

ENRICHMENT OF THE MANGANESE CONTENT BY WET HIGH INTENSITY MAGNETIC SEPARATION FROM CHIKLA MANGANESE ORE, INDIA

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Manganese ores from Chikla region, Bhandara district, Maharashtra, India, by and large are low and medium grade types and need beneficiation to utilise them in ferromanganese industry. Isodynamic separation followed by chemical characterisation of ores from this region indicated their susceptibility to Mn enrichment. Details of characterisation, heavy media and magnetic separation studies carried out on a medium grade manganese ore, containing 44% Mn, 7.8% Fe and 22% acid insolubles, from the Chikla region are presented. By processing the material on a wet high intensity magnetic separator, a product with 51% Mn at 95% recovery could be obtained.

Keywords: Manganese ore; Mn/Fe ratio; Ferromanganese; Magnetic separation

INTRODUCTION

The estimated *in-situ* reserves of the manganese ores in India are of the order of 370 million tonnes, with recoverable reserves of about 177 million tonnes [1]. The grades suitable for various industries and the total manganese ore reserves are given in Table I. The domestic consumption pattern of manganese ore during 1990–1993 is given in Table II. The major manganese ore consumption is by ferroalloys and iron and steel industries in the country. Out of the 24 ferromanganese units in the country, 10 units are in the organised sector and the rest

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TABLE I Reserves of manganese ore

Grade	Recoverable reserves, in '000 tonnes (as on 1.4.1990)			
	Proved	Probable	Possible	Total
All India total	28,567	41,794	106,116	176,477
Battery/chemical	1,387	782	827	2,996
Ferromanganese	9,706	5,953	5,722	21,381
Medium	7,528	5,056	9,923	22,507
BF	7,895	16,951	33,237	58,083
Ferromanganese and medium, mixed	47	1,174	3,582	4,803
Medium and BF mixed	627	2,860	2,186	5,673
Ferromanganese, medium and BF mixed	56	618	1,780	2,454
Ferromanganese and BF	787	1,707	8,633	11,127
Others	15	12	—	27
Unclassified	471	6,082	37,351	43,904
Not known	48	598	2,876	3,522

TABLE II Manganese ore domestic consumption pattern

Industry	1990-91 Tonnes	1991-92 Tonnes	1992-93 Tonnes
Alloy steel	200	100	100
Battery	25,100	26,400	24,200
Chemical	2,800	2,600	2,700
Ferro alloys	616,200	670,600	641,200
Iron and Steel	572,500	605,300	663,200
Lead-zinc smelters	2,700	2,600	2,600
Others (e.g., ceramics, foundry, glass & paint industries)	100	100	200

14 units are in small scale sector with total capacity of about 0.488 million tonnes per year [2]. The location, capacity and the grade of manganese ore being used in the 10 units of the organised sector [3] is given in Table III.

The manganese ore requirement for the iron and steel industry is assessed at 1.065 million tonnes, based on the envisaged hot metal production target of 21.3 million tonnes by nine major pig iron plants. The blast furnaces of the steel plants in India consume manganese ore with 25-30% Mn, 5-25% SiO₂, 5-8% Al₂O₃, 14-26% Fe and 0.074-0.34% P and do not face any serious problem due to availability of adequate ore meeting the above specification.

TABLE III Ferromanganese plants in the country and the composition of the manganese ores being used

