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BENEFICIATION OF LOW/OFF GRADE IRON ORE: A REVIEW

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ABSTRACT

An attempt has been done to collect information regarding methods apply for the recovery of iron values from various Mechanical & Chemical techniques. The main aim of this review paper to determines the Industrial practice and fundamental research activities for the up gradation of low/ off grade iron ore. Practically mechanical separation and float flotation methods applicable in different composition and size of iron ore with different recovery percentage of Fe. the Iron content in the concentrated ore is obtained with reduction in SiO2 and Al2O3 after beneficiation operation on it. After various beneficiation processes Fe content could be enriched from 38% to 60%.

1. INTRODUCTION

The rapid industrialization in the field of iron & steel industry increases the demand of iron ore. From last two-three decades, consumption of iron ore has increased rapidly. In the metallurgy of iron ore, blast furnace utilize different form of products of iron ore like lumps (which used directly in the furnace) & pellet / sinter which are normally agglomerates of iron ore fines. Both the form of iron ore contain < 2% of Al_2O_3 (alumina). India is one of the countries which have reserves of best quality of iron ores, around 14 Billion tones. These ores contain huge quantity of physical impurities such as clay or other earthy impurities which can be easily removed by physical process and thus, iron content increase simultaneously (Gururaj and Ramchanadran, 1979., Roy choudhury and Dash, 2003) the states which have iron ore mines are Orissa (Barbil, Cuttack, Gua, Joda, Mayurbhanj and Keonjhar) Karnataka (Donamalli, Kudremukh, Pathikonda, Vyasanakere) Jharkhand (Gua , West Singhbhum) Chhattisgarh (Bailadila, Dalli-Rajhera) Maharashtra (Rantnagiri) (Raoand Kumar, 2003., Rajuand Prabhakar, 2003). Indian iron ores are generally quite soft and friable in nature and generates significant amount of fines while mining of ores, physical processing and process of handling. Many literatures, highlights, that mining and physical processing of iron ore, produce large amount of slimes and fines, typically 35% & 25-10% of run of mines. (Sengupta and

Mukherjee 2003) which is a great concern of loss of iron values in tem of economy and it also badly effect the component of the environment.

Due to gradual depletion of high-grade iron ores (65-77 % of Fe) has develop the maximum possibility of utilization of low-grade iron ore. But this required much more economical support. Many literature highlight that upgrading the fines ores utilizing this fraction in the sinter feed up to 40% by micro-balling of the sinter prior to sintering (Shrivastava and Prasad 2001). The simple way of washing with water is not enough process to change Al_2O_3/ Fe and Al_2O_3/ SiO_2 ratio in the concentrate much from the feed. The ratio of Al_2O_3/ SiO_2 in low grade iron is high, which make it not suitable to use in metallurgy operation directly without prior beneficiation. Many literatures also explained that ores with high content of alumina or silica deteriorate the blast furnace and also reduce the its efficiency. Including reduction in productivity of sinter plant. During physical operation like mechanical sizing and normal washing process with water only remove earthy impurities not the impurities chemically bonded with the iron ore such as Al_2O_3, SiO_2, P, S, As, and C or other elements in trace amount. So, in order to increase the productivity of blast furnace, ore required having Al_2O_3/ SiO_2 ratio less than 1. There are many process implemented to enhance the Fe% in their ores (Table 1). Few beneficiation process in discuss in this paper which are popular now a days.

2. METHODS OF BENEFICIATION

The objective in beneficiation of iron ore/ fines/ slimes is to treat mechanically, chemically and other methods. The beneficiation process can be classified into two categories, namely Mechanical Separation & Float Flotation by using surface-active agent or flocculating agent (Figure 1).

Table 1: Beneficiation Methods apply for low grade iron ores & the percentage of Treated ore by each method, (Ryan 1990).

