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Washability Study on El-Maghara Coal Mine Reject

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Abstract

Egypt is not a coal-rich country; however, El-Maghara coal seams in Sinai (52 million tons with about 27 million tons as minable reserves) is the only coal reserve. Due to the importance of coal as a source of energy, this work deals with an attempt to retrieve escaped coal (gangue) as much as possible using Sink-and-float technique. A bulk sample was collected from the waste dumps of El-Maghara coal mine. The results were characterized by measuring yield recovery and ash contents. Sample was prepared by successive stages of crushing through jaw and roll crushers. Crushed sample was introduced to the screening process using a set of screens (6, 4, 2, 1 and 0.5 mm). Organic liquids such as Bromoform ($CHBr_3$), Carbontetrachloride (CCl_4) and Gasoline with specific gravities of 2.6, 1.59 and 0.721 respectively were used. Several bathes of various specific gravities (1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2.0 g/cc) were prepared from organic liquids. The obtained results indicated that, we can achieve about 18.94% clean coal yield recovery with ash content of 2.58%, washing degree of 18.10 and separation efficiency of 95.53% respectively at heavy medium of 1.3 specific gravity. Also, the obtained results at 1.4 specific gravity were 19.78 % clean coal yield recovery with ash content of 2.61%, washing degree of 18.88 and separation efficiency of 95.47%.

Keywords

Coal; Waste dump; Dense Medium Separation; Washability; Float–sink Separation.

Introduction

El-Maghara coal seams in Sinai is the only one of the main coal reserves in Egypt. However, the present reserves is not exceed 52 million tons; with about 27 million tons as minable reserves. Concerning the modern mining methods, about 35 % (18.2 M. tons) of the reserves will be misplaced as a waste. The price of coal, as compared to the other mineral commodities, is relatively low, therefore the costs of mining, processing and transportation to the market are critical factors in the economics of the project, and must be balanced by the quality of mined coal and total product usable coal [1-3]. Recently, coal mining has been revolutionized by adopting highly developed and automatically controlled machines. This resulted in substantial amounts of impurities associated with the run of mine, and a higher content of finer materials. Impurities in coal, regardless of their origin, include mineral matters, which are the main source of the produced ash after complete combustion [4, 5]. The washability of any particular coal seam is directly related to the amount and type of mineral matter associated with the coal matter [6]. Coal is usually crushed and screened into different size fractions; each of the coarse, medium and fine fractions is separately washed and cleaned with suitable methods. The cleaning of coarse and medium sizes of coal (-150 + 0.5 mm) are being carried out by physical method, which depend upon the differences in specific gravity between coal forming organic macerals and the associated inorganic minerals, however, the majority of fine fraction (- 0.5 mm) is mainly cleaned by froth flotation methods[7-10].

Washability curve is drawn in accordance with the results of the sink-and-float test, which is used to reflect all the densities levels or any density distribution of coals and it is the necessary mean to understand the washability process, evaluate, predict, and optimize the effect of gravity separation of the raw coal [9, 10]. Commercially cleaned coal contains only very disseminated impurities and has a density ranging from 1.2 to 1.6. The carbonaceous shale density ranges from 2.0 to 2.6, and the pure shale, clay, and sandstone have a density of about 2.6 [6]. The washability test is the laboratory method of separating the coal and mineral matter, takes advantage of the specific gravity difference between coal and mineral matter in a coal seam. This is carried out by using liquids of particular specific gravities.

The liquids of the particular specific gravity that could be made by using various methods.

They are made up of long organic chains, which is why they are referred to as organic liquids. Practically all specific gravities values that are preferable in coal washability work can be prepared using three organic liquids (Bromoform ($CHBr_3$), Carbontetrachloride (CCl_4) and Gasoline). The following gravities were used for the Pittsburgh No. 8 coal: 1.30, 1.40, 1.55, and 2.00 SG [11- 13]. Furthermore, from the environmental point of view, excavation of coal seams is a process leading to the disturbance of the natural environment and production of waste material (waste dumps), because of both mining and processing. Coal preparation produces reject material, in the form of rock and middling's, which accumulated as waste. Characteristics of waste material (waste dumps) can easily be predicted from the washability parameters. This information can be useful in the decision-making about possible utilization of waste products (waste dumps) during the environmental impact assessment [2, 3]. This study deals with an attempt to retrieve the escaped coal as much as possible, using sink-and-float process.

