

# Studies on beneficiation of ferruginous manganese ores using solid reductants

\* S. Rafiuddin      \* J. P. Srivastava      and      \*\* N. Chakravorty

## INTRODUCTION :

A manganese ore sample from TISCO, Joda West analysing 37.5% Mn, 13.6% Fe, 3.4% SiO<sub>2</sub> and 7% Al<sub>2</sub>O<sub>3</sub> was studied for its amenability to beneficiation by reduction roasting followed by magnetic separation. It contained pyrolusite, cryptomelane, manganite and psilomelane as manganese minerals associated with goethite, limonite and quartz. Manganese minerals were liberated at a size below -48 mesh.

## Magnetic Reduction Roasting :

Magnetising reduction roasting employing gaseous or solid reductant below 570°C converts iron oxide minerals into magnetite facilitating magnetic separation at low intensity giving a non-magnetic manganese concentrate with high Mn/Fe ratio suitable for ferromanganese production. Earlier studies (1,2) on bench scale applying magnetising reduction roast technique using coke oven gas on ferruginous manganese ores of lean and medium grade followed by magnetic separation gave a satisfactory yield of non-magnetic manganese concentrate. The present sample when subjected to similar treatment yielded a non-magnetic concentrate analysing 51.59% Mn with Mn/Fe ratio 8.7 and a recovery of 75.5% Mn.

## Tests using non-coking coal :

Keeping non-availability of coke oven gas at the mine site in view, reduction roasting with non coking coal was considered a suitable alternative. The technical feasibility of the same

was studied in bench scale tests as detailed below.

A few blank tests were also conducted heating manganese ore and coal separately at the same temperature for various lengths of time. The average loss on heating (LOH) of coal and ore was deducted from the loss on reduction (LOR) from reduction tests for 1:1 ore and coal ratio. The difference of LOR-LOH gives the extent of reduction and has bearing on recovery.

## Blank and reduction tests :

100 g. each of -6 mesh manganese ore and -10 mesh non coking coal were tested separately by heating them at  $560 \pm 20^\circ\text{C}$  for 2 to 2½ hrs in a tubular furnace, cooled and weighed. The loss in weight was recorded as LOH.

Reduction tests were conducted using 100 g. -10 mesh non-coking coal and 100 g. -6 mesh manganese ore by heating them mixed together in a tubular furnace at  $560 \pm 20^\circ\text{C}$  for 2 to 2½ hrs and the LOR recorded.

## Magnetising reduction roasting :

The representative ROM sample crushed to -8 mm and mixed with a non-coking coal of relatively finer size in 1:1 ratio by weight which was charged into a static horizontal tubular furnace electrically heated externally and maintained at a temperature of 570°C for 1½, 2 and 2½ hrs respectively. The material was allowed to cool after the test by sealing both ends of the tube. After cooling, the contents were removed and loss on reduction (LOR) was noted.

---

\* Scientists and

\*\* Head, Ore-dressing Division

National Metallurgical Laboratory, Jamshedpur-831 007.

The product was crushed to —48 mesh for further processing by following three routes.

**1) Wet magnetic separation by Davis tube :**

The above product of —48 mesh size was subjected to wet magnetic separation in Davis tube at two different intensities viz., 0.6 and 1.3 amp (1900 and 4000 gauss) respectively. The magnetic product obtained showed the enrichment and separation of iron minerals.

The non-magnetic manganese concentrate was further enriched by a) sink and float tests, b) isodynamic separation.

a) Sink and float tests :

A portion of the non-magnetic fraction containing manganese,  $\text{SiO}_2 + \text{Al}_2\text{O}_3$  gangue, unburnt coal and ash were subjected to H. M. separation using bromoform (SG 2.9) to separate heavier fractions of manganese. The results are shown in the table No. 1. It was observed that test with a shorter reduction time of  $1\frac{1}{2}$  hrs gave a relatively superior sink product of manganese concentrate analysing 46.2% Mn and 4.48% Fe with a recovery of 61.6% Mn in it. The product however contained 12.8% LOI, indicating presence of combustibles still present.

b) Isodynamic separation :

Another portion of non-magnetic fraction was separated in Frantz Isodynamic (magnetic) separator at 0.2 and 0.5 amp field intensity respectively. Neither magnetic nor non-magnetic fraction appeared to be of acceptable grade.

**2) Flotation followed by magnetic separation :**

The reduced ore was ground to —65 mesh and coal particles floated using pine oil and kerosene oil for 2 min in Fagergren cell. The tailing was separated in Davis tube at about 1800 gauss to give magnetic and non-magnetic products. The non-magnetic manganese

concentrate analysed 34—35% Mn, 3.08% Fe, 19.14% loss on ignition (LOI) with 64.8% Mn recovery indicating the presence of associated unburnt coal.