<i>Plant location</i>	<i>Installed capacity, tonnes</i>	<i>%Mn</i>	<i>%Fe</i>	<i>%SiO₂</i>	<i>%Al₂O₃</i>	<i>%P</i>
1. Ferro alloys corporation, Garividi, Andhra Pradesh	45,000	40-48	8	8	—	0.16
2. Khandelwal ferro alloys corporation, Kanhan, Maharashtra	30,000	40-48	9	7	3	0.14
3. Tata steel, Joda, Orissa	30,000	46	10	10*		0.12
4. Universal ferro and allied chemicals, Tumsar, Maharashtra	85,000	40-48	7.5	9		0.15
5. Maharashtra electrosmelt ltd., Chandrapur, Maharashtra	1,00,000	39-48	6.5-15	5-10	3.5-5	0.05-0.07
6. Jaypore sugar co. ltd., Rayagada, Orissa	24,000	46-48	8	9		0.15
7. Dandeli steel and ferro alloys ltd., Dandeli, Karnataka	12,000	40-48	10-12	8	5	0.10
8. Visvesvaraya iron and steel ltd., Bhadravati, Karnataka	1,800	42-47	13	5	—	0.10
9. Nava bharat ferro alloys ltd., Paloncha, Andhra Pradesh	15,000					
10. Sandur manganese and iron ores ltd., Sandur, Karnataka	36,000					
11. Total installed capacities of small plants (14 units)	109,500					
Grand total	488,300					

* SiO₂ + Al₂O₃

However, based on the average norm of 12 kg of ferromanganese/tonne of the steel requirement, the demand for ferromanganese in steel production during 1996–97 is about 289,000 tonnes. Applying the average norm of requirement of 2.6 tonnes of manganese ore per tonne of ferromanganese the demand for high grade manganese ore is estimated at 752,000 tonnes.

The ferromanganese industry requires a manganese ore with somewhat stringent specifications demanding higher Mn, Mn/Fe ratio, lower SiO₂, Al₂O₃ and P contents. The specifications of the manganese ore (IS: 4763-1982) for the manufacture of ferromanganese are 38–48% Mn, 7–15% Fe, 2.5–7 Mn/Fe ratio, 7.5–13% SiO₂ and 2–6% Al₂O₃ and less than 0.15% P. Due to the limitation of availability of such a grade of the manganese ore, currently the ores with 38% Mn are being used by blending with manganese ores of 44% to 48% Mn. Unfortunately the total estimated recoverable reserves of the ferromanganese grade ore are only 21 million tonnes out of which only 10 million tonnes are in the proved category. With the projected demand of 0.75 million tonnes of ore per year, the reserves may last around 15 years. An immediate need of augmenting the ferromanganese grade ore reserves through exploration and upgradation of the low and medium grade ores by application of suitable beneficiation techniques thus arises.

Manganese ores of different types are distributed mostly in the states of Karnataka, Orissa, Andhra Pradesh and Maharashtra. Of these, potential deposits of primary gondite types are extensively exposed in Madhya Pradesh–Maharashtra region. Several open cast and underground mines have been opened up by Manganese Ore India Ltd. (MOIL) to exploit manganese ores from many of these deposits.

This paper deals with the characterisation and beneficiation of manganese ores from Chikla deposit, of Maharashtra (Fig. 1). The manganese formation of Chikla belongs to the Sausar group of rocks of Archaean age. In-depth mineralogical, petrological, genesis etc. are reported elsewhere on the ore bodies of Chikla [4,5,6]. The paper describes the chemical characteristics of low and medium grade manganese ores drawn from Chikla and the beneficiation studies carried out on a medium grade ore sample at the instance of MOIL.

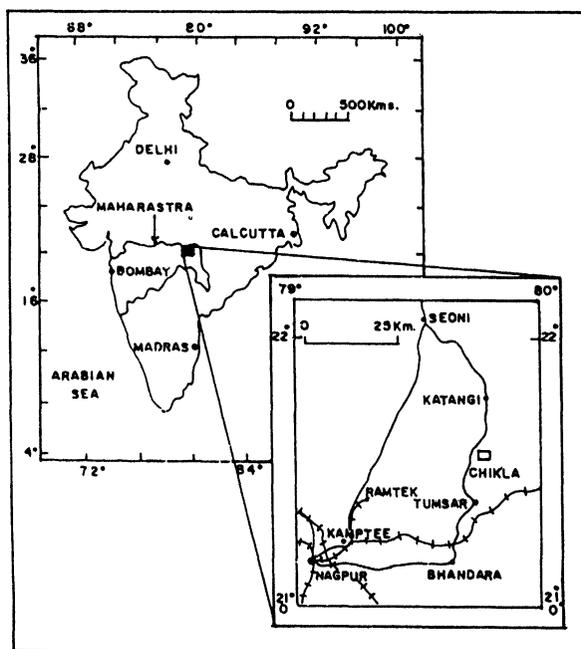


FIGURE 1 Location map of Chikla, Maharashtra.