The results were characterized by ash content and yield at each separation density. Washability curves of a given reject coal sample are constructed from the results of sink-and-float tests.

Experimental methodology

Materials

Coal sample **-** A bulk sample was collected from the wast dumps, at the entry of El-Maghara coal mine. These dumps were produced from the development and operation processes of Safa mine before the mine shutdown. The sample was prepared by successive stages of crushing through jaw and roll crushers. The crushed sample was introduced to the screening process using a set of screens (6, 4, 2, 1 and 0.5 mm). Particle size distribution analysis are shown in Fig. 1.

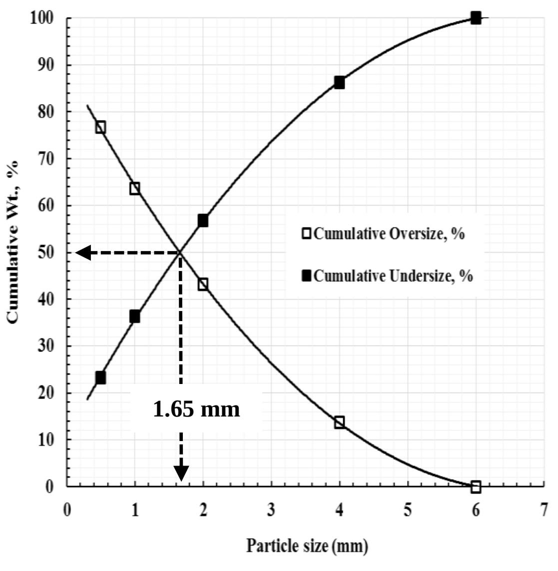

Figure 1 Coal reject (waste dumps) particles size analysis.

The most common types of liquids used in sink-and–float testing are heavy petrochemical compounds produced as derivatives from oil.

The obtained results from particle size analysis test indicated that, the weight retained on each screen were 18 % for -6+4 mm, 38.3 % for -4+2 mm, 26.7 % for -2+1 mm and 17 % for -1+0.5 mm size fraction. Each fraction analysed for ash content and the obtained results were 61.5 % for -6+4 mm, 64 % for -4+2 mm, 51 % for -2+1 mm and 50 % for -1+0.5 mm, while ash content for the total sample was 64 %. Also, we find median size $\mathbf{W_{50}}$ (50 % of sample weight) was retaind oversize screen of 1.65 mm at 62 % ash content. While, the weight % of -0.50 mm size fraction was 23 % from the bulk sample at 58 % ash content.

Sink and Float Test

Dense Liquids

To carry out this work, organic liquids such as: Bromoform ($CHBr_3$), Carbontetrachloride (CCl_4) and Gasoline with specific gravities of 2.6, 1.59 and 0.721 respectively were selected. Several bathes of various specific gravities (1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2.0) grams per cubic centimetre (g/cc) were prepared by using the following technique: Two equations were used:

$$S_1 \times X + S_2 \times Y = S_3 \times 100\ \% \quad (1)$$

$$X + Y = 100\ \% \quad (2)$$

Where:

$\mathbf{S_1}$, $\mathbf{S_2}$ and $\mathbf{S_3}$ are the specific gravities for first, second and wanted liquids respectively.

X and **Y** are the unknown liquid volume percentages.

Procedure

Each separate size fraction from the prepared sample was introduced to a succession of 250 cc beakers containing a prepared dense liquid ranging in densities from 1.3 to 2.0 with interval of 0.1 specific gravity. Hydrometers with density scales ranging from 1 to 1.5 and from 1.5 to 2.0 were used to adjust the liquid density to the proper one value. The test procedure started from lower density (1.3) and stirred the float layer gently to release the entrapped sink particles, and the bottom of the beaker tapped gently to release the entrapped float particles.

