Proceedings of the International Seminar on Mineral Processing Technology - 2006, Chennai, India. pp. 476 - 484.

A Comparative Study on Characterisation and Processing of Iron Ore Slimes

S. Roy and **A. Das**

MNP Division, National Metallurgical Laboratory, Jamshedpur

Abstract

Beneficiation of iron ore slimes has been studied. Three different iron ore slimes from Chitradurga, Jilling and Ukraine have been characterized in detail. The slime samples have been beneficiated with a view to produce a sufficiently enriched concentrate. The Chitradurga iron ore slime contained 49.36% total Fe, 10.2% silica and 7.9% alumina. Jilling sample contained 37.86% total Fe, 19.8% silica and 14.4% alumina while the slime from Ukraine sample had 27.89% Fe, 54.8% silica and 1.8% alumina.

Characterisation indicates that substantial amount of the slime is below 20 μm size. Chemical analysis results show that the iron is concentrated in the +20 μm size in Jilling-Langalota and Chitradurga iron ore slime. However, distribution of iron in Ukraine slime sample is more or less uniform. It was also found that the heavies content within the former two samples decreased with decreasing particle size. However, the heavies were somewhat evenly distributed in all size classes for the Ukraine sample.

Considering the characterisation data, a scheme of exploratory nature for the beneficiation of each sample was chosen. The Chitradurga sample was treated in a hydrocyclone followed by WHIMS. While the Jilling sample was classified in a hydrocyclone and subjected to flowing film concentration in Wilfley Table. The grade of the Chitradurga sample could be improved from 49% Fe to 64% Fe while for the Jilling sample the Fe content could be enriched from 38% to 60%. In the Ukraine sample the iron content could be enriched from 28% to 62.3% in simple two-stage concentration operation.

INTRODUCTION

Indian iron ores are generally quite soft and friable in nature and generate significant amount of fines while mining, processing and handling. Also on crushing and sizing of ores, the high alumina bearing laterite and friable ores have greater propensity to break down into fine sizes as compared to hard ores. These slimes are relatively lower grade and can not be utilized directly in blast furnace. Hence the slimes are either dumped as stocks at the mine or permanently lost due to lack of proper beneficiation facilities. However it is reported in the literature that even -150 micron fraction in the sinter feed can be accepted up to 40%, by microballing of the sinter mix prior to sintering. Therefore to avoid the loss of fines in the form of slime it is very important to upgrade the slime using appropriate technique.

The reduction degradation behavior of the sinter can be improved considerably by lowering its alumina content and increasing the iron content. With the increase in use of sinter in blast furnaces, there exists a need for lowering the alumina content of iron ore slimes and an opportunity for greater utilization of these. Several measures are being taken to bring down alumina in sinters. Earlier efforts made to reduce alumina in the ore primarily focused on flocculation techniques that met with limited success [1-4].

Using wet-high intensity magnetic separators followed by classification in hydrocyclone, Prasad et al. [5] studied the beneficiation of iron ore slime produced from washing plants and tailing ponds of Kiriburu mines. They showed that a concentrate assaying 63% Fe and 3.3% alumina could be produced with an overall iron recovery of 56%.

Pradip. [6] used the multi-gravity separation technique for treating the iron ore slime and for reducing alumina. Das et al. [7] used classification by hydrocyclone followed by high intensity magnetic separator for the separation of Barsua, Bolani and Kiriburu iron ore slimes. Their results show that it is possible to obtained iron concentrate assaying 60-65% Fe and 60-80% recovery.

Srivastava et al. [8] using classification in hydrocyclone followed by spiral for the iron ore slime obtained from washing plants and tailing ponds of Kiriburu mines. The experimental results show that it is possible to raise the iron content to 64.17% at a solid recovery of 37.3% with simultaneous decrease in the alumina content down to 1.17%.

Earlier work indicates that beneficiation of iron ore slime is not difficult, but the beneficiation of iron ore slime containing very low iron content and very high alumina content is difficult. Also it is difficult to know the characteristic properties of the particles where most of the population is below 50 micron. So a detail initial characterization of the particles is required before selecting a suitable beneficiation scheme. The beneficiation techniques should be cost-effective to recover the iron ore from its slime in pilot plant scale.

The impact of chemical and mineralogical characterization plays an important role in beneficiation of iron ore slime. Same beneficiation process is not applicable for all types of iron ore slime as they differ in characteristics and consequently their response to beneficiation. In the present work three different iron ore slimes having different chemical and mineralogical characteristic were taken up for comparative studies of slimes. These slimes had lower iron content compared to those in most of the work reported above.