CHARACTERISATION STUDIES

The manganese ore samples in bulk quantities were collected from various levels of the Chikla mine. The mineralogical investigations were carried out with optical microscope (Leitz-ortho plane), X-ray diffraction (Philips diffractometer) and scanning electron microscopy (Jeol, JSM 35 CF with WDS attachment). The samples were classified into various sieve fractions and each fraction was subjected to magnetic separation using isodynamic magnetic separator (with 20° side tilt, 30° forward slope and with the current of 0.8 A). All the magnetic products of various size fractions were analysed with the help of XRF (Philips, for Mn, Fe, Si, As, P, S, Ti, Ba, Mg) and flame photometer (systronics model K-111, for Na, K, and Ca) to determine the metal distribution pattern. The details are reported elsewhere [7]. However, the metal

TABLE IV Results of isodynamic separator studies on low and medium grade manganese ores of Chiklia

Size, μm	MnO_2	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	TiO_2	LOI	P_2O_5	BaO	K_2O	Na_2O	S	Total
Major and minor metal distribution of bulk and classified fractions of low grade manganese ROM from Chiklia (IVa)														
Bulk	43.07	6.47	33.99	0.78	11.11	0.14	0.04	2.47	0.42	0.15	0.21	0.19	0.31	99.35
+1000	44.58	8.95	33.97	0.95	8.59	0.10	0.04	1.54	0.40	0.19	0.20	0.16	0.17	99.65
-1000 + 500	43.14	7.01	34.69	0.77	10.67	0.15	0.04	1.82	0.42	0.15	0.21	0.18	0.25	99.5
-500 + 250	42.85	6.65	34.20	0.65	11.81	0.13	0.04	1.94	0.42	0.14	0.22	0.19	0.30	99.54
-250 + 125	41.07	5.81	34.33	0.62	13.31	0.14	0.04	2.70	0.42	0.15	0.20	0.19	0.37	99.34
-125 + 63	43.16	5.30	33.77	0.69	11.33	0.16	0.04	3.23	0.41	0.13	0.17	0.19	0.44	99.01
-63	43.16	5.10	32.95	1.05	11.43	0.16	0.05	3.56	0.46	0.13	0.27	0.22	0.34	99.33
Major and minor metal distribution in the magnetic fraction of the classified fractions of low grade ore														
Bulk	43.07	6.47	33.99	0.78	11.11	0.14	0.04	2.47	0.42	0.15	0.21	0.19	0.31	99.35
+1000	59.8	9.27	13.34	1.70	10.93	0.11	0.05	3.40	0.46	0.18	0.07	0.11	0.26	99.74
-1000 + 500	59.26	8.51	13.14	1.53	11.77	0.10	0.05	3.90	0.47	0.20	0.07	0.10	0.32	99.48
-500 + 250	61.53	8.67	12.71	1.56	10.69	0.14	0.05	3.20	0.47	0.20	0.15	0.14	0.32	99.84
-250 + 125	63.49	9.11	10.29	1.69	10.79	0.11	0.05	2.46	0.45	0.19	0.08	0.11	0.30	99.15
-125 + 63	68.90	9.58	7.96	1.33	8.47	0.09	0.06	1.99	0.47	0.14	0.07	0.09	0.17	99.34

