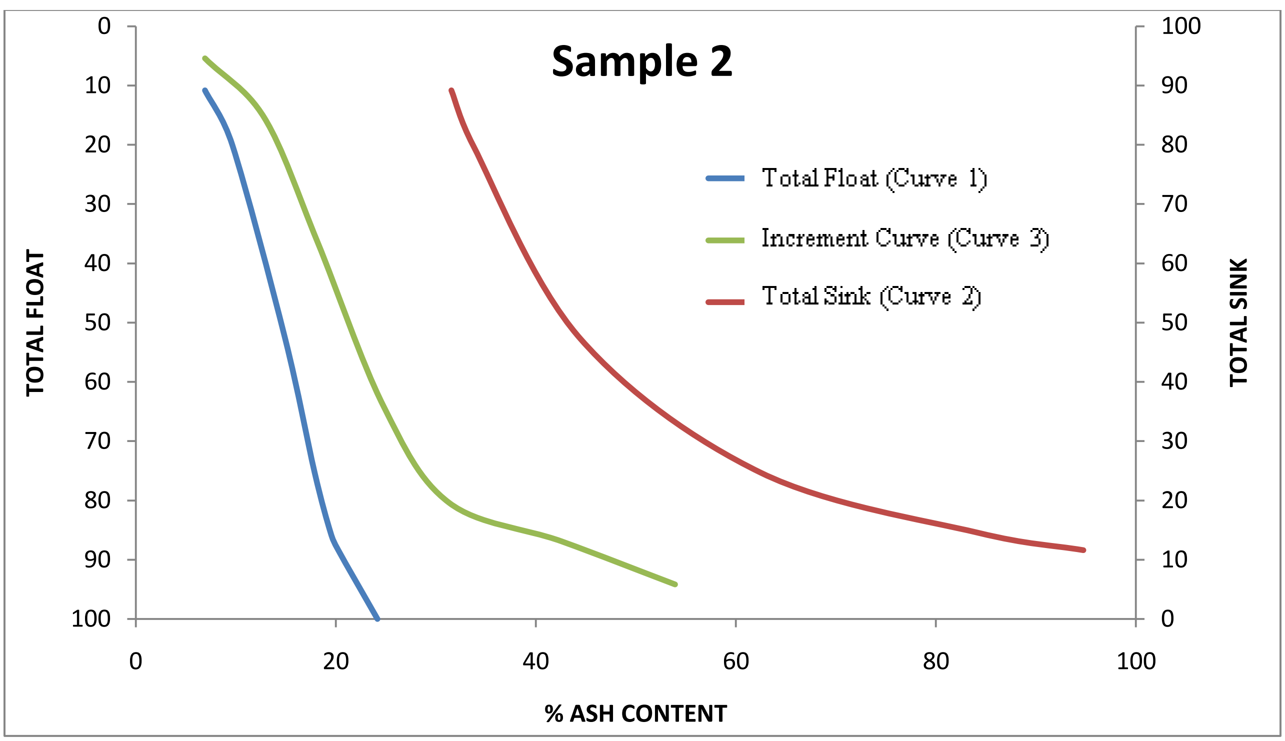
Washability characteristics curve for Sample 1

From the above curve, it is clear that the increment curve is having sharp bend at certain specific gravity. So, this sample comes in category of easy-to-wash coal. The specific gravity of separation is 1.8. Hence, maximum yield of clean coal obtained corresponding to this specific gravity is 95.306% having ash content of 21.069%. From the Total sink-Ash curve, corresponding to specific gravity of 1.8, we are getting 4.695% of sink with very high ash content of 98.84%. Ash of fraction of coal at specific gravity of 1.8 is 39.81% which is relatively higher than the ash content of clean coal.

5.2.2. Sample 2

Float and Sink test results for sample 2:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	10.817	6.931	0.7497	0.74973	10.817	6.931	89.183	28.141	31.553	5.4085
1.4	9.277	12.871	1.1941	1.94376	20.094	9.6734	79.906	26.946	33.722	15.4555
1.5	32.615	18.181	5.9297	7.87351	52.709	14.937	47.291	21.016	44.440	36.4015
1.6	22.615	24.752	5.5976	13.4712	75.324	17.884	24.676	15.418	62.485	64.0165
1.7	10.131	31.313	3.1723	16.6435	85.455	19.476	14.545	12.246	84.197	80.3895
1.8	2.937	42.574	1.2504	17.8938	88.392	20.244	11.608	10.996	94.728	86.9235
>1.8	11.608	53.921	6.2592	24.1531	100	24.153	0	4.7369	-	94.196