To evaluate the results, the separated fractions were, dried, weighted and analysed for ash content using muffle furnace. The obtained results were used to plot the washability curve for each size fraction and finally for the total sample as a combined washability curve. However, these curves are drawn to illustrate the different conditions, usually on the same axes, thus presenting the results on one sheet of paper. The main types of washability curves offered are characteristic ash curve, cumulative float curve, cumulative sink curve, specific gravity curve, ordinate D curve and ±0.1 specific gravity distribution curve. All different curves are based on the relation between ash, density and particle size distribution [14-16].

Results and discussion

Washability curves of a given coal sample (waste dumps) were constructed from sink-and-float test results. Ash contents were obtained for both sink and float products for each particle size fraction and the achieved results were discussed as the following.

Washability study for particles size fractions.

Figure 2 presents varying washability characteristics (as predicted from the ash versus clean coal yield curves) for different size fractions of the tested coal sample. Results illustrated in Fig. 2 indicated that, the decreases in particles size increase the recovrable coal yield, however, at course particles sieze of -6+4mm, the obtained yields were 9.6 % at specific gravity of 1.3 and 11 % at specific gravity of 1.6, while, ash % were 3 and 3.4 respectively. For particles size fraction of -4+2mm, the obtained yields were 19.4% and 21.2% with ash contents of 2.7 and 3% at specific gravities of 1.3 and 1.6 respectively. Also, Fig. 2 illustrate the results of particles size fraction of -2+1mm, the achieved yields were 22 % at specific gravity of 1.3 and 23 % at specific gravity of 1.6, while, ash % were 3 and 3.2 respectively. However, for particles size fraction of -1+0.5mm, the obtained yields were 23% and 24% at ash contents of 2% and 2.1% at specific gravities of 1.3 and 1.6 respectively. From the obtained results, the characterization of the achieved clean coal at different size fractions showed that the yield clean coal % increase as the particle size fraction decrease. While, ash (mineral matter) present in particle size fraction -4+2mm (64%) showed that liberation degree at that size fraction is less than the other fraction. Fig. 3 indicates the obtained results at specific gravity 1.3 of the four size fractions. Results illustrated in figure 3 indicated that as size fraction decreases the clean coal yield increased and ash content decrease, also, the results showed that separation efficiency reached the maximum value at size fraction of -1+0.5mm (96 %).and that may be due to increases of degree of liberation of clean coal from associated impurities. The results indicate that the size reduction has a significant influence on the specific gravity versus clean coal yield relationship. The obtained results agreed with the former reporters [17, 18].

Combined washability curve

Properties of the reject coal (waste dump) from El-Maghara coalmine were first analyzed for particle size distribution and ash contents as discussed before. Then, washability study of coal sample. The combined washability data and plot illustrated in table 1 and Fig. 4 [19].

The obtained results as shown in figure 4 indicated that there are slightly differences between specific gravities 1.4 and 1.6. However, the obtained results at specific gravity 1.4 were cumulative float weight (yield) of 19.78%, cumulative float ash of 2.61%, ±0.1 Specific gravity distribution of 1.16 and Ordinate D of 19.36%. The obtained results at specific gravity 1.6 were cumulative float weight (yield) of 20.38%, cumulative float ash of 2.73%, ±0.1 Specific gravity distribution of 0.48 and Ordinate D of 20.29%. From Fig. 4, it is clear that the increment curve is having sharp bend at specific gravity 1.4. Therefore, the results come in category of easy-to-wash coal. At the specific gravity of 1.8, the curve is gently inclined, that means it slightly difficult to wash. However, specific gravity separation 1.4 was selected, because of the expected yield gained at proper ash content from escaped coal. in table 1 and figure 5 using equations 3 and 4 [16- 18]:

$$N = w\,(a-b)/a \qquad (3)$$

Where:

a = the ash content of the raw coal (feed).

b = the ash content of the clean coal at a given density of separation.

w = the yield of clean coal at a given density of separation.

Increasing the degree of washing number means increase-washing difficulty of the sample, which in agreed with previous investigations. Fig. 5 illustrates also, the efficiency of the washability process depends upon specific gravity of dense medium separation, and that might be due to variation in particle size fractions [17, 18]. For example the washability degree and separation efficiency at specific gravity 1.3 were 18.1 and 95.52 % respectively.

