DEVELOPMENT OF PROCESS FOR BENEFICIATION OF LOW-GRADE IRON ORE SAMPLES FROM ORISSA, INDIA

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ABSTRACT

The paper deals with the results of characterisation and beneficiations studies undertaken on two low-grade Indian iron ore samples (IO-1 and IO-2) with a view to develop process for beneficiation of composite of the two samples to a high-grade concentrate, suitable for iron making through pelletisation. Indian iron ores contain relatively high iron but cost effective reduction of alumina within the specified limits has been a challenging task. Characterisation of the samples revealed the ore to be laminated and fine grained with hematite as the major mineral. Clay is the dominating gangue in most of the ore pieces followed by silica. Occasionally goethite and quartz/jasper were recorded. Clay occurs either as patches within the hematite mass or as cavity/fracture fillings. Liberation studies on the representative samples crushed to 2 mm indicated that around 95 per cent of the grains are liberated below 105 micron.

Beneficiation of the two individual samples and their composite based on gravity and magnetic separation techniques resulted in products with varying yield and grade of the products. The effects of various process parameters were studied. Granulometry of the feed was observed to be important for improving quality of concentrate. The results of bench-scale studies were validated through pilot-scale continuous trials. Based on the studies undertaken a suitable process was developed for beneficiation of the composite sample, comprising 60 per cent IO-1 and 40 per cent IO-2, to a high-grade product assaying over 65 per cent Fe and material balance was computed. A commercial plant for beneficiation of low-grade iron ore to produce DRI pellet grade concentrate is proposed to be installed.

Keywords: iron ore, high alumina, characterisation, gravity and magnetic separation, process flow-sheet

INTRODUCTION

India is one of the leading producers of iron ores in the world and it can meet the growing demand of iron and steel industry in the country and also sustain considerable foreign trade. As per the National Steel Policy, India will be producing 110 million tonnes of steel by 2019-20. This would require about 190 million tonnes of iron ore for domestic steel production in addition to meeting the demand on foreign trade (Anonymous, 2007). Though the Indian hematitic ore used for iron making, is rich in iron but it contains high alumina which is not favourable for efficient operation of blast furnace. High alumina results in high viscosity of blast furnace slag. As a consequence, problems connected with blast furnace permeability are frequently encountered. This impairs the upward flow of reducing gases and decreases reduction kinetics of iron oxide. Viscous slag is also not conducive to efficient desulfurising. High alumina has adverse effects on sinter properties and blast furnace coke rate. For the efficient operation of blast furnace, the alumina:silica ratio in iron ore should be <1.0 and alumina should be <2 per cent (Singh and Mehrotra, 2007). Presently most of the Indian iron ore mines are operated by selective mining for maintaining a high-grade of iron ore (Fe >60 per cent). With the availability of high-grade ores and the economic reasons, a simple washing scheme has

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been industrially adopted for beneficiation of Indian hematitic ores. The present scheme of iron ore beneficiation broadly comprises crushing ore to the required size followed by scrubbing and/or wet screening and classification to produce washed lumps (typically -40+10 mm), fines (-10+0.15 mm) and slimes (particles below 0.15 mm). Washing helps in removal of adhering clay and silica to produce free flowing lumps and sand but alumina content is not significantly lowered. The scheme was developed for processing of high-grade ores with comparatively liberal product's quality norms and targeted for utilisation of lumps and high-grade fines only. But it has limitations in processing of low-grade iron ores. In particular it can not handle huge quantity of low-grade ores and fines available from earlier workings (Singh *et al*, 2004).