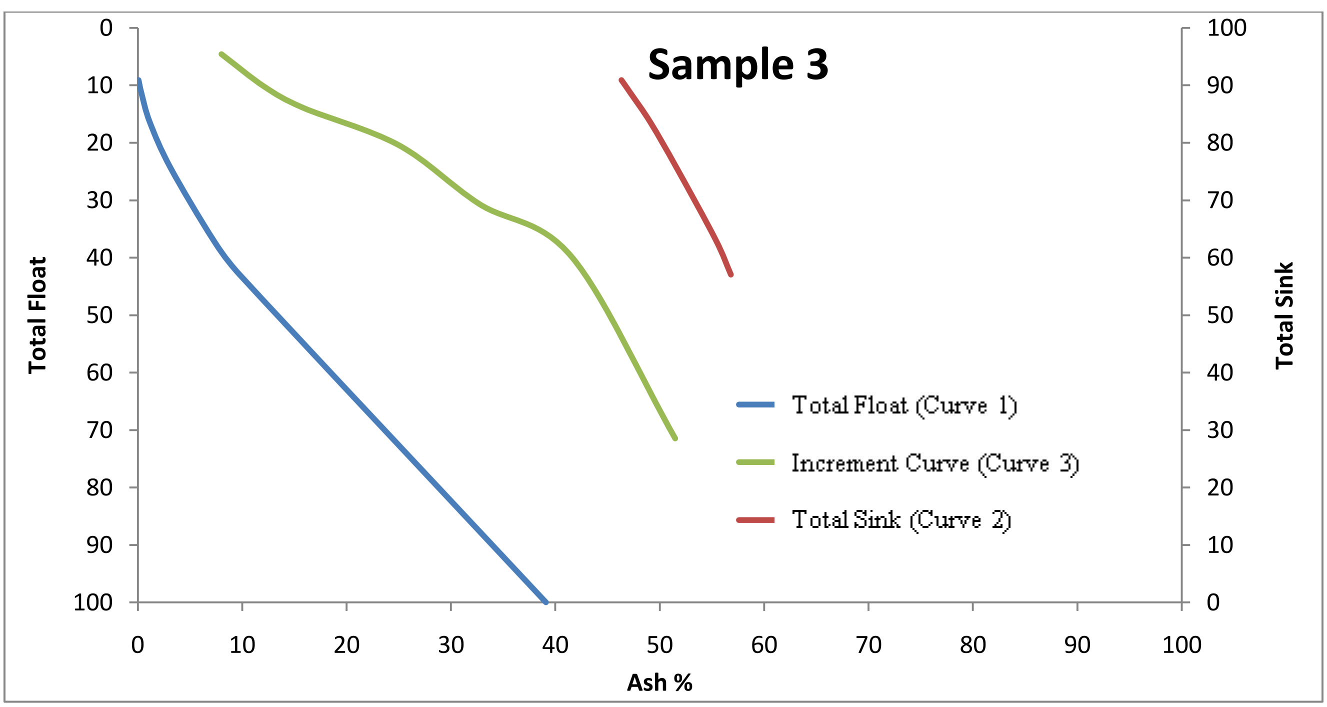
Washability characteristics curve for Sample 2.

From the washability characteristics curve drawn for sample 2, the specific gravity of separation is 1.7 and increment curve is having sharp bend at this specific gravity. So, it is easy-to-wash coal. The yield of clean coal obtained at specific gravity of 1.7 is 85.455% with ash content of 19.476%. so it is relatively clean coal than the previous sample. From the Total sink-Ash curve, we get 14.545% of sink at specific gravity of 1.7 with ash content of 84.197. Ash of fraction of coal at specific gravity of 1.7 is 31.313% which is relatively higher than the ash content of clean coal.

5.2.3. Sample 3

Float and Sink test results of sample 3:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	9.108	8	0.7286	0.05829	9.108	8	90.892	42.09	46.316	4.554
1.4	2.253	12.121	0.2731	0.33137	11.361	8.8173	88.639	41.82	47.185	10.2345
1.5	5.091	15.842	0.8065	1.13789	16.452	10.991	83.548	41.02	49.095	13.9065
1.6	7.905	25	1.9762	3.11414	24.357	15.537	75.643	39.04	51.613	20.4045
1.7	12.48	32.673	4.0775	7.19173	36.837	21.343	63.163	34.96	55.355	30.597
1.8	6.1	41.584	2.5366	9.72836	42.937	24.218	57.063	32.43	56.827	39.887
>1.8	57.063	51.485	29.378	39.1073	100	39.777	0	3.048	-	71.4685



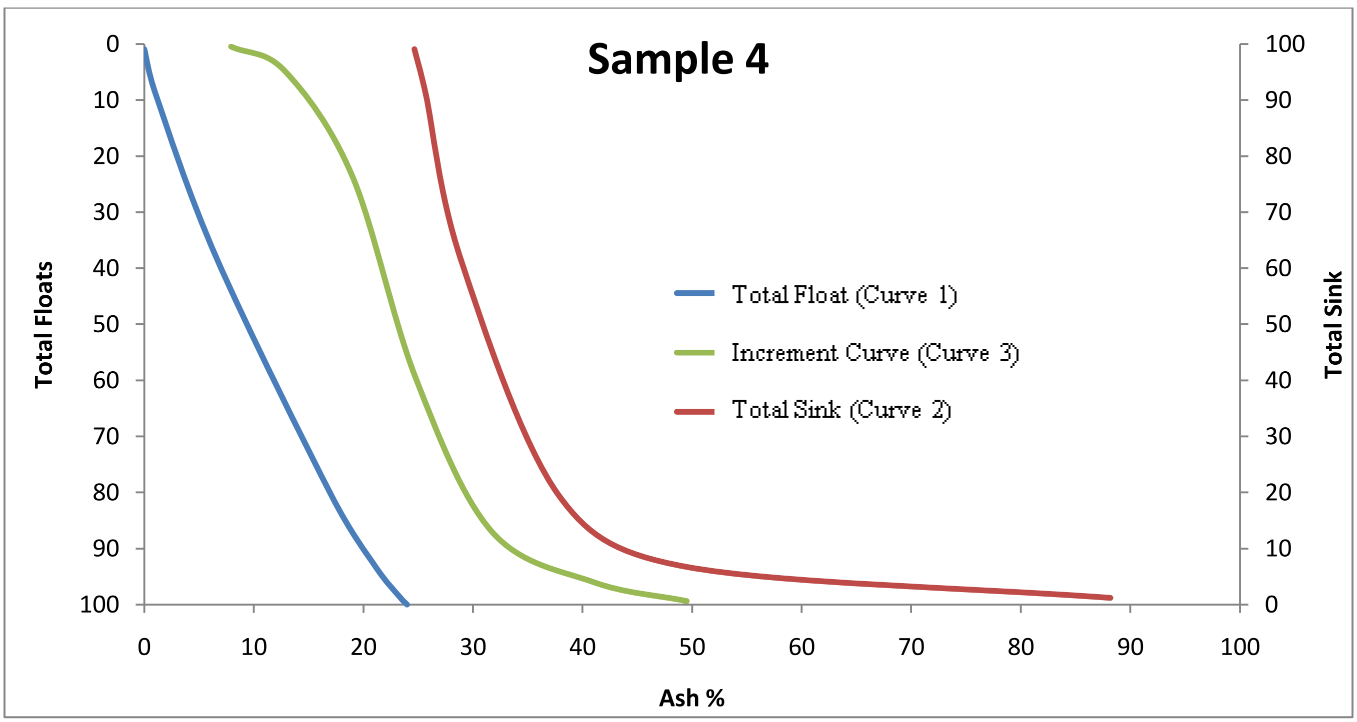
Washabitlity characteristics curve for Sample 3.

