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Short Communication

Beneficiation of Malakand Graphite Ore

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Abstract. On benefication of an indigenous graphite ore of Malakand, Pakistan, on laboratory and pilot plant scale by froth flotation technique, the ore, which initially contained 17% graphitic carbon, was upgraded to a graphite concentrate containing 84% graphitic carbon with more than 70% recovery. The concentrate conforms to the specifications of the foundry grade graphite. Maximum recovery is achieved at pH 7.5 and pulp density of 33% solids with a dose of 0.14 kg/ton sodium silicate, 2.2 kg/ton kerosene oil and 0.02 kg/ton pine oil.

Keywords: froth flotation, graphite, beneficiation, Malakand graphite ore

Natural graphite is a form of carbon, found as crystals of high graphite content or in amorphous form of lower purity. (Brady, 2004: Liu and Yuyan, 2003; Kalyoncu, 2001; Gordon, 1995). Due to its conductivity, high thermal stability and lubricating properties, graphite is used in various industries according to the grade. (Anwar *et al.,* 2006; Kalyoncu, 2001; Gordon, 1995).

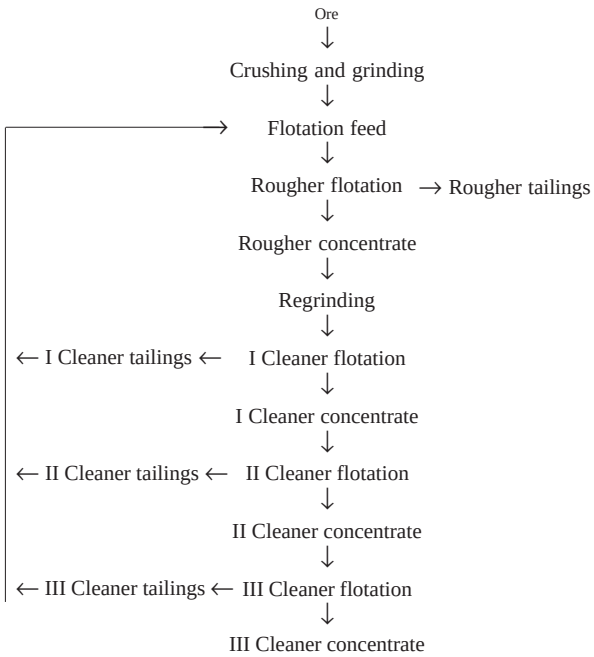
At present, Pakistan imports all its requirements of foundry grade graphite containing 75-85% graphitic carbon (Anwar *et al.,* 2006; Kalyoncu, 2001; Crossley and Peter, 2000; Qureshi *et al.*, 1967). In the Malakand area of North Western Frontier Province (NWFP) of Pakistan, an extensive deposit of low grade graphite ore, containing 10-17% graphitic carbon, has been found which can be exploited on commercial scale.

This paper deals with the beneficiation study of the said graphite deposit using froth floatation technique. Chemical analysis was carried out by conventional gravimetric and volumetric methods. Characteristics of the ore were defined by petrography, X-ray diffraction and ore microscopy. Flotation feeds of the ore were prepared by subjecting the ore to crushing and wet grinding at 1:1 solid/ liquid ratio. Flotation tests were carried out in a Denver D-12 flotation machine. The steps of beneficiation of the ore are given in the flowsheet. Optimum flotation parameters and metallurgical balance are presented in Table 1 and 2.

The grade (graphitic carbon=16.94%) of the ore (Table 3) is sufficient to exploit the ore on commercial scale (Hand, 1997; Hussain *et al.*, 1967). The ore was found as fine grained graphitemica schist. The gangue mostly comprised of clay with hydrated oxides of iron and predominant quantities of silica and mica. The ore contains crystalline graphite (Table 4) so flotation can be considered a proper route for its beneficiation (Kalyoncu, 2001).

The ore can be upgraded up to 38.5% at rougher flotation stage @ 91.56% recovery at a feed size of 84.81%. Regrinding of the rougher concentrate before three cleaning operations and re-circulating the cleaner tailings to the rougher flotation feed ensured a final concentrate grade of 84.05% @ 72.09% recovery.

The grade of the rougher concentrate improves tangibly while the recovery increases slightly as the amount of fine material increases in the flotation pulp. Although the increase in the recovery is not very significant with the decrease in the



Flowsheet: Beneficiation of Malakand graphite ore.

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Table 1. Optimized parameters/conditions of graphite flotation

Roughing	
grind size	84.81% passing 73 µm
rougher pulp density	33% solids
rougher pulp pH	7.5
rougher reagents	
- collector	kerosene oil 2.2 kg/T
- depressant	sodium silicate 0.14 kg/T
- frother	pine oil 0.02 kg/T
conditioning time	3 min
flotation time	10 min
rougher concentrate	C=38.5%; recovery = 91.56%
I Cleaning	
grind size	97% passing 63 µm
pulp density	15%
cleaner reagents	
- collector	kerosene oil 0.01 kg/T
- depressant	sodium silicate 0.015 kg/T
- frother	nil
conditioning time	1 min
flotation time	9 min
I cleaner concentrate	C=51.56%; recovery=82.06%
II Cleaning	
pulp density	10%
cleaner reagents	nil
conditioning time	1 min
flotation time	8 min
II cleaner concentrate	C=68%; recovery=75.86%
III Cleaning	
pulp density	10%
cleaner reagents	nil
conditioning time	1 min
flotation time	9 min
III cleaner concentrate	C=84.05%; recovery=72.09%

particle size, it is quite reasonable at 91.56%. Through grinding for 6 min, 84.81% of the ground material passes 73 µm screen (Table 5); further increase in grind time does not affect the size distribution of ground mill product. The maximum liberation of graphite grains in Malakand ore was found to be 73 µm. Maximum purity was achieved at a pH of 7.5. A neutral pH or a more alkaline pH adversely affects the optimum conditions.