Method of Beneficiation Apply	Treated Iron Ore (in %)
Magnetic Separation	41.6 %
Flotation following Magnetic Separation	51.2 %
Flotation	6.3 %
Gravity Concentration	<1[1] %
Total	100 %

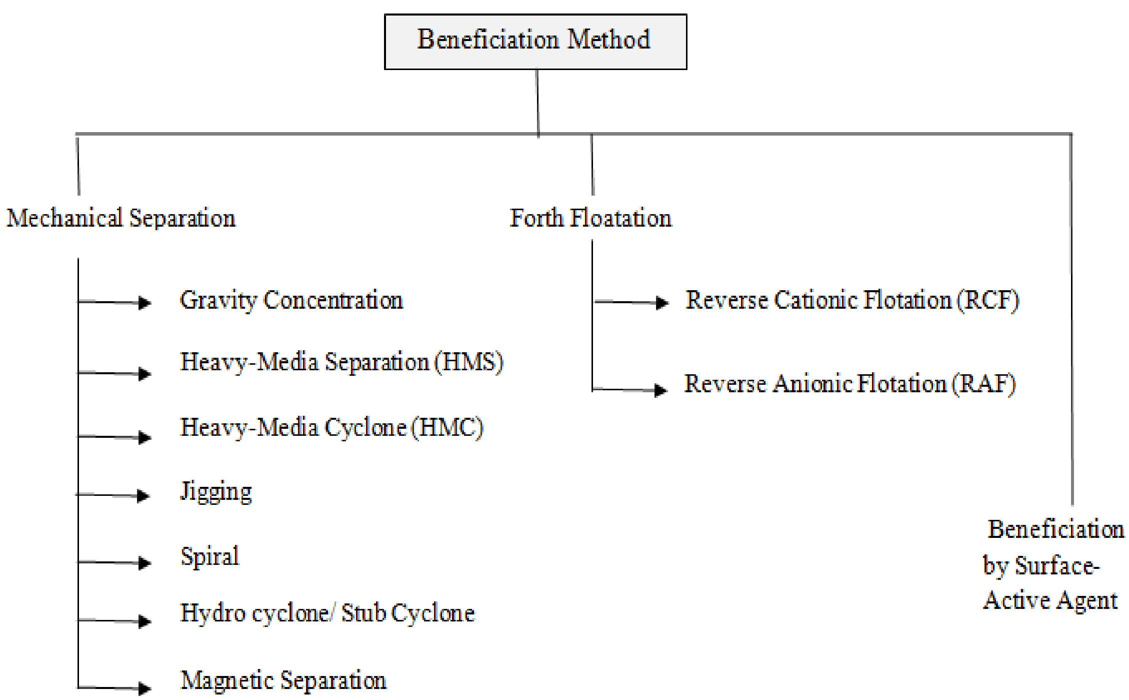

Figure 1: Schematic diagram for different method of beneficiation.

2.1. MECHANICAL SEPARATION

In recent years, lots of developments have been reported in the field of iron ore processing all over the world. The prominence is to develop a method for the beneficiation of low grade/slimes/fines iron ore which should be cost effective. It is also very necessary that beneficiated ore should be suitable for sinter, blast furnace & in pellet making. Few among reported method, found to be effective in the development features in the processing equipment are as:

- Heavy media cyclone (HMC),
- Jigging,
- spiral concentrator with new innovations
- Floatex Density Separator (FDS),
- Hydro-cyclone,
- Stub-cyclone,
- Auto-genus grinding,
- High gradient magnetic Separators (HGMS),
- Fine size screening etc

All are popular for beneficiation of off grade ores.

2.1.1. GRAVITY CONCENTRATION

Gravity concentration or in other word this process is also known as gravity separation. This process is applicable for those ores in which principle metals have higher density as compared to their gangue and other earthy impurities. The specific gravity of iron ore is higher than its gangue. The specific gravity of common iron ores are given with iron percentage in it. (Table 2). The common earthy impurities or gangue attached with iron ores have lower specific gravity like, Calcite/ Limestone (2.70-2.75), Gibbsite (2.67), Clay/Shale (2.65), Quartz & Calcite (2.35). Thus, this technique is very effective for beneficiation of iron ores.