From the above washability characteristics curve, we can see there is an uncertain bend in the increment curve. This shows that the coal sample is not easy-to-wash coal. Further, there is not a sharp bend but one can observe the specific gravity of separation from the above curve. The specific gravity of separation for this sample is 1.8. The yield of clean coal obtained at this specific gravity is 42.937% which is very low. The ash content of clean coal is 24.218%. The yield of clean coal is very low because of the higher yield of sink we are getting. From the curve 2 i.e. Total sink-Ash curve, we get that the amount of sink is very high even at SG> 1.8. This shows the coal is very dirty coal having high amount of mineral matter associated with it. Ash of fraction of coal at specific gravity of 1.8 is 41.584% which is higher than the ash of clean coal.

5.2.4. Sample 4

Float and Sink test results for Sample 4:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	0.886	7.921	0.0702	0.00556	0.886	7.921	99.114	24.43	24.649	0.443
1.4	7.995	12.871	1.0291	1.03459	8.881	12.377	91.119	23.40	25.683	4.8835
1.5	29.465	19	5.5983	6.63295	38.346	17.466	61.654	17.80	28.877	23.6135
1.6	42.259	24.752	10.459	17.0929	80.605	21.286	19.395	7.344	37.865	59.4755
1.7	12.634	31.683	4.0028	21.0957	93.239	22.695	6.761	3.341	49.419	86.922
1.8	5.553	41	2.2767	23.3724	98.792	23.724	1.208	1.064	88.125	96.0155
>1.8	1.207	49.505	0.5975	23.9699	99.999	24.035	0.001	0.467	-	99.3955



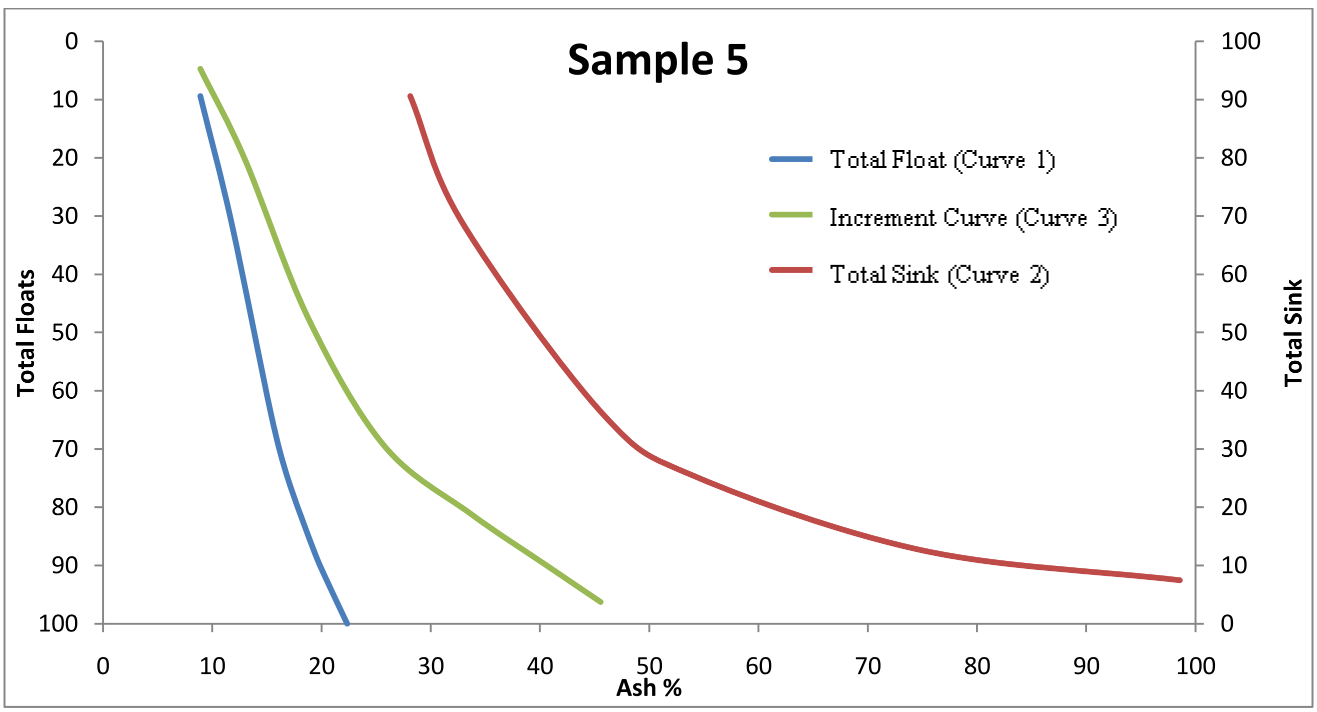
Washabiltiy characteristics curve for Sample 4