RAW MATERIAL

Three different iron ore samples of varying characteristics were taken up for investigation. Two Indian iron ore samples were taken up while the third one was from abroad. One of the samples was taken from M/s Essel Mining and Industries Ltd., India from Jilling Langalota area and the second sample was received from M/s. Mineral Enterprises Ltd, Bangalore, i.e. Chitradurga iron ore. The third sample was from Ukraine. The three samples are contrasting in their physical as well as chemical character. The slime was obtained by washing of the bulk ore and wet sieving at 150 micron. The Chitradurga iron ore slime contained 49.36% total Fe, 10.2% silica and 7.9% alumina. Jilling sample contained 37.86% total Fe, 19.8% silica and 14.4% alumina while the slime from Ukraine sample had 27.89% Fe, 54.8% silica and 1.8% alumina.

PARTICLE CHARACTERIZATION

The characterization of the three iron ore slimes consisted of their size analyses, chemical analyses, microscopic examinations and heavy liquid separation. These steps are described in detail in the following sections and corresponding results are presented.

Size Measurements

Particle size measurements of three iron ore slimes have been done using Shimadzu SA-CP3, centrifugal particle size analyzer. In order to collect samples in each size range, sieving of iron ore slime of each sample was carried out using the Vibratory Laboratory Sieve Shaker "analysette3". For separation of -50 μm particles micro-precision sieves were used. Size distribution of the slime samples is presented in Table. 1. It is seen from the size measurement that all three slimes are extremely fine in nature; substantial amount of the slime is below 20 μm. In case of Jilling Langalota sample, the fraction less than 20 microns is 71.22%. In Chitradurga and Ukraine iron ore slimes it is 54.46% and 55.84% respectively.

Table 1: Distribution of Particles in Different Size Fractions

Size in micron	Jilling-Langalota iron ore slime		Chitradurga iron ore slime		Ukraine iron ore slime	
	Wt. %	Cumulative % under size	Wt. %	Cumulative % under size	Wt. %	Cumulative % under size
150	1.64	100	5.35	100	1.16	100
105	4.3	98.36	8.17	94.66	2.8	98.98
75	4.94	94.06	4.18	86.49	2.08	96.04
63	1.78	89.12	3.85	82.31	4.95	93.96
50	16.12	87.34	24	78.46	33.17	89.01
20	10.1	71.22	12.88	54.46	30.02	55.84
10	61.12	61.12	41.54	41.58	25.82	25.82

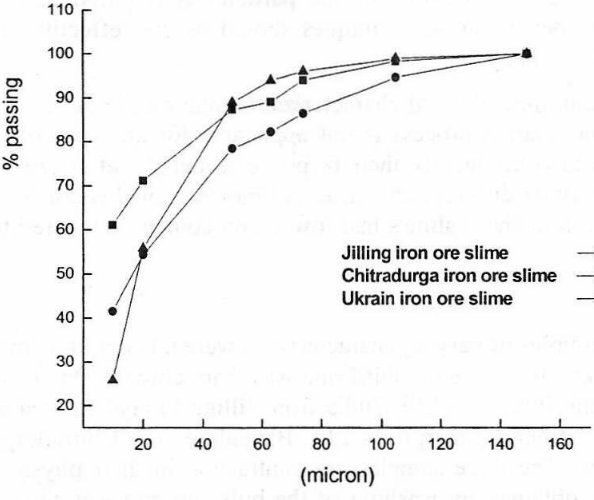

Fig. 1: Graphical Representation of Size Distribution

Table 2: Chemical Analyses of the Three Iron Ore Slimes

	Jilling slime			Chitradurga slime			Ukraine slime		
Size in micron	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	Fe (%)	SiO_2 (%)	Al_2O_3 (%)
149-50	52.44	5.62	11.61	56.78	8.48	6.84	29.02	54.82	1.04
50-20	45.92	14.06	12.50	56.62	9.21	7.61	27.00	54.95	1.42
-20	33.33	21.84	15.12	43.22	11.26	8.45	28.06	54.68	2.27
Composite	37.86	19.08	14.4	49.36	10.19	7.93	27.89	54.83	1.84

Chemical Analysis

Chemical composition of each size fraction is given in table 2. The table shows that +20 μm are richer in Fe content in Jilling Langalota and Chitradurga iron ore slimes. From table 2 it can be calculated that in case of Jilling-Langalota + 20 μm fraction contains 49.07% Fe while + 20 μm fraction of Chitradurga iron ore slime contains 56.70% Fe. Most of the alumina and silica is concentrated in lower sizes. In Ukraine sample, iron is almost equally distributed in all sizes. Silica distribution is uniform at about 54%. Very little alumina is observed in the Ukraine sample.