Table 2: Showing specific gravity of common iron ores.

S.No	Name of the ore	Fe%	Specific gravity
1	Hematite Fe_2O_3	70	5.0-5.3
2	Magnetite (Fe_3O_4)	72.4	5.17-5.18
3	Goethite FeO (OH)	62.5	3.96
4	Limonite $2Fe_2O_3.3H_2O$	60	2.7-4.3
5	Siderite $FeCO_3$	48.3	3.85
6	Iron Pyrite FeS_2	46.6	4.9-5.2

The usefulness of gravity concentration most probably depends on appropriate feed preparation which includes, crushing of ores, screening of proper size and grinding to liberate desire size and ensure feed of a correct size to a particular unit operation (machine), removal of slimes, which affects the separation efficiency of the machine, as it increase the viscosity of the pulp and hampers the proper sizing of crude fractions before subsequent treatment.(Fashuiddin,1997.,Vinod and Jadhav 2007., Bajjal 2003., Pradip 2003). Separate minerals based on particle specific gravity differences and are available to treat particles across a wide size ranges from 50 mm to 0.03 mm (30μm).

2.1.2. HEAVY-MEDIA SEPARATION (HMS)

This technique is implemented in the course iron ore having the size range of -50+3 mm. Ferro-silicon suspension is generally used in these separators as dense medium. Rotary drum (spiral & drum-type vessels) is most commonly used. Ferro-silicon ground or atomized (-300mesh) is used as suspension to create a parting density of

3-3.2 that is sufficient to separate common gangue minerals to float. The suspension medium can be easily recovered by low intensity magnetic separator (LIMS) (Majumdar 2008., Sarkar 2008)

2.1.3. HEAVY-MEDIA CYCLONE (HMC)

The method is used for fine ore in the size range of -6+ 0.2 mm. The cyclone type separation utilizes centrifugal as well as gravitational forces to make separation between ore and gangue minerals. The centrifugal force makes it possible to bring about separation at a specific gravity lower than that required in the conventional separator. Ferrosilicon (-3.25 mesh) in water is used as a media in cyclones (Mohan 2001., Venkatesh 2002).

2.1.4. JIGGING

In gravity concentration process, Jigging method is oldest one. This technique is applicable where large fractions of materials are separated into three sections as lighter fraction, medium density fraction & heavy density fraction. Processing is possible for iron at the size of 30mm to 0.5 mm. Batac jig is one of the commercial units available in the markets (5 m x 6.2 m size) with a throughput capacity of 500 tph. This jig is reported to have capability to treat both coarse as well as fine feed. (Rong 1992., Tsunekawa 2001., Das and Prakash 2007., Xia 2007).

2.1.5. SPIRAL

In the spiral technique, the range of feeder material should be of 1mm to 0.03 mm (30μm). Mostly, this method is applicable for pulp density of 25- 30% solids. A single spiral is treat up to 3 tph and several different configurations to take care in feed characteristic variations (Olubanbi 2005., Raghukumar 2012).

2.1.6. HYDROCYCLONE OR STUB CYCLONE

This is obtuse angle short cone cyclone and uses water as a medium to separate particles based on specific gravity, at a coarser size and produce a consistently high density well de-slimed spigot product. Stub cyclone has many advantages over other beneficiation method like this method is economically cheap, very effective process for beneficiation of ore -100 mesh (-150μm) size particles, high capacity on account of very less residence time, have steady parts, establishment space requirement is less, best metallurgical performance, it is environment friendly and low operating cost (Das 1995., Mohanty 2010)

2.1.7. MAGNETIC CONCENTRATION

In India, magnetic concentration is very effective method for the beneficiation of iron ore, nearly 90% of ores are concentrated by this method (Ryan 1991) (Table 1). Approximately 20-35% of all the unit of iron lost their value by magnetic separation, because hematite ore of iron is weakly magnetic response. The Magnetic separation can be processed in both dry as well as wet (using of water) environment, in which although wet condition are more common. This method can be operated under low as well as high intensity. In low intensity, magnetic separators works under the magnetic fields between 1,000 & 3,000 gauss. Magnetite ore is strongly response in magnetic field due to that reason it is concentration by magnetic separation in low intensity environment. This is a low-cost separation method (Prasad and Ponomarer 1988., Pradip 1994). High intensity separators utilize fields as strong as 20,000 gauss. This method is used to concentrate weakly magnetic iron ore, like hematite ore, from non-magnetic or low magnetic gangue materials (Das 1995).