In the above washability characteristics curve, the increment curve shows the L-shaped bend which shows that the coal is easy-to-wash coal, having specific gravity of separation of 1.7. The yield of clean coal obtained at this specific gravity is 93.239% having ash content of 22.694%. From the Total sink-Ash curve, the yield of total sinks at specific gravity of 1.7 is 6.761% with ash content of 49.419%. So, this coal is relatively clean coal with less yield of sink. From the increment curve, the ash fraction of coal at specific gravity of 1.7 is 31.683%.

5.2.5. Sample 5

Float and Sink test results for sample 5:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	9.3924	8.911	0.8369	0.07458	9.39247	8.911	90.60753	25.47	28.113	4.6962
1.4	21.788	13	2.8325	2.90714	31.1814	11.768	68.81862	22.64	32.898	20.2869
1.5	32.885	18.812	6.1864	9.09354	64.0667	15.384	35.93323	16.45	45.789	47.6240
1.6	10.754	25.743	2.7683	11.8618	74.8204	16.873	25.17958	13.68	54.351	69.4436
1.7	12.607	33.663	4.2441	16.1059	87.4281	19.294	12.57194	9.44	75.096	81.1243
1.8	5.0916	40.594	2.0669	18.1728	92.5197	20.466	7.480307	7.37	98.581	89.9739
>1.8	7.4803	45.545	3.4069	21.5797	100	22.342	0	3.96	-	96.2599



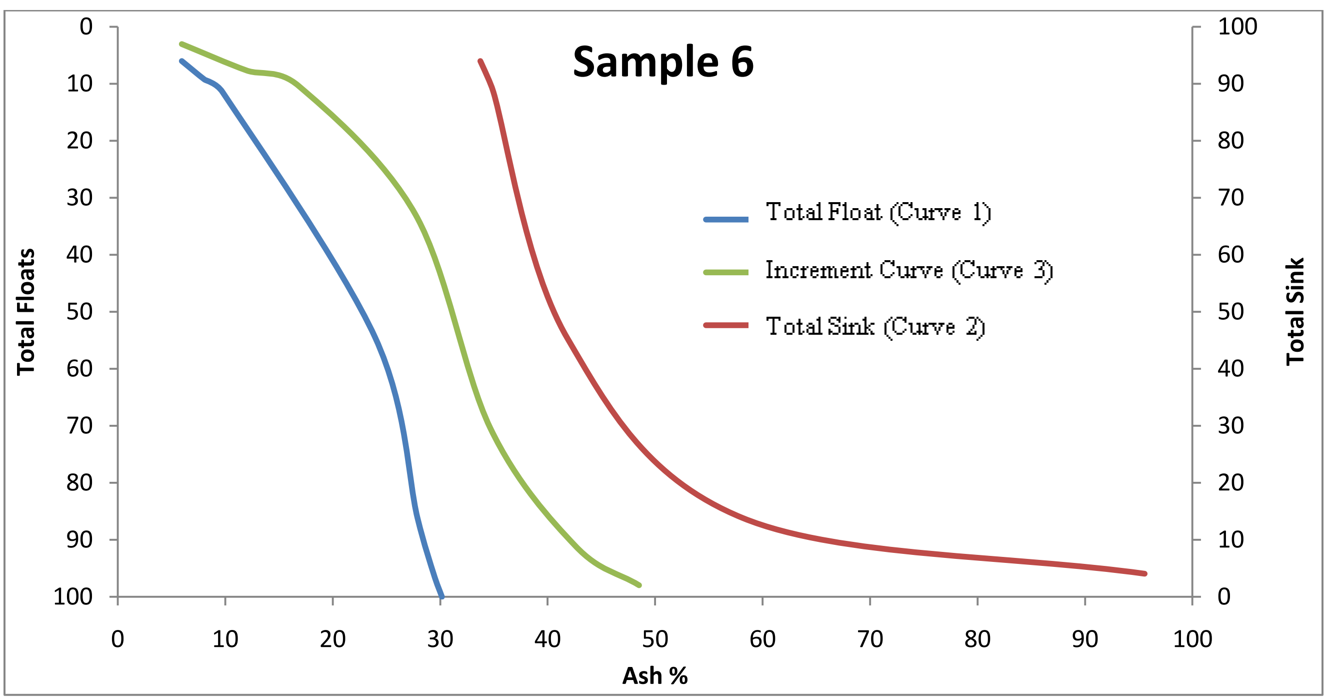
Washability characteristics curve for Sample 5.

From the above washability characteristics curve, the specific gravity of separation is 1.6 which is the specific gravity of separation of bituminous coal. So this coal must be bituminous coal. The curve is not having the sharp bend, so it is not easy to wash coal but the specific gravity of separation is 1.6 which is lower than the other coal samples. The yield of clean coal obtained at this specific gravity is 74.821% with ash content of 16.873%. From this we can say that the coal is clean coal but the yield of clean coal obtained is vey less relative to other coal samples. From the Total sink-Ash curve, we get 25.179% of sink material with ash content of 54.351%. Ash of fraction of coal at specific gravity of 1.6 is 25.743%.