Microscopic Study

Microscopic examination was taken up with a view to identify mineral phases of the slime samples. This study was done with the +20 µm fraction by taking 8 g representative sample of each iron ore slime. Fraction less than 20 µm was not taken due to difficulty in mounting. Each of these samples was carefully mounted using bakelite powder in Simplimet mounting press. Microscopic examination reveals that in Chitradurga and Jilling iron ore slimes hematite and goethite are the main iron bearing phases. Quartz and clay occur as main gangue phases. Some magnetite grains are found in the Chitradurga iron ore slime. In case of Ukraine iron ore slime hematite and goethite are the main iron bearing phases and quartz is the main gangue phase. Clay was found to be negligible in this sample.

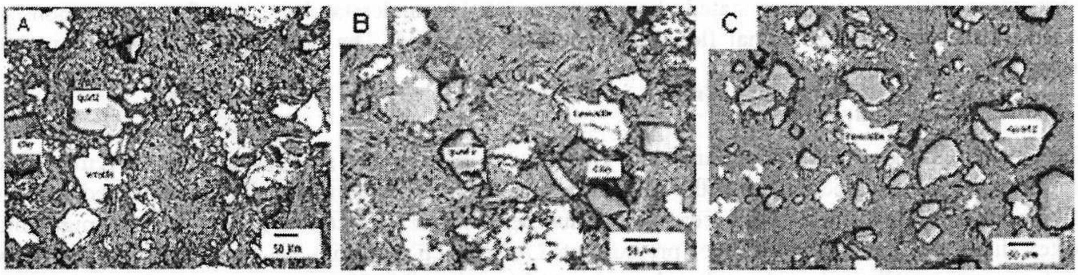

Fig. 2: Photomicrographs of Iron Ore Slimes. (A) Chitradurga Iron Ore Slime, (B) Jilling Iron Ore Slime, (C) Ukraine Iron Ore Slime

Table 3: Heavy Liquid Sink-Float Data

Size in micron	Jilling iron ore slime			Chitradurga iron ore slime			Ukraine iron ore slime		
	wt. %	Sink in wt%	Sink wt% (w.r.t.o.)	wt. %	Sink in wt%	Sink wt% (w.r.t.o.)	wt. %	Sink in wt%	Sink wt% (w.r.t.o.)
-150+105	1.64	82.32	1.35	5.35	91.3	4.88	1.16	58.51	0.68
-105+74	4.3	72.47	3.12	8.17	93.2	7.61	2.8	59.9	1.68
-74+63	4.94	69.64	4.44	4.18	88.26	3.69	2.08	29.43	0.82
-63+50	1.78	63.2	1.13	3.86	87.33	3.36	4.95	26.74	1.32
-50+20	16.12	65.63	10.62	24	92	22.08	33.17	20.37	6.76
-20+10	10.1	62.32	6.32	12.89	92.91	11.97	30.02	26.4	7.93
-10	61.12	62.74	38.34	41.55	86.58	35.96	25.82	26.58	6.86
Total	100		65.32	100		89.55	100		26.05

Heavy Liquid Separation

Characterization was also performed using sink-float studies in heavy liquid to assess the quality of the samples. Pure bromoform (sp. gr. 2.81) was used to quantify the heavy (sp.gr. >2.81) and light (sp.gr. < 2.81) fraction content of the slime samples. The sink float data are presented in the table 3. It may be seen from this table that in Chitradurga slime the percentages of heavies is 89.55% and for Jilling-Langalota sample it is 65.32% while for the Ukraine sample it is 26.05%. Heavies content within the former two samples generally decreased with decreasing particle size. High weight percentage of –10 µm fraction and lowest heavy content of this fraction indicate the presence of high clay and silica in this class. However, the heavies were somewhat evenly distributed in all size classes for the Ukraine sample below 75 microns. Although the heavies content of the +75 micron fraction was much higher (about 60%), the weight percentage of material above 75 micron was negligible (about 4%).