And Efficiency:

$$\eta = \frac{(feed\ ash - float\ ash)}{feed\ ash} \times 100 \qquad (4)$$

Figure 5 indicated that, as specific gravity increased the degree of washing number increased and separation efficiency decreased.

Conclusion

Individual particle size fractions as well as their accumulated (combined) effect were studied using float–and-sink test, and from the obtained results, it could be concluded that:

- The dense-medium process is useful to retrieve the escaped coal from El-Maghara coalmine rejects (waste dumps), and that will increase the produced mineable reserves.
- The washability analysis data for the sample under investigation indicated a reasonable yield recovery with reasonable ash content using float–and-sink test. The results showed that decreasing ash from 58 % to 2.67 % could give coal yield of 20.10 %.
- The obtained results indicated that we can achieve a promise results. About 19.78 % clean coal yield (3.5 M tons of clean coal) with ash content of 2.61%, ±0.1 specific gravity distribution of 1.16 and ordinate D and washing degree of 18.88 and separation efficiency of 95.47 % at specific gravity of 1.4.
- Characterization of the floated coal at different sizes showed that the combustible matter might mainly be present in the fine particle size, while, ash

(mineral matter) is mainly present in the coal with coarse particle size with some of shale, which cannot be easily removed through float–sink process.

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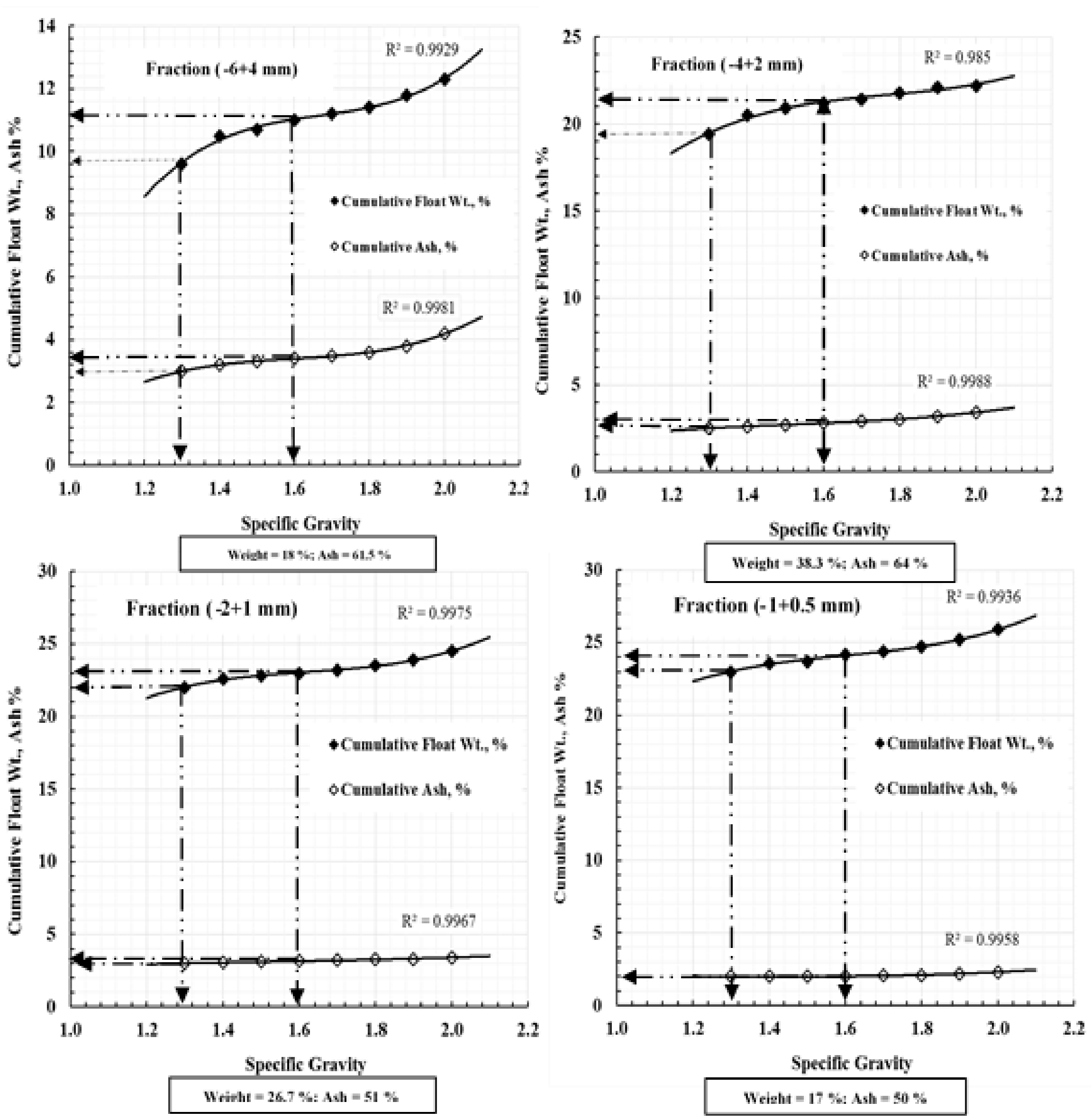
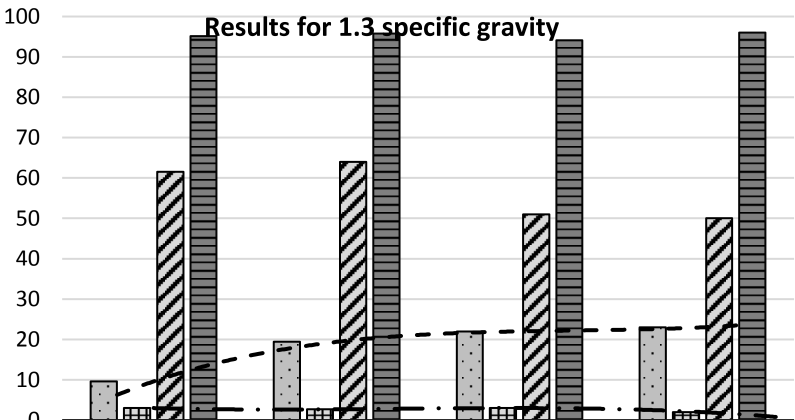