5.2.6. Sample 6

Float and Sink test results for Sample 6:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	6.0359	5.941	0.3586	0.02131	6.0359	5.941	93.9641	31.71	33.744	3.0179
1.4	3.2517	12	0.3902	0.41151	9.2876	8.0623	90.7123	31.32	34.523	7.6618
1.5	2.1793	16.832	0.3668	0.77832	11.4669	9.7289	88.5331	30.93	34.958	10.3772
1.6	43.066	27.723	11.939	12.7175	54.5330	23.939	45.4669	19.02	41.812	32.9996
1.7	31.617	34.653	10.956	23.6739	86.1504	27.872	13.84952	8.05	58.154	70.3417
1.8	9.7772	42.574	4.1626	27.8365	95.9278	29.369	4.07219	3.89	95.562	91.0392
>1.8	4.0721	48.515	1.9756	29.8122	100	30.149	0	1.91	-	97.9639



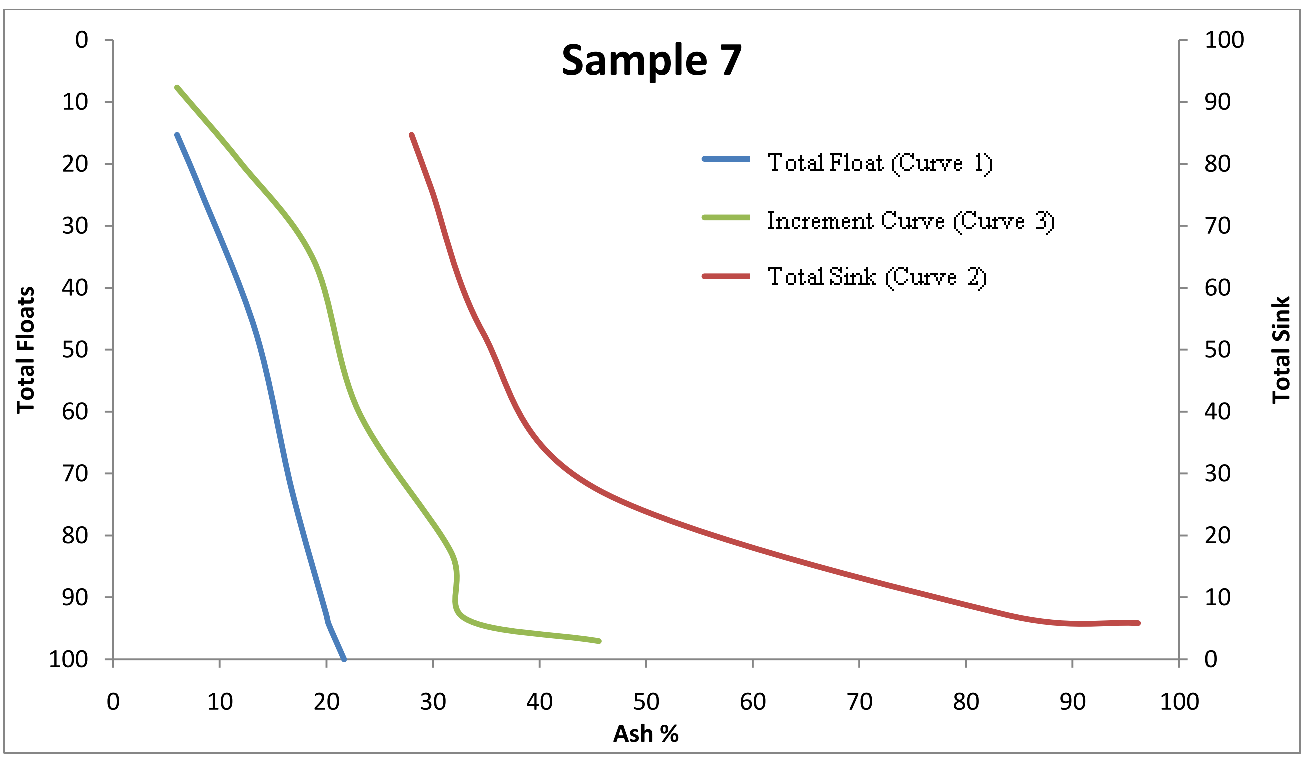
Washability characteristics curve for Sample 6

From the washability characteristics curve for Sample 6, we get unsymmetrical increment curve. This shows that the coal is difficult-to-wash coal. Since the curve is having bend, the specific gravity of separation is 1.7. The yield of clean coal obtained at this specific gravity is 86.151% having ash content of 27.871% which is relatively high than the other coal samples. So, this coal is dirty coal with difficult-to-wash characteristics. Corresponding to the specific gravity of 1.7, the amount of sink we get is 13.849% with ash content of 58.154%. From the increment curve, we get the ash of fraction of coal at specific gravity of 1.7 is 42.574 which is very high than the ash of clean coal.