BENEFICITION STUDIES

Detail Characterisation of the three iron ore slimes revealed that in case of Jilling and Chitradurga iron ore slimes most of the alumina and silica is concentrated in the fraction less than 20 μm size. Therefore, it is imperative that a desliming operation to remove the ultrafine fraction would improve the grade. Thus a beneficiation scheme was chosen involving classification followed by tabling or WHIMS. However, since the distribution of Fe and SiO_2 was uniform across the size classes for the Ukraine sample, classification in hydrocyclone for this sample was not undertaken. In the present work, some unit operations as stated above were studied to understand the beneficiation responses. Based on the observation a final flowsheet would be designed. The results of these operations are discussed in the following section.

Classification in Hydrocyclone

The Iron ore slimes from Chitradurga and Jilling were first treated in hydrocyclone to remove the ultrafines. It is always beneficial if the desired mineral is enriched by this technique provided the loss of value in over flow product is acceptable. A number of tests were conducted by varying spigot and vortex diameters, pulp density, inlet pressure etc. After each test both the underflow and overflow fractions were collected and analysed w.r.t. grade and yield. However, test results under best conditions are given in the Table 4. It may be seen from this table that about 50% yield could be obtained for both samples in the U/F. However, Jilling concentrate grade was poorer at about 50% than Chitradurga concentrate, which was about 57%. The flow sheets of Chitradurga and Jilling samples are given in figure 3 and 4 respectively.

Table 4: Hydrocyclone Test Results of Iron Ore Slimes.

Product	Fe (%)	Yield (%)	Test condition
Jilling sample			
Cyclone U/F	49.33	51.05	Spigot: 6.5 mm.
Cyclone O/F	25.92	48.95	Vortex: 15mm.
Feed	37.86	100	Pulp: 10%
			Feed pressure: 20psi
Chitradurga sample			
Cyclone U/F	57.21	49.5	Spigot: 6.5 mm.
Cyclone O/F	41.67	50.5	Vortex: 15mm.
Feed	49.36	100	Pulp: 15%
			Feed pressure: 10psi

Concentration of Chitradurga Sample Using Wet High Intensity Magnetic Separator

The Hydrocyclone underflow of Chitradurga irons ore slime was treated in Wet High Intensity Magnetic Separator (WHIMS). A number of tests were conducted with variable pulp density, current and wash water. Under best condition of Current: 1 Amp, wash water: 20 l/min. and pulp density of 10% solids the concentrate product contained 63.94 % Fe with about 65.7% yields. The test result is given in table 5.

Table 5: WHIMS Test for Hydrocyclone U/F Product of Chitradurga Iron Slime

Product	Fe (%)	Yield (%)	Test condition
Magnetic product	63.94	65.7	Current: 1Amp,
Middling product	46.65	15.1	Wash water: 20 lpm
Non magnetic product	42.43	19.1	Solid: 10%.
Feed (Hydrocyclone U/F)	57.21	100	

Gravity Separation of Jilling Sample using Wilfley Table

To study the efficacy of Tabling for treating slimes, the Hydrocyclone underflow of the Jilling was subjected to concentration in Wilfley Table. A number of tests were conducted by varying pulp density, inclination and speed. After each test, both the concentrate and tailing were collected and analyzed. The best result was obtained with 10% pulp density, 0.25 inch inclination and 280 rpm speed. The test results are presented in table 6 below.

Table 6: Wilfley Table Test Results with Jilling Langalota Iron Ore Slime.

Product	Fe (%)	Yield (%)	Test condition
Concentrate product	60.8	53.0	Pulp density: 10%,
Middling product	39.56	12.3	Inclination: 0.25 inch
Tailing product	35.28	34.7	Speed: 280 rpm.
Feed (Hydrocyclone U/F)	49.33	100	Wash water: 3 lpm.

It may be seen from the above table that about half of the solids could be recovered in the concentrate product. The concentrate grade, however, was not as high as that obtained with Chitradurga sample in WHIMS concentrate product.

Concentration of Ukraine Sample using Wilfley Table Followed by WHIMS

The Ukraine iron ore slime was first treated in Wilfley table. The performance in this stage is given in the following Table.

Table 7: Wilfley Table Test Results with Ukraine Iron Ore Slime.