Figure 2 Washability curves of the different size fractions (-6+4mm, -4+2mm, -2+1mm and -1+0.5mm).



	Fraction +4mm	Fraction +2mm	Fraction +1mm	fraction +0.5mm
Clean Coal Yield %	9.6	19.4	22	23
Ash % in clean Coal	3	2.7	3	2
Feed Ash %	61.5	64	51	50
Ash Removal Efficiency	95.12195122	95.78125	94.11764706	96

Figure 3 Separation process results at specific gravity of 1.3 of the four size fractions.

Table 1 Combined washability data calculations methods (Cont.)

Specific gravity	Total Wt. Product	Total Ash Product	Wt. %	Ash %	Ash Product	Cumulative Float Wt. %	Cumulative Float Ash Product	Cumulative Float Ash %	Cumulative Sink Wt.%	Cumulative Sink Ash Product	Cumulative Sink Ash %
1	2	3	4	5	6	7	8	9	10	11	12
1.3	1453	3744	18.94	2.58	48.81	18.94	48.81	2.58	100.00	5766.76	57.67
1.4	64	216	0.83	3.38	2.82	19.78	51.62	2.61	81.06	5717.95	70.54
1.5	25	158	0.33	6.32	2.06	20.10	53.68	2.67	80.22	5715.13	71.24
1,6	21	156	0.27	7.43	2.03	20.38	55.72	2.73	79.90	5713.08	71.50
1.7	16	144	0.21	9.00	1.88	20.58	57.59	2.80	79.62	5711.04	71.72
1.8	25	237	0.33	9.48	3.09	20.91	60.68	2.90	79.42	5709.16	71.89
1.9	30	286	0.39	9.53	3.73	21.30	64.41	3.02	79.09	5706.07	72.15
2	37	361	0.48	9.76	4.71	21.78	69.12	3.17	78.70	5702.35	72.46
+2	6000	437066	78.22	72.84	5697.64	100.00	5766.76	57.67	78.22	5697.64	72.84
Total	7671	442330	100.00	57.66	5766.76	18.94	48.81	2.58	100.00	5766.76	57.67

Table 1: Combined washability data. (Cont.)