Finely disseminated low-grade iron ores with siliceous impurities have been upgraded by gravity, magnetic and flotation based processes (Burt, 1994; Svoboda, 1987; Houot, 1983). The processing of low-grade Indian hematitic ore containing high level of alumina bearing minerals as the impurities have difficult separation characteristics and poses special problem in achieving high-grade concentrate (Pradip, 1994; Singh and Mehrotra, 2007). Hematitic ore basically consists of varying amounts of hematite, goethite, martite and magnetite in association with quartz and clay as the gangue forming minerals. Alumina is mainly contributed by clay (kaolinite, montmorillonite, illite, alunite), lateritic material and gibbsite and some alumina occurs as solid solution in iron oxide minerals viz., goethite and limonite. Silica is mainly contributed by quartz and the associated clay. Finely disseminated alumina bearing minerals (kaolinite, gibbsite) show preferential association with iron oxide minerals. One of the most important aspects in the beneficiation of Indian hematitic ores is their complex nature from the standpoint of elimination of alumina. The general mode of occurrence of aluminous minerals in the ore is as coating on lumps, as cavity fillings or as lateritic material. Laterites containing over eight per cent alumina exists as a constituent phase with iron oxide. Quartz occurs as bands with hematite in banded hematite quartzite (BHQ) and banded hematite jasper (BHJ) as inclusions, adherent and vug fillings. By washing, alumina present as clay-like material as well as fine silica can be partially removed but a significant portion of impurities remain locked with iron oxide minerals and not affected by washing. Comminution to fine size and elaborate beneficiation is considered necessary to effectively remove the impurities and beneficiate low-grade ores for iron making. Considering the increasing future demand of quality iron ores, limitations of the current beneficiation scheme and the conservation of iron ore resources, there is need to develop and adopt suitable technology for beneficiation of Indian low-grade hematitic ores. The present paper deals with the results of characterisation and beneficiations studies carried on the two low-grade iron ore samples (IO-1 and IO-2) with a view to develop process for their beneficiation to a high-grade concentrate (65 per cent Fe). Effort is made on developing simple and economically viable technological process for commercial exploitation of the ore.

EXPERIMENTAL

Iron ore samples

The two iron ore samples namely, IO-1 and IO-2 assaying 58.29 per cent and 61.26 per cent Fe with alumina contents of 5.60 per cent and 4.56 per cent respectively and their combination (60:40) were used for the present study. The samples IO-1 and IO-2 contained 6.73 per cent and 4.63 per cent silica respectively. The samples consisted of lumps of varying sizes to ultrafines. The d_{80} of the two samples IO-1 and IO-2 were 5 mm and 4 mm with top sizes of ~40 mm and 8 mm respectively. The mineralogical and liberation characteristics of the samples are discussed in the subsequent sections.

Methods

Mineralogical characterisation of the iron ore samples were carried out by megascopic, microscopic and X-ray diffraction techniques. For optical microscopic studies polished sections were prepared and studied under a Leitz/Leica orthoplan universal research microscope. Liberation characteristics of the samples were determined using a Leitz/Leica zoom stereomicroscope.

Bench-scale beneficiation studies involving gravity and magnetic separation methods were undertaken on the two iron ore samples and were extended to their composite. For assessing the results of beneficiation studies products were analysed for iron content while the end product was assayed for iron, alumina and silica contents by wet chemical method. Pilot-scale trials on the composite sample, comprising 60 per cent IO-1 and 40 per cent IO-2 were carried out in pilot plant

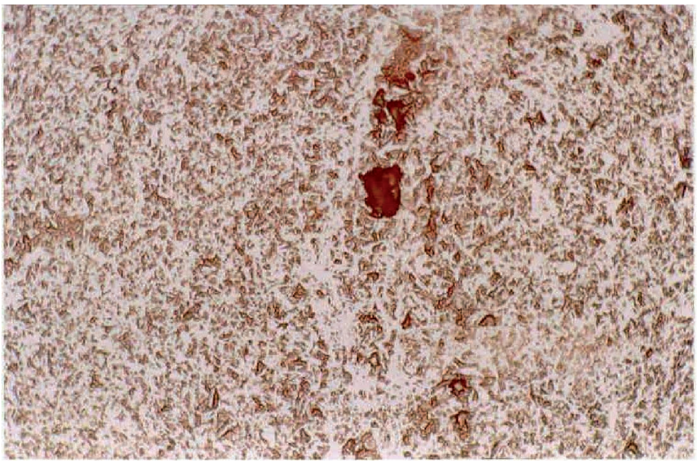

FIG 1 - Optical photomicrograph of massive type ore showing acicular crystals of specular hematite. The small cavity towards the centre is partially filled with clay. Plane polarised reflected light X 200.