**3) Heavy liquid separation followed by magnetic separation :**

Heavy liquid separation of a reduced ore sample ( $2\frac{1}{2}$  hrs with LOR 15%) was carried out at —48 mesh using bromoform to remove coal. The sink product was separated by a hand magnet into magnetic and non-magnetic products. The non-magnetic manganese concentrate assayed 55.22% Mn, 2.24% Fe with 28.45% Mn recovery in it.

From the above results, it may be concluded that out of all techniques employed, gravity separation followed by magnetic separation gave satisfactory manganese concentrate analysing 46.2% Mn (53% Mn LOI-free basis) 4.48% Fe, 12.8% LOI and 61.6% Mn recovery. The results can be compared with those carried out using coke oven gas on the same ore sample which after magnetic separation of —48 mesh sample gave a manganese concentrate assaying 51.59% Mn, 5.93% Fe and with 75.5% Mn recovery.

The tests have shown that with the ferruginous manganese ores using solid reductant, it is possible to produce manganese concentrate with acceptable Mn : Fe ratio suitable for ferromanganese production. Further work on this line is planned to be carried out including scale-up studies for obtaining the necessary data and confirming the process for large scale commercial production.

**Summary and conclusions :**

A ferruginous manganese ore analysing 37.5% Mn, 13.6% Fe, 3.4%  $\text{SiO}_2$  and 7%  $\text{Al}_2\text{O}_3$  was studied to explore suitability of direct reduction for magnetising reduction roasting to produce a manganese concentrate of commercial grade. The ore contained pyrolusite and other manganese minerals associated with goethite, limonite and quartz. It was subjected to reduction roast test in a horizontal tubular furnace

using ore and non-coking coal in 1 : 1 ratio at a temperature of  $560 \pm 20^\circ\text{C}$  for different lengths of time. The cooled, reduced material was ground to -48 mesh and iron was separated as magnetic in Davis tube at 0.6 and 1.3 amp (1900 & 400 gauss) respectively. Manganese concentrate from the non-magnetic fraction containing gangue, ash and unburnt coal was separated by 1) Davis tube followed by sink and float or isodynamic separator, 2) coal flotation followed by Davis tube separator 3) heavy liquid separation followed by magnetic separation.

The route (1) stated above established the superiority of technique over the others. The non-magnetic fraction of the reduced ore ground to -48 mesh gave a sink product assaying 46.2% Mn and 4.48% Fe with a manganese recovery of 61.6%. The product containing coal has 12.8% LOI. These results with solid reductant can be compared with those obtained under gaseous reduction conditions on the same

sample when it yielded a non-magnetic manganese concentrate assaying 51.59% Mn, 5.93% Fe with 75.5% Mn recovery after magnetic separation in Davis tube.

The investigation indicated the feasibility of the use of non-coking coal as reductant for magnetising reduction roasting of ferruginous manganese ores.

#### **Acknowledgement :**

The authors thank Prof. V. A. Altekar, Director, National Metallurgical Laboratory, Jamshedpur for his guidance in the work and permission to present the paper.

Their thanks are also due to S/Shri Peravadhanulu and B. Banerjee for petrological studies on the sample and to the staff of Chemistry Division for chemical and XRF analysis.

**Table—1 Results of magnetising reduction roast test for 1½ hrs using non-coking coal with subsequent sink and float separation (SG 2.9)**

Product	Wt %	LOI	Assay %		Dist %		Mn/Fe
			Mn	Fe	Mn	Fe	
Mag (D. T. 0.6)	24.08	—	31.62	30.8	24.05	71.60	
Mag (D. T. 1.3)	6.88	2.68	45.37	11.76	9.85	7.83	
Sink	42.21	12.80	46.20	4.48	61.60	18.30	9.63
Float	12.83	49.80	11.00	1.68	4.50	2.11	
LOR	14.00	—	—	—	—	—	
Head (Calc)	100.00	—	31.64	10.33	100.00	99.84	

**Table—2. Summary of the test results**

(a) With solid reductant (non-coking coal)

(b) With gaseous reduction (coke oven gas)