2.2. FROTH FLOTATION

Now a days, for the beneficiation of major iron ore, froth flotation is popular. For effective flotation, the feed should be finer than 65 mesh. Anionic flotation employing fatty acid or petroleum sulfonate collector is adopted to float out most of the iron oxide minerals leaving behind the gangue, minerals (quartz & clay) in the tailings. Crystalline hematite, such as, specularite can be effectively floated. Earthy hematite and limonite do not respond well to flotation and hence is not recovered by this method. Anionic flotation is also resorted to for selective flotation of apatite from iron ore by depressing iron minerals with starch. As a collector, amine is used in cationic flotation for the separation of quartz/silicate minerals from magnetite iron ore (Table 3). Cationic flotation is effective in de-slimed feed and useful only for cleaning of gravity and magnetic concentrate (Pankratov 1970., Gujraj, 1983., Hanumantha 1985., Sengupta 1988., Prabhakar and Rao 2010).

Table 3: Common reagents used for forth flotation of iron ore.

Reagent used for forth flotation	Chemical formula or Composition
Frothers	
Methyl isobutyl Carbinol	Methyl isobutyl Carbinol (IUPAC Name = 4- methyl 2- pentanol)
TX-4733	C4-18 alcohols, aldehydes, and esters; butyric acid; 2- ethylhexane
DP-SC-79-139	Blending of aldehydes, alcohols & esters
Amines used as Collectors	
Arosurf MG 83 A	1,3-propendiamine, N- [3-branched tridecyloxyl propyl] derivatives; acetic acid
MG-580	1,3-propendiamine, N- [3-branched tridecyloxyl propyl] derivatives
Antifoams	
7810	Hydrocarbon used as solvent & Polyglycol esters as solute

2.2.1. REVERSE CATIONIC FLOTATION

In forth flotation method reverse cationic flotation (RCF) is most acceptable operation has adopted by iron & steel industries. Through RCF method, hematite ore is upgraded by 36.4 to 65.4 % of Fe with 82.5 % of recovery. As a collector, fatty acid has been used. It chemically contains 91% of oleic acid & linoleic acid, 6% of rosin acid & 3% of unsaponifiables materials. The quantity of fatty acid used depend on the quantity of feeder (Concentrated iron ore) used. Generally, its weight varies between 0.45 to0.67 kg/tone. (Devaney 1985., Yang 1988).

In direct forth floatation operation, fatty acid adsorbed on the surface of hematite ore. Here, chemisorptions take place between oleic acid/sodium oleate and hematite ore. Another reagent has been also applied in place of fatty acid named Hydroxamtes (Peck et al, 1966., Buckland et al, 1980). It established an oleic acid /Sodium oleate chemisorptions on hematite. This reagent has also given acceptable result in case of goethite & hematite flotation. The same operation was also performed by the using of amines as collector (Bulatovic, 2007) Hydroxamtes, which behave similarly to fatty acid in solution) were used successfully in the laboratory as collector for hematite and goethite flotation. The adsorption mechanism of hydroxmates on hematite iron ore was categorized as classical chemisorptions (Han and Healy 1973). Using of amines only effective when oxides of the adsorbent is negatively charged. Hence it has been that NH_4^+ ion at the oxide-water interface are hold by purely electrostatic force in the stern layers(Raghavan and Fuerstenau 1955., Fuerstenau 1956., Iwasaki et al 1960), as individual countertops behaving almost like an different electrolyte (Somasundaran et al, 1964., Smith et al, 1973.,Vidyahar and Hanumantha 2007).