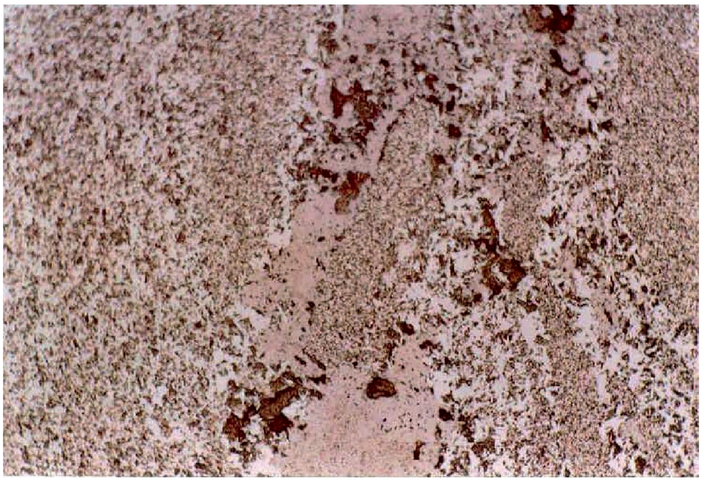

FIG 2 - Patches of goethite that are developed within hematite matrix. The dark-brown smaller patches are clays. Note the intimate association of the three phases. Plane polarised reflected light X 200.

of National Metallurgical Laboratory (NML). The samples IO-1 and IO-2 are to be treated in the proposed beneficiation plant in the ratio of 60:40.

RESULTS AND DISCUSSION

Mineralogical and liberation characteristics of the samples

In hand specimens the ore pieces appeared to be of slightly inferior grade due to relics of jaspery-laminations, lateritic impurities, limonitisation or fine clay impregnations. The colour was generally reddish brown. Under optical microscope, the ore was observed to be laminated and fine grained with hematite as the major mineral. Clay was the dominating gangue in most of the ore pieces followed by silica. Occasionally goethite and quartz/jasper were recorded. Clay occurred either as patches within the hematite mass or as cavity/fracture fillings. Figures 1 and 2 show typical microstructural features of the samples. The results of microscopic studies were corroborated with X-ray diffraction studies.

Liberation studies on the representative samples crushed to 2 mm indicated that around 65 per cent of the grains were liberated below 300 micron. There was significant improvement in liberation in subsequent size fractions and around 95 per cent of the grains were liberated below 105 micron. The liberation trends for the two samples are shown in Figure 3.

Beneficiation studies

Considering the mineralogical, liberation and chemical characteristics of the samples basically the beneficiation techniques such as scrubbing and washing, desliming, gravity and magnetic separation were studied for enriching iron content of the samples. Initially laboratory studies were undertaken

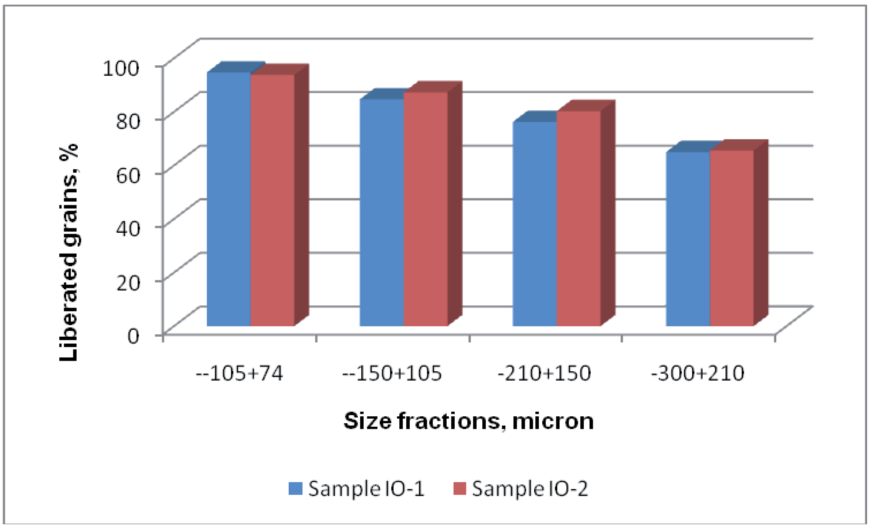

FIG 3 - Liberation of iron bearing and gangue minerals with decreasing particle size.

on individual samples IO-1 and IO-2 and subsequently extended to composite sample, consisting of 60 per cent of IO-1 and 40 per cent of IO-2. The salient results are discussed below.