5.2.7. Sample 7

Float and Sink test results for Sample 7:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	15.309	6	0.9185	0.0551	15.3093	6	84.6907	23.71	27.995	7.6546
1.4	8.634	11.881	1.0258	1.0809	23.9436	8.121	76.0564	22.68	29.824	19.6264
1.5	23.188	18.812	4.3622	5.4432	47.1321	13.381	52.8678	18.32	34.654	35.5378
1.6	25.551	23	5.8766	11.3198	72.6825	16.763	27.3175	12.44	45.554	59.9074
1.7	20.005	31.683	6.3382	17.6579	92.6875	19.983	7.3125	6.11	83.502	82.6851
1.8	1.465	33	0.4832	18.1412	94.1519	20.185	5.8480	5.63	96.147	93.4197
>1.8	5.848	45.545	2.6635	20.8047	100	21.668	0	2.96	-	97.0759



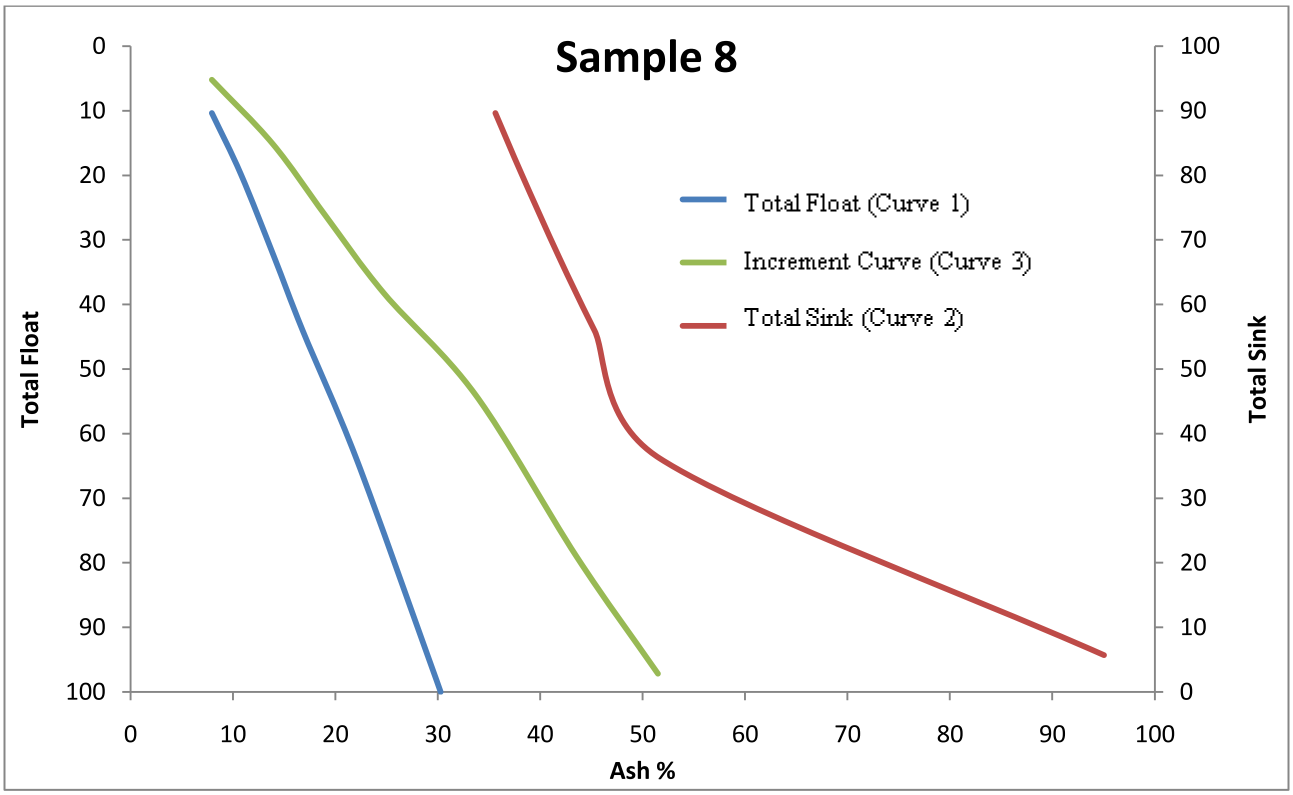
Washability characteristics curve for Sample 7.

From the washability characteristics curve for the above sample, we can see a sharp bend in the increment curve. This shows that the coal is easy-to-wash coal with specific gravity of separation 1.8. The yield of clean coal obtained at that specific gravity is 94.152% with ash content of 20.185%. Hence, the coal is having high yield of product with relatively less ash content. From the Total sink-Ash curve, the amount of sink we get at specific gravity of 1.8 is 5.63% with ash content of 96.147%. This shows that the coal is having very less amount of sink material in it with high ash content. From the increment curve, the ash of each fraction corresponding to the specific gravity 1.8 is 33%.

5.2.8. Sample 8

Float and Sink test results for sample 8:

Sp. Gravity	Yield of each Fraction (%)	Ash of Each Fraction (%)	Ash of Each Fraction as % total	ash cumulative %	Cumulative Yield of Total Float (%)	Ash of Total Floats (%)	Cumulative Yield of Total Sinks (%)	fractional sinks % ash	Ash of Total Sinks (%)	Cumulative Yield upto Middle of Fraction (%)
1.3	10.372	7.921	0.822	0.0651	10.3715	7.921	89.6285	31.92	35.612	5.1857
1.4	9.463	13.861	1.312	1.3766	19.8339	10.755	80.1661	30.61	38.178	15.1027
1.5	12.696	19	2.412	3.7887	32.5294	13.973	67.4706	28.19	41.787	26.1816
1.6	11.527	24.752	2.853	6.6421	44.0568	16.793	55.9432	25.34	45.297	38.2931
1.7	19.791	33.663	6.662	13.3041	63.8473	22.022	36.1527	18.68	51.666	53.9521
1.8	30.464	43.564	13.272	26.5756	94.3117	28.981	5.6883	5.41	95.061	79.07945
>1.8	5.688	51.485	2.928	29.5043	100	30.261	0	2.48	-	97.1558



Washability characteristics curve for Sample 8.