2.2.2. REVERSE ANIONIC FLOTATION

Several modification in forth floatation was done. Such as experiment on different chemical reagents in order to increase the effectiveness of this method. First time lime was used in place of Quartz as floating reagent and fatty acid as collector. These are many positive aspects have been reported of reverse anionic flotation (RAF) with respect to reverse cationic floatation (RCF). For example RAF has reasonable reagents cost for fatty acid and it is relatively lower sensitivity to the presence of slimes and fines. Generally, fatty acid used in RAF is a waste material of paper industry. According of Zhang (2006) this method upgrade the percentage of iron from 29.3% to 67.5 %, it means that recovery of iron was calculated 82.1%. The beneficiation of iron ore is relatively more effective, when RAF operation applied along with magnetic concentration. Data indicate that it enhance the Fe% value from 29% of Fe to 50 % Fe. The magnetic operation removes the slimes, which beneficiate the iron ore of 65.22% of Fe whereas recovery percentage has been calculated 78.42% (Zhu 1994., Lima and Pierce, 2013).

2.2.3. COLUMN FLOTATION

During 19th century, various industries not used column flotation for the mineral processing. But there was drastic changes happened and around 1990 this method was going to more popular. (Dobby and Finch 1991, 1995., Bouchand and Desbiens 2009). The column flotation cells is the lack of agitation of column floatation which reduces energy and maintenance costs, this is the major operating difference between column flotation cell & & mechanical floatation cells. (Fuerstenau and Somasundaran 2003). The installation charge of a column flotation cell is approximately 25%- 40% less than as the cost of set up of flotation circuit of mechanical floatation cell (Murdock & Tucker 1991). The South America, Sydvaranger mine in Norway and in several Brazilian operations are used column cell for the flotation of iron ores. (Sandvik and Nybo 1991., Dobby 2002., Peres and Araujo 2007).

2.3. BENEFICIATION BY USING SURFACE-ACTIVE AGENT

Recently a novel method has been develop for the beneficiation of iron ore fines & slimes which is techno-economically cheap and using eco-friendly surface-active agent (s). The common synthetic chemicals are used for beneficiation of iron ore listed in Table 4. The surface-active agents used in forth flotation may be either simple or complex compound, adsorb onto the surface of hematite resulting in flocculation of the surfaces of hematite particles and dispersion of gangue minerals which mostly contain Al_2O_3 (alumina). The key role of surface-active agent to form surface complex with the metal oxide over the surface of the ore (Subramanian et al., 1989., Yost and Anderson 1992., Gue et al, 1995., Au et al, 1999., Guan et al, 2006., Das and Mahiuddin 2007).

Table 4: List of few surface-active agents reported effective for beneficiation.

S. No	Surface-active agent	Reference
1	Charged and uncharged polyacrylamide	Moudgil, 1982., Bagster 1984, 1985., Jin and Hu 1987
2	Starch	Lien, 1978., Zulet aand Gutierrez, 1984., Subramanian and Nataraj 1991., Biber and Stumm 1994., Weissenborn 1994
3	Humate	Mahiuddin 1989., Dutta 1991
4	Inorganic or Organic additives	Gururaj and Prasad 1979., Gururaj and Sharma 1983

3. CONCLUSION

The beneficiation of iron ore by popular method has been reviewed in this paper. The ore beneficiation has been broadly classified in two categories dealing with mechanical separation & froth flotation method. Gravity separation, Hydro cyclone, magnetic separation, jigging & spiral have been discussed under mechanical methods. Float flotation is considered to be a conventional method which deals with cationic & anionic float flotation with chemical reagents based on organic compounds used for the beneficiation. Recently surface-active reagent also used in beneficiation process. During the formation forth, a stable dispersed phase produced by the active agents in the aqueous slurry of iron fines & slimes. With the removal of gangue & earthy impurities, the concentration of iron value increases. Mostly Kanolinite & Goethite are gangue mineral have been appeared in dispersed phase.

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CONFLICT OF INTEREST

The author have declared that no competing interests exist.

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