Scrubbing, washing and classification

Initial efforts were directed towards preconcentration of ore and preparing feed for subsequent concentration by gravity and magnetic methods. In particular, in view of the presence of clay as the major impurities and taking liberation size of iron oxide minerals and gangues into consideration studies were undertaken for two stage removal of fine grained clay particles and enriching iron content by scrubbing, washing and classification/desliming. For this purpose in the first step, as received ore sample was subjected to scrubbing with water using laboratory scrubber followed by washing and classification at 0.15 mm screen. The coarse fraction was further subjected to grinding to passing 150 micron (about 84 per cent liberation, Figure 3) and desliming using laboratory hydrocyclone (50 mm diameter). It was observed that due to removal of adhering clay and fine silica, washing and classification/desliming led to improvement in iron content of the coarse fraction by 3.91 per cent and 3.23 per cent for samples IO-1 and IO-2 but there was substantial loss of iron with yields of washed ore to be 68 per cent and 72 per cent respectively. Considering the high loss of iron in two stages of washing, direct comminution followed by desliming of the ground product was considered. Desliming of the ground ore was carried out under varying conditions of process parameters. The typical hydrocycloning results on the ore samples ground to passing 0.15 mm is presented in Table 1. It is evident that by dropping scrubbing, washing and classification a reasonably high iron distribution in the cyclone underflow is possible. However, second stage hydrocycloning (using cyclone of lower diameter) of overflow product of the first cyclone is expected to further reduce iron loss.

TABLE 1

Results of hydrocycloning of ore samples ground to 0.15 mm.

Products	Sample IO-1			Sample IO-2		
	Weight %	Assay, %Fe	Distribution, %Fe	Weight %	Assay, %Fe	Distribution, %Fe
Cyclone underflow	83.6	59.70	85.9	83.0	62.56	84.6
Cyclone overflow	16.4	50.14	14.1	17.0	55.33	15.4

Gravity concentration

Gravity concentration of the samples were carried out with varying particle size of the feed. For this purpose the ore was ground to different granulometry, deslimed using hydrocyclone and subjected to gravity concentration using wilfley shaking table. Salient beneficiation results with sample IO-1 are shown in Figure 4. As it can be seen from the results, due to better liberation with a decrease in particle size of feed from 300 micron to 200 micron, there is improvement in concentrate grade

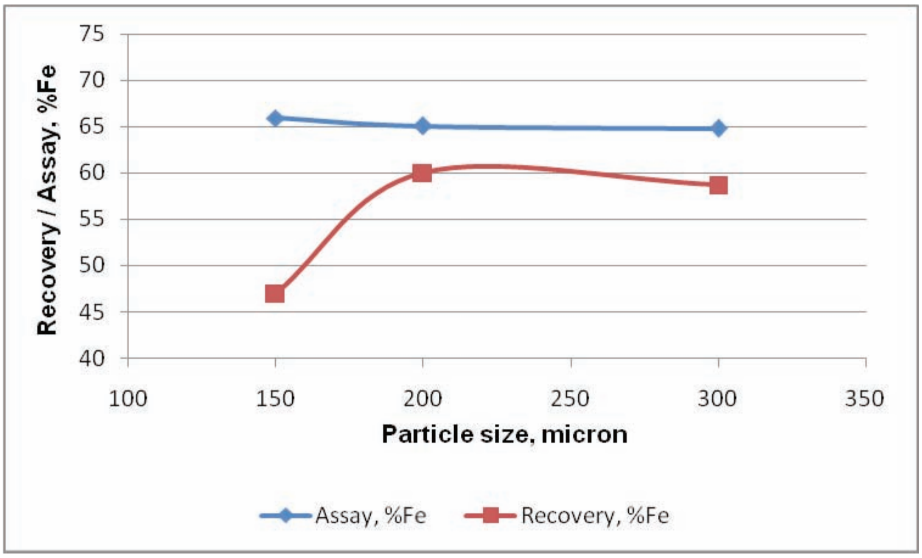

FIG 4 - Results of gravity concentration of iron ore sample IO-1 with varying granulometry.

from 64.81 to 65.08 as well as iron recovery from 58.7 to 60.0. A further increase in fineness of feed to 150 micron, though improves iron content of the concentrate to 65.94 per cent but with a loss in recovery. The sharp lowering in iron recovery was mainly due to limitation of shaking table in handling fine particles resulting in increased iron loss as slimes.