Product	Fe (%)	Yield (%)	Test condition
Concentrate product	51.54	40.2	Pulp density: 10%
Middling product	12.05	5.8	Inclination: 0.25inch
Tailing product	11.9	54	Speed: 280 rpm.
Feed	27.89	100	Wash water: 3 lpm

It may be seen that a feed with 28% Fe, can be enriched to 52% in one single step. The Table concentrate was further treated in WHIMS and the final concentrate product had 64.7% yield (overall yield 26%) with total Fe content of 62.59%.

DISCUSSION

Detailed particle characterization of three iron ore slimes revealed the following characteristic properties of iron ore slime that is applicable for selecting the processing of the samples.

- From size measurement of the three iron ore slimes it is seen that all three slimes are extremely fine in nature with substantial amount of slime below 20 μm. In case of Jilling Langalota sample the slime fraction less than 20 μm is 71.22%. In Chitradurga and Ukraine iron ore slimes it is 56.46% and 55.84% respectively.

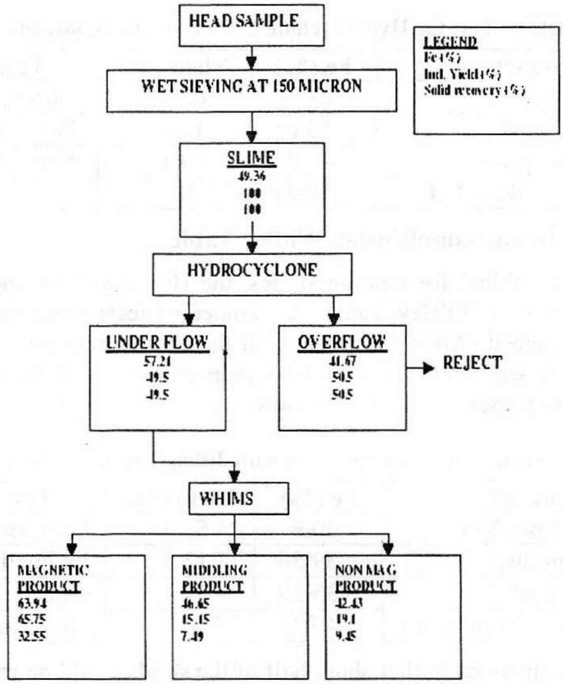

Fig. 3: Flowsheet for Chitradurga Iron Ore Slime Processing

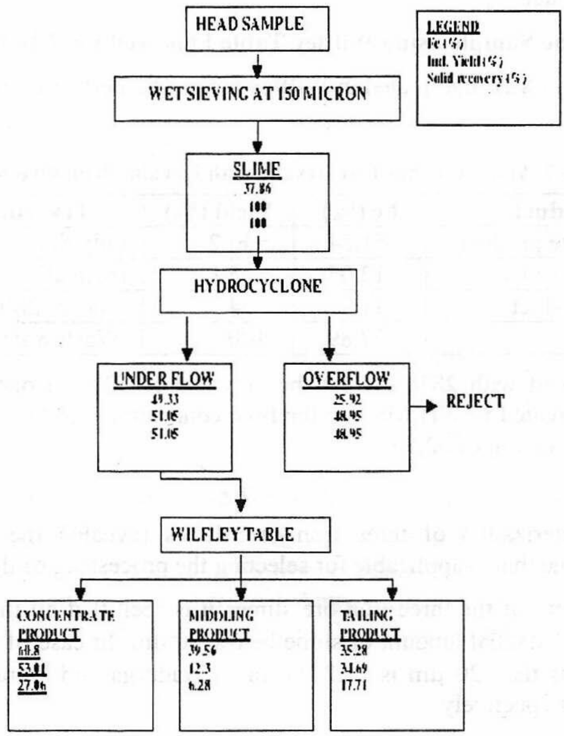

Fig. 4: Flowsheet for Jilling Iron Ore Slime Processing

- Chemical analysis reveals that in the Indian iron ore slimes besides the silica, alumina is also a major impurity. This is mainly concentrated in the finer size range. The alumina content is 15.12% and 8.45% in the -20 μm size in Jilling-Langalota and Chitradurga respectively while it is relatively low in Ukraine iron ore slime at 2.27% in the-20 μm fraction. Most of the iron is concentrated in coarser sizes in Jilling Langalota and Chitradurga iron ore slimes where as in Ukraine slime it is evenly distributed.
- Microscopic examination reveals that hematite and goethite are the main iron bearing phases, however some magnetite is seen in Chitradurga iron ore slime. Quartz and clay are the main gangue phases except in Ukraine iron ore slime where clay is negligible.
- Heavy liquid separation reveals that the percentage of heavies in Chitradurga and Jilling slime is decreasing with decreasing size of particles. Most of the lights concentration is in the lower size range indicating high iron content in higher size and impurities in the lower size. However, the heavies were somewhat evenly distributed in all size classes for the Ukraine sample below 75 microns. Although the heavies content of the +75 micron fraction was higher, the weight percentage of material above 75 micron was negligible (about 4%).