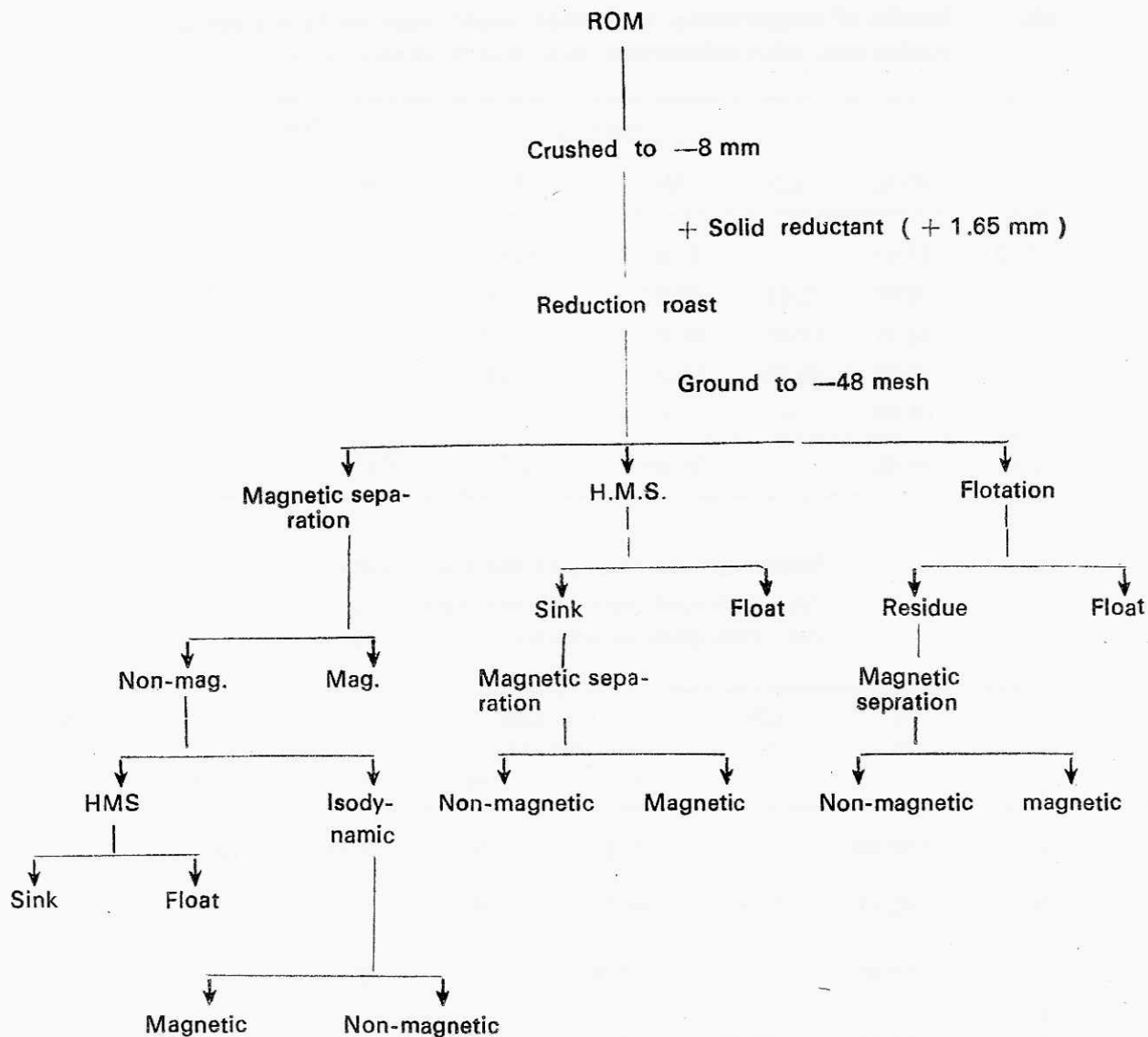
(a)

Product	Wt %	LOI %	Mn. Conc		Dist %		Mn/Fe
			Assay %		Mn	Fe	
			Mn	Fe			
ROM ore	100.00	—	37.5	13.6	100.00	100.00	2.76
Sink and float 1½ hr.	42.21	12.8	46.2	4.48	61.6	18.3	9.63
Sink and float 2 hr.	22.63	—	50.05	5.04	55.2	14.7	9.93
Sink and float 2½ hr.	15.12	22.72	53.25	7.84	43.53	13.96	6.79
Isodynamic 1½ hr.	22.53	29.52	28.6	2.8	30.78	6.57	10.21
Isodynamic 2 hr.	33.36	—	29.7	3.92	48.58	16.54	7.58
Isodynamic 2½ hr.	51.95	29.64	26.95	4.48	65.20	25.44	6.02
Flotation + M. Sepn.	36.40	19.14	34.35	3.08	64.80	15.10	11.15
HMS + M. Sepn.	10.60	4.43	55.22	2.24	28.45	2.70	24.65

(b)

Non-magnetic Mn concentrate	54.50	—	51.59	5.93	75.50	23.30	8.70
-----------------------------	-------	---	-------	------	-------	-------	------

## Flowsheet of tests conducted



### References :

1) Bench scale beneficiation studies on three manganese ore samples from M/s. TISCO Ltd., (IR. No. 1060/80, June 1980) by S.N. Prasad, S. Rafiuddin, N. Chakravorty & G. P. Mathur.

2) Beneficiation studies on two large tonnage ferruginous manganese ore lump and fine samples from Joda West Manganese Mines of M/s TISCO Ltd., (IR. No. 1114/82, May 1982) by P. N. Pathak, S. Sivaiah, S. Rafiuddin & N. Chakravorty.