Magnetic separation

Hematite was observed to be the major iron bearing mineral with the iron ore samples. Considering paramagnetic nature of hematite, studies were undertaken for its recovery by wet high-intensity magnetic separation (WHIMS). Typical results showing the effects of magnetic field intensity on recovery of iron for sample IO-1 with a feed consisting of particles below 200 micron are shown in Figure 5. As it can be observed that magnetic field intensity plays an important role in iron recovery. An increase in field intensity from 8500 Gauss to 13500 Gauss improved recovery from 72.9 per cent to 89.1 per cent with a lowering in iron content of the product from 64.21 per cent to 63.12 per cent. Use of feed with 150 micron resulted in improvement in concentrate grade to 65.35 per cent Fe with stage iron recovery of 76 per cent. This was attributed to enhancement in liberation of with decrease in particle size. Magnetic separation studies were further extended to recover iron values from middlings and slimes resulted from gravity based techniques.

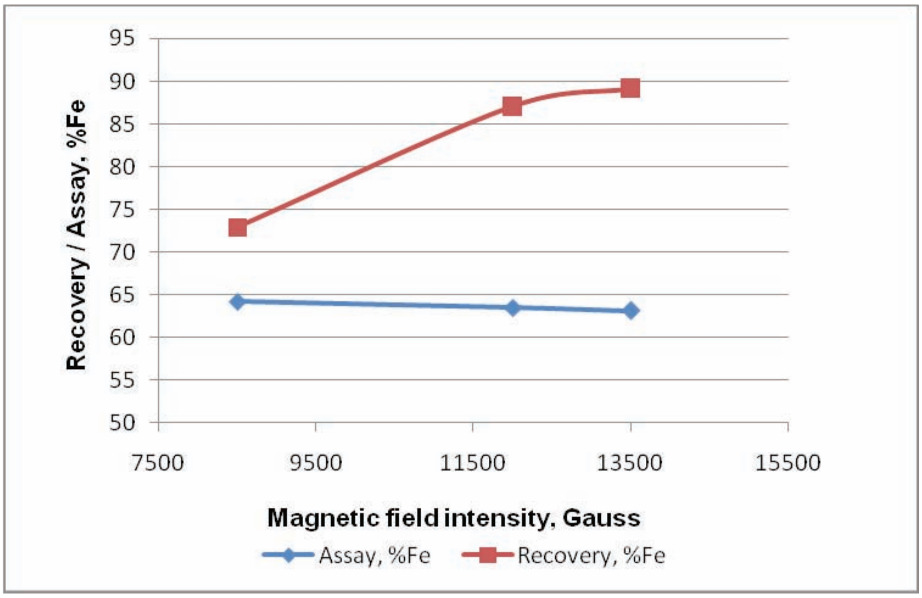

FIG 5 - Effect of magnetic field intensity on concentration Sample IO-1.

Pilot-scale studies and development of technological process flow-sheet

The laboratory studies undertaken on the individual and composite iron ore samples helped in developing basic process routes for beneficiation of low-grade iron ore samples which were validated through pilot-scale trials conducted on the composite sample (Singh *et al*, 2006). Based on the studies undertaken beneficiation process was designed and material balance was computed. The beneficiation process is schematically shown in Figure 6. It may be noted that two stages of hydrocycloning have been adopted to improve iron recovery. Further considering the large scale operation, spiraling has been used for gravity concentration of the ore as against wilfley shaking table. The process basically involves two stages of crushing to -6.32 mm, closed circuit grinding to 0.15 mm, classification using hydrocyclone (100 mm diameter), spiralling of cyclone underflow, further desliming of cyclone overflow from 100 mm diameter cyclone using 25.4 mm diameter cyclone, wet high intensity magnetic separation of middlings and tailings from spiralling operation alonwith underflow from 25.4 mm cyclone followed by dewatering of the products. The final iron concentrate analysed 65.44 per cent Fe, 1.98 per cent Al_2O_3 and 2.23 per cent SiO_2 with iron recovery of 65 per cent.