The pulp density variation has a significant effect on the grade and the recovery of graphite. As the pulp density is reduced from 40 to 20% solids, the grade of the concentrate improves

Table 2. Metallurgical balance for graphite flotation

Product	Weight (%)	Grade (%)	Recovery (%)
III Cleaner concentrate	14.40	84.05	72.09
III Cleaner tailings	4.50	14.19	3.77
II Cleaner concentrate	18.90	68.00	75.86
II Cleaner tailings	8.06	13.03	6.20
I Cleaner concentrate	26.96	51.56	82.06
I Cleaner tailings	13.33	12.07	9.50
Rougher concentrate	40.29	38.50	91.56
Rougher tailings	59.71	2.39	8.44
Calculated head sample	100.00	16.94	100.00

Table 3. Chemical analysis of Malakand ore

Constituents	% (w/w)
Graphitic carbon	16.94
Amorphous carbon	3.60
SiO_2	50.81
Fe_2O_3	8.77
Al_2O_3	13.07
CaO	3.38
MgO	0.85
Na_2O	0.18
K_2O	0.83
Others	1.57

Table 4. X-ray diffraction analysis of Malakand ore

Seq	2θ	d	Rel. I	Seq	2θ	d	Rel. I
1.	18.143	4.8865	6.55	4	26.905	3.3118	100.00
2.	21.188	4.1907	5.09	9	45.802	1.9799	6.66
3.	24.298	3.6609	2.39	1	18.143	4.8865	6.55
4.	26.905	3.3118	100.00	2	21.188	4.1907	5.09
5.	36.361	2.4693	2.09	11	54.984	1.6690	3.58
6.	36.870	2.4363	3.52	6	36.870	2.4363	3.52
7.	40.608	2.2203	1.51	10	50.451	1.8078	2.86
8.	42.773	2.1128	1.84	3	24.298	3.6609	2.39
9.	45.802	1.9799	6.66	5	36.361	2.4693	2.09
10.	50.451	1.8078	2.86	12	60.251	1.5351	1.98
11.	54.984	1.6690	3.58	8	42.773	2.1128	1.84
12.	60.251	1.5351	1.98	7	40.608	2.2203	1.51

and *vice versa*. At pulp density of 33% solid, the grade of the rougher concentrate is better than 40% solid, while there is no big difference in the recovery. The better result at 33% solid is due to fine grained nature of Malakand ore while for flaky

Table 5. Size distribution of ground mill product

Size	3-min		6-min		9-min	
(μm)	Passing	Retained	Passing	Retained	Passing	Retained
175	100	-	100	-	100	-
147	98.53	1.47	100	-	100	-
123	94.12	5.88	99.77	0.23	100	-
103	87.72	12.28	97.05	2.95	97.38	2.62
87	80.54	19.46	91.98	8.02	92.25	7.75
73	72.71	27.29	84.81	15.19	84.99	15.01
61	64.94	35.06	76.55	23.45	76.63	23.37
51	57.75	42.25	68.28	31.72	68.31	31.69
30	40.32	59.68	47.46	52.54	47.50	52.50
15	26.23	73.77	30.22	69.78	30.21	69.79
10	19.76	80.24	24.50	75.50	24.43	75.57
05	13.78	86.22	15.92	84.08	15.21	84.79
0.9	2.20	97.80	2.66	97.34	2.29	97.71

ores, low pulp densities are recommended (Parashar *et al.*, 2001; Hand, 1997; Hussain *et al.*, 1967).

An increase in the quantity of collector affects adversely the recovery than the grade. A dose of 2.2 kg/t of kerosene oil followed by the frother (pine oil) dose of 0.02 kg/t gives reasonable grade and recovery. Increase in the dosage of frother lowers the recovery and does not have significant effect on grade. Graphite is naturally hydrophobic. Despite the natural floatability, the separation of gangue is normally improved by the addition of a small amount of kerosene oil and floated with pine oil as the frother (Didolker *et al.*, 2001; Patil *et al.*, 2000; Crossley and Peter, 1999; Wills, 1988). For separation of gangue from ore, mineral sodium silicate was used which efficiently depressed quartz and silicates at the dose of 0.14 kg/t and gave reasonable grade and recovery of graphite.

Conditioning time had a pronounced effect on the grade of concentrate but very little on the recovery of graphite. A conditioning time of 3 min and flotation time of 10 min was sufficient for optimum recovery and grade of the concentrate. It is concluded that indigenous Malakand graphite ore can be beneficiated by froth flotation technique to produce foundry grade graphite concentrate assaying more than 84% graphitic carbon content at a recovery of 70-75%. The concentrate produced was quite suitable for the production of graphite based products.

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