Specific gravity	±0.1 Specific gravity distribution	Ordinate, D	Degree of Washing	Efficiency
1	13	14	15	16
1.3		9.47	18.10	95.53
1.4	1.16	19.36	18.88	95.47
1.5	0.60	19.94	19.17	95.37
1,6	0.48	20.29	19.41	95.26
1.7	0.53	20.48	19.59	95.15
1.8	0.72	20.75	19.86	94.97
1.9	0.87	21.11	20.18	94.76
2	-	21.54	20.58	94.50
+2	-	60.89	-	-

Column 1	Specific gravities used for float and sink tests.
Column 2	Summation of clean coal weight for each size fraction at that specific gravity.
Column 3	Summation of clean coal ash for each size fraction at that specific gravity.
Column 4	Column 2 items for each specific gravity divided by the total of column 2.
Column 5	Column 3 divided by column 2.
Column 6	Column 4 times column 5.
Column 7	Cumulative summation of column 4.
Column 8	Cumulative summation of column 6.
Column 9	Column 8 divided by column 7.
Column 10	Cumulative summation of column 4 starting at the bottom and adding up.
Column 11	Cumulative summation of column 6 starting at the bottom and adding up.
Column 12	Column 11 times column 10.
Column 13	Found as follows: (Cumulative float wt. % for gravity 1.5+0.1= 1.6= 20.36); (Cumulative float wt. % for gravity 1.5-0.1=1.4=19.76), then 20.36-19.76=0.60 % ±0.1%.
Column 14	Formula used is A+B/2 = Ordinate D; where A= is the cumulative float wt., % column 7 of material down to gravity being considered and B= the wt. % of material column 4 in gravity fraction. Ordinate D for 1.4-1.5 gravity fraction = 19.78 (A) +0.3(B/2) =19.93.
Column 15	Degree of Washing calculated as follows: N= w (a-b)/a Where: *a* = the ash content of the raw coal (feed). *b* = the ash content of the clean coal at a given density of separation. *w* = the yield of clean coal at a given density of separation.
Column 16	Efficiency calculated as follows: $\eta = \frac{(feed\ ash - float\ ash)}{feed\ ash} \times 100$