From the washability characteristics curve of sample 8, we can observe that the increment curve is a straight line. Hence, this coal is difficult-to-wash coal. However, there is a very minor bend at specific gravity of 1.7. From the total sink-Ash curve, we get the amount of clean coal at that specific gravity is 63.847% with ash content of 22.022%. So, the yield of clean coal obtained is very less. From the Total sink-Ash curve, the amount of sink we get at specific gravity of 1.7 is 36.153% which is very high. The ash content of sink material is 18.68%. From the increment curve, we get the ash of fraction of material at specific gravity 1.7 is 33.663%.

6. DESIGN OF A COAL WASHING PLANT

Coal washing is a process of separation which is mainly based on the difference in specific gravity of coal and associated impurities like shale, sand and stones, etc so that relatively pure marketable coal can be obtained. Coal washing separates non-combustible material from useful combustible material. Coal washing uses the method of gravity separation, floatation and a technology which uses dense media. Magnetite having a specific gravity of about 5.17 is used in washery for washing process. Indian coal has a very high NGM value and its difficult to wash it. Heavy media separation provides the best solution for Indian coal. [11]

Figure 6.1.Design of Heavy media separator vessel.

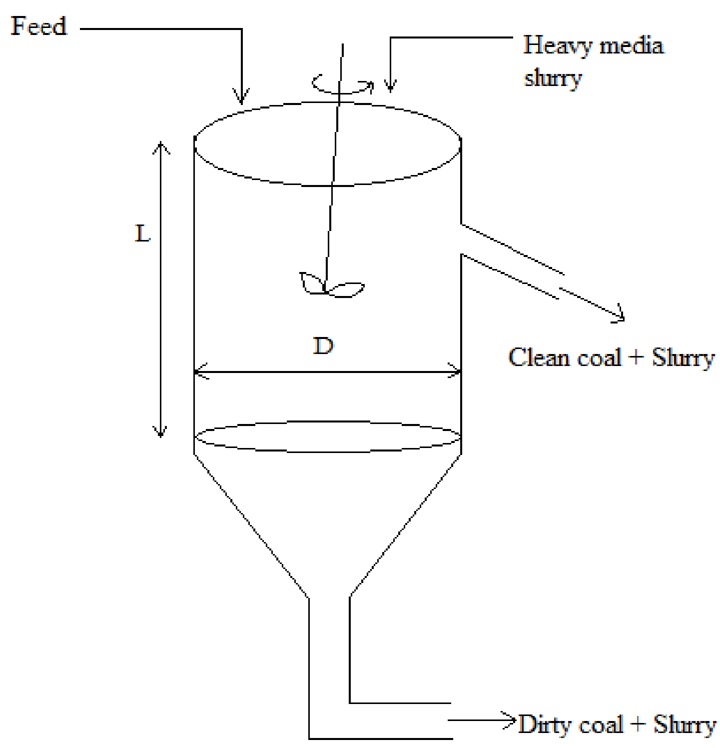


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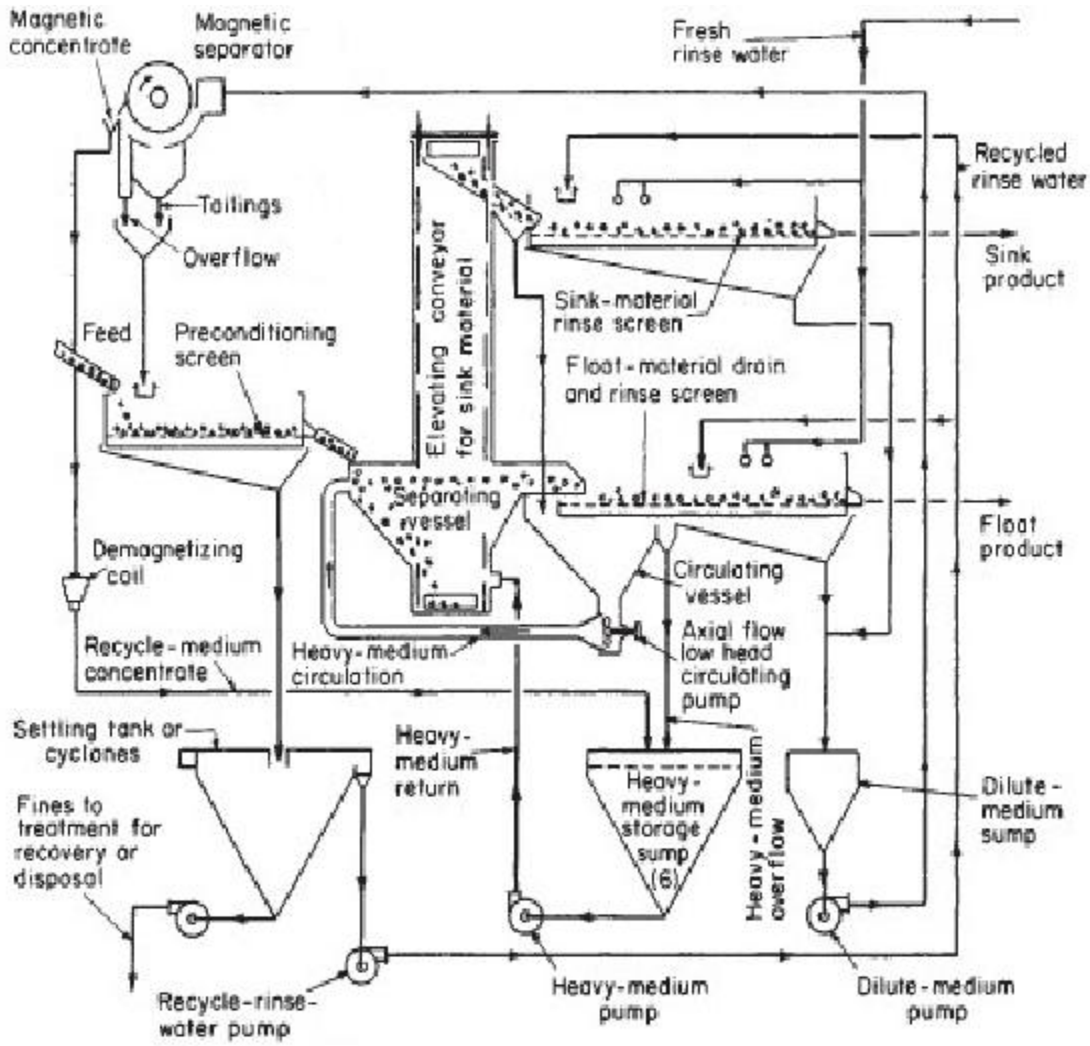
Figure 6.2.Typical dense-media flow sheet for a coal-cleaning plant