Considering all of the above characterization data a first stage classification by hydrocyclone is imperative for the removal of ultrafines. Classification data of Jilling and Chitradurga iron ore slimes indicate that Fe values can be upgraded to 49% and 57% from 38% and 49% respectively. This shows that good grade of iron concentrate can be obtained in this stage. But to use the concentrate as sinter feed more processing of the Hydrocyclone U/F is required to enrich the iron content. Since the hematite particles are feebly magnetic and gangues are non-magnetic in nature, the impact of a second concentration stage was studied. Wet high intensity magnetic separator (WHIMS) was used for Chitradurga iron ore slime. The WHIMS result indicates that better grade product can be obtained by using wet high intensity magnetic separation. The grade improved substantially. This indicates that classification followed by WHIMS is a feasible route for concentration of this slime. The Jilling iron ore slime was treated by gravity separation technique using Wilfley table to explore its feasibility. It was observed that quality of the slime could be improved significantly. However the concentration grade was about 60% indicating the requirement of further concentration process. Of course, it must be noted that the feed grade of the Jilling sample was much lower at about 38% Fe.

In the Ukraine sample the distribution of iron and silica was uniform. Also, it did not contain any significant amount of clay and was essentially silica and iron oxide. Therefore, gravity separation was tried and the response was good. Single stage tabling resulted in the enrichment of iron from 28% to 52%. The tabling concentrate, when treated in WHIMS, produced a magnetic concentrate with about 63% Fe.

CONCLUSIONS

Three different iron ore slime samples were thoroughly characterized. Characterisation data showed that the three slimes are widely different from each other.

Beneficiation studies indicate that simple two-stage concentration may produce substantial enrichment in the concentrate. A poorer feed grade may require an additional stage of concentration operation.

Classification in hydrocyclone itself enriches the slime substantially. Both WHIMS and Tabling are feasible second stage operations. In simple two-stage concentration operation in all three cases the feed grades of 28%, 38% and 49% Fe could be enriched to 63%, 61% and 64% Fe respectively. Thus, it appears that it is possible to enrich iron ore slimes using relatively simple process flowsheet.

REFERENCES

[1] Das, B., Prakash, S., Mohapatra, B.K., Bhaumik, S.K., Narasimhan, K.S., 1992. Beneficiation of iron ore slimes using hydrocyclone. Min. Met. Pr. 9(2), 101–103.

[2] Gujraj, B., Sharma, J.P., Baldawa, A., Arora, S.C.D., Prasad, N., Biswas, A.K., 1983. Dispersion–flocculation studies on hematite-clay systems. Int. J. Min. Pro. 11, 285–302.
[3] Hanumantha Rao, K., Narasimhan, K.S., 1985. Selective flocculation applied to Barsuan iron ore tailings, Int.J. Miner. Process. 14, pp. 285-67-75.
[4] Mahiuddin, S., Bandopadhyay, S., Baruah, J.N., 1989. A study on the beneficiation of Indian iron ore fines and slime using chemical additives. Int. J. Min. Pro. 11, 285–302.
[5] Prasad, N., Ponomarev, M.A., Mukherjee, S.K., Sengupta, P.K., Roy, P.K., Gupta, S.K., 1988. Introduction of new technologies for beneficiation of Indian hematite ores, reduction of losses and increase in their quality. In: Forssberg, E. (Ed.), XVI International Mineral Processing Congress, pp. 1369–1380.
[6] Pradip, 1994. Beneficiation of alumina-rich Indian iron-ore slimes. Met., Mater. Processes 6 3 , 179–194.
[7] Das, B., Mohapatra, B.K., Reddy P.S.R., Das, S.,1995. Characterisation and Beneficiation of iron ore slimes for Further Processing. Pow. Ha. and Pro. 7, 1, 41-44.
[8] Srivastava, M.P., Pan, S.K., Prasad, N., Mishra, B.K., 2001. Characterization and processing of iron ore fines of Kiriburu deposit of India. Int. jou. of min. pro.61, 93-107.