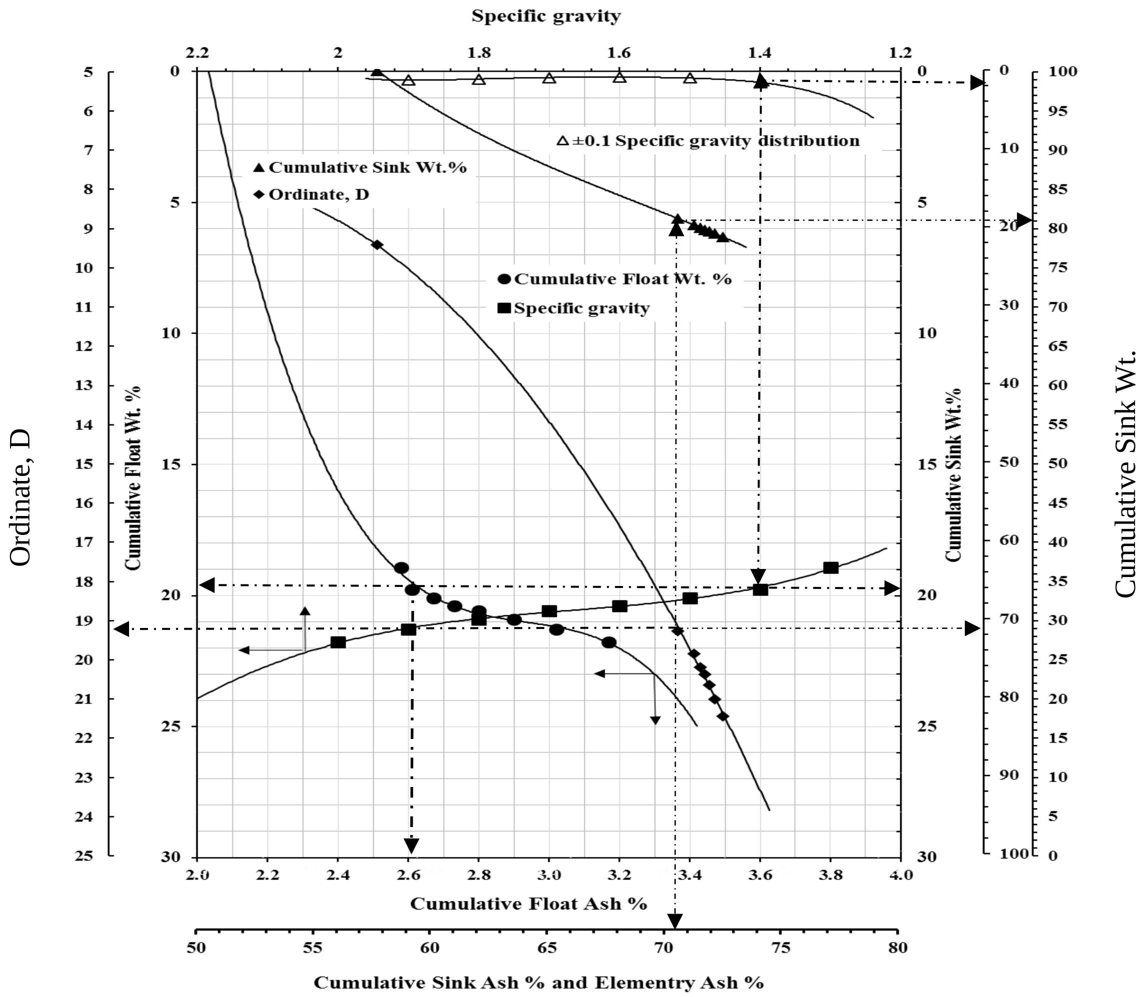


Figure 4 Washability characteristics curve of the reject coal sample.

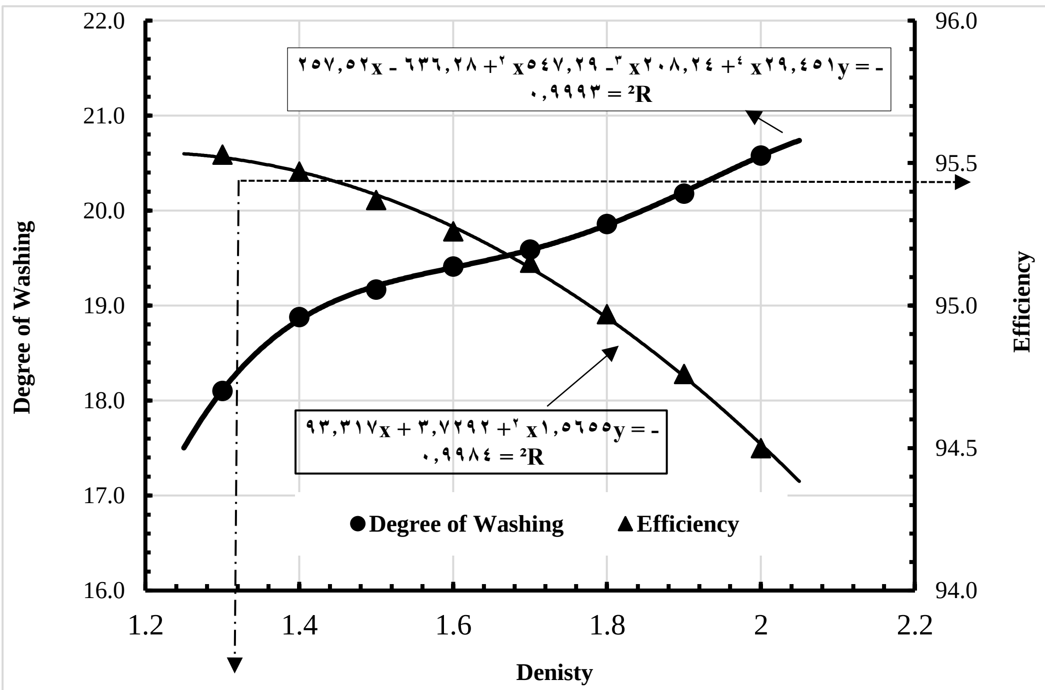


Figure 5 Washing Degree and separation efficiency related to density.