6.1 Calculations

Let, 100 tons per hour of coal is need to be washed.

Fie finding the specific gravity of the feed i.e. coal, the coal lump is immresed in water taken in measuring cylinder. The weight of coal is weighed. The volume of water displaced is measured. Hence, the density can be calculated as:

Density = $\frac{\text{Weight of coal lump}}{\text{Volume of water displaced}}$

1. Weight of coal lump = 210.26 grams

   Volume of water displaced = 140 ml

   Hence, density of coal = 1.502 gm/ml
2. Weight of coal lump = 229.83 grams

   Volume of water displaced = 150 ml

   Hence, density of coal = 1.532 gm/ml
3. Weight of coal lump = 181.57 grams

   Volume of water displaced = 120 ml

   Hence, density of coal = 1.513 gm/ml

Taking average of all the densities, we have density of coal or feed = 1.516 gm/ml.

Now, 100 tons/hr of feed is given.

Specific gravity of feed = 1.516 gm/ml or 1516 kg/m^3.

So, for 100 tons/hr of coal feed, we have volume of coal = $\frac{100 \times 1000}{1516}$ = 65.963 m^3

From the Float and Sink test, we use 200 ml of liquid mixture is used for cleaning 100 grams of raw coal.

Hence, for 100 tons of coal, we use 200 m^3 of heavy media-water slurry.

Therefore, volume of heavy media-water slurry = 200 m^3.

So, when both the coal and the slurry of heavy media-water are mixed in a tank, we need a minimum volume of (200 + 65.963) = 265.963 m^3.

Let, 15 minutes of retention time, the total volume will be = 265.963 $\times\frac{15}{60}$ = 66.491 m^3.

Taking this as basis, we tend to calculate the dimensions of a cylindrical coal washing unit.

We also assume an empty space of 20% or a total height of 80% liquid in the tank.

Now, the volume of tank = V = $A = \pi/4\ D^2$ L

Where, D is the diameter of the tank and L is the Length or Height of the tank.

As assumed above, the length should be 80% of the tank length,

The minimum volume of slurry and coal per hour in tank = $\pi/4\ D^2$ (0.8L)

= 0.8 V

We know that the minimum volume that should be maintained = 66.491 m^3

Hence, V = $\frac{66.491}{0.8}$ = 83.113 m^3

Or, $\pi/4 D^2$L = 83.113 m^3 --- (a)

Taking different L/D values for cylindrical vessels, we can find out the different values of diameter of the vessel and the length of the vessel as shown in the following table:

L/D Value	Diameter of the vessel (D) (m)	Length of the vessel (L) (m)
4	2.9802	11.921
3	3.280	9.841
2	3.755	7.51
1.8	3.889	7.001

Table 6.1.Diameter and Length of vessel for different L/D values.

From the above data, we can observe that the vessel design is actually not seems to be possible in case of L/D = 4 and L/D = 3. It is because; the length of the vessel is very much greater than the diameter. In case of L/D = 1.8 and L/D = 2, the vessel design is possible and they are considered to be the ideal values.

7. CONCLUSION

The Float-and–sink test of all the eight samples collected from various mines of Orissa was performed and the results were shown in the form of washability characteristics curve. From the curve, we can easily distinguish which coal is easy to wash and which is difficult to wash which depends on the increment curve. The increment curve for sample 8 is a straight line which shows that it is difficult-to-wash coal. The increment curves for sample 2, sample 4 and sample 7 are having sharp bends and hence they are easy-to-wash coal. Moreover, Sample 7 i.e. the sample collected from Lakhanpur Open Cast Project, Jharsuguda, shows an L-shaped bend in the increment curve. Also, the yield of clean coal is high with less ash content. Hence, this coal sample is clean coal with respect to other coal samples. From the design of a coal washing plant, it is clear that L/D value should be maintained around 2.

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