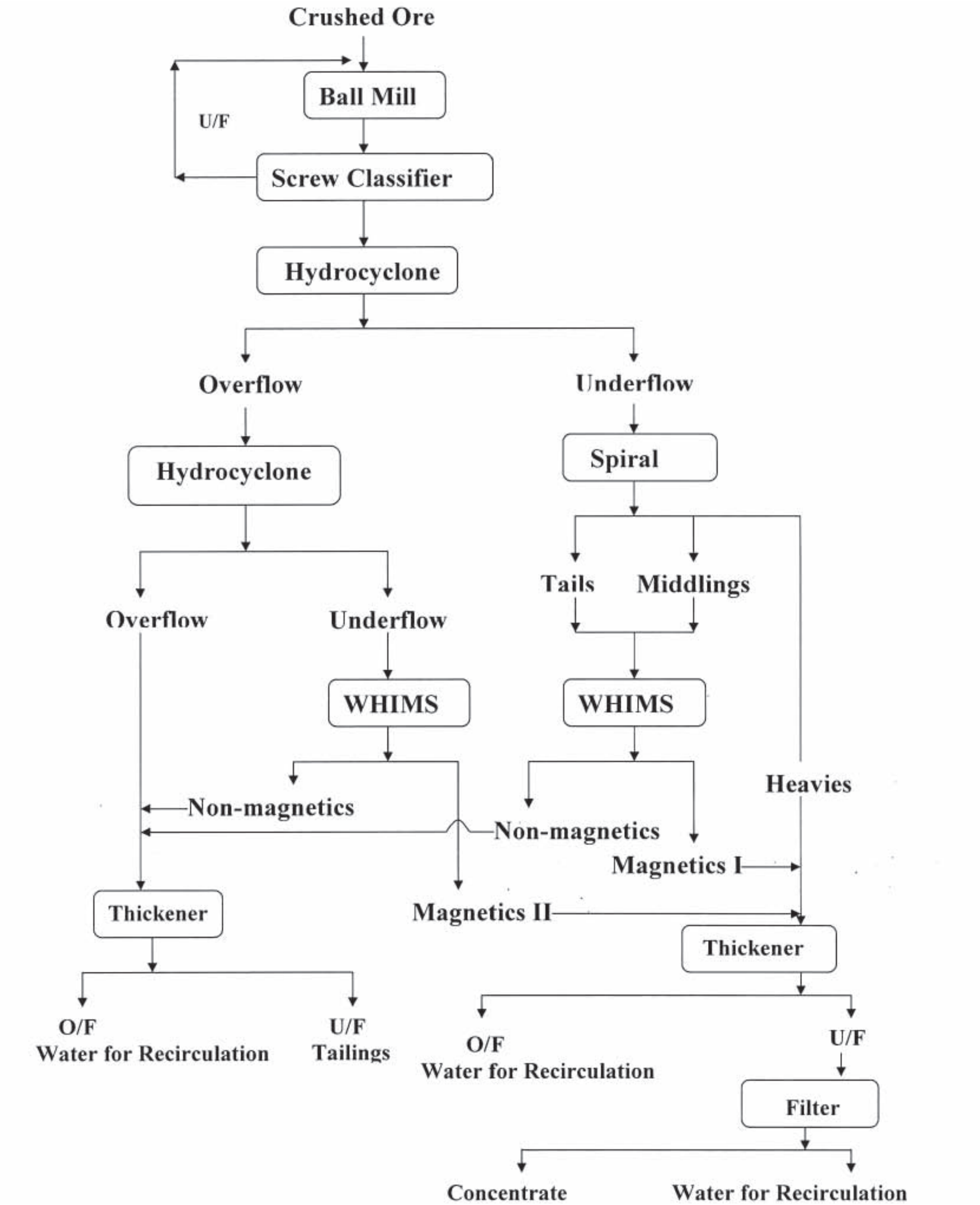

FIG 6 - Schematic representation of process for beneficiation of composite iron ore sample.

CONCLUSIONS

Characterisation and beneficiation studies were undertaken on low-grade iron ore samples. The samples were found to contain hematite as the major mineral with clay as the dominating gangue. The ore was found to be fine grained with about 84 per cent liberation below 150 micron. Beneficiation of the samples based on gravity and magnetic separation techniques resulted in products with varying iron recovery and grade of the concentrate. Laboratory results were validated through pilot-scale trials. The final iron ore concentrate assayed 65.54 per cent Fe with 65 per cent iron recovery. Based on these studies beneficiation process was developed and material balance was computed.

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