Major and minor metal distribution in various size fractions of medium grade ROM manganese from Chikla (IVb)														
Bulk	61.21	12.51	19.68	0.59	3.17	0.42	0.05	1.17	0.46	0.15	0.14	0.16	0.08	99.80
+1000	63.20	12.80	18.56	0.41	2.66	0.40	0.06	0.18	0.46	0.16	0.11	0.14	0.06	99.20
-1000+500	63.13	12.75	18.95	0.51	2.78	0.40	0.05	0.22	0.44	0.16	0.13	0.14	0.06	99.72
-500+250	61.22	12.60	19.90	0.55	2.97	0.39	0.05	1.31	0.41	0.16	0.14	0.16	0.07	99.93
-250+125	59.21	12.55	20.28	0.62	3.62	0.41	0.05	1.51	0.47	0.16	0.14	0.16	0.10	99.28
-125+63	60.35	12.25	20.12	0.70	4.12	0.39	0.04	1.82	0.49	0.15	0.14	0.17	0.14	100
-63	60.11	12.05	20.25	0.77	2.91	0.39	0.06	1.96	0.51	0.12	0.17	0.19	0.17	99.66
Major and minor metal distribution of the magnetic fraction of the classified fractions of medium grade ore														
Bulk	61.21	12.51	19.68	0.59	3.17	0.42	0.05	1.17	0.46	0.15	0.14	0.16	0.08	99.80
+1000	73.17	16.65	5.56	0.49	2.67	0.05	0.04	0.87	0.49	0.13	0.24	0.16	0.87	99.08
-1000+500	73.27	15.19	5.78	0.57	2.86	0.05	0.04	0.23	0.47	0.14	0.26	0.16	0.23	100
-500+250	72.64	16.79	5.75	0.56	2.91	0.05	0.05	1.18	0.50	0.14	0.16	0.16	1.18	100
-250+125	71.41	16.97	5.87	0.52	2.61	0.06	0.05	0.84	0.51	0.14	0.15	0.15	0.84	99.32
-125+63	72.76	16.83	5.11	0.56	2.31	0.05	0.06	1.13	0.53	0.16	0.16	0.15	1.13	99.32

TABLE V Weight, Mn and Fe distribution in various size fractions of the roll crushed material

Size, μm	%Wt	%Mn	%Fe	Distribution, %	
				Mn	Fe
+2000	47.8	45	7.8	48.2	48.3
-2000 + 1000	21.8	45.6	7.8	22.4	22.1
-1000 + 420	11.5	45.6	7.2	11.8	10.7
-420 + 210	4.0	41.7	7.2	3.75	3.74
-210 + 105	5.4	40.0	8.4	4.86	5.90
-105	9.7	41.0	7.3	8.95	9.10
Head (calc)	100	44.4	7.69	100	100

distribution pattern in low and medium grade ores are shown in Table IV.

Subsequent to these investigations, another medium grade manganese sample from the Chikla region was received from MOIL to study its amenability to beneficiation. The ore was jaw and roll crushed (at 3 mm rolls gap) and a representative sample was drawn for wet sieving, heavy medium and magnetic separation studies. The weight and the Mn and Fe distribution in various size fractions of the roll crushed material are given in Table V.

HEAVY MEDIA STUDIES

Various size fractions of the roll crushed material were subjected to sink and float test using an organic liquid, tetrabromoethane of specific gravity 2.96. The heavy and light fractions were collected after washing them thoroughly with acetone and water. All the heavies and light fractions were weighed (Table VI) but not analysed for Mn and Fe, since only 6% of the material resulted as the overall light fraction.

MAGNETIC SEPARATION STUDIES

Wet Low Intensity Separation

The roll crushed manganese ore was ground to below 100 μm size and the ground ore was treated on SALA wet low intensity drum magnetic

TABLE VI Distribution of heavies and lights in various sieve fractions

Size, μm	% <i>Wt</i>	% <i>Lights (float)</i>	% <i>Heavies (sink)</i>
+ 2000	47.6	3.74	96.26
-2000 + 1000	21.8	4.38	95.6
-1000 + 420	11.5	6.90	93.1
-420 + 210	4.00	12.5	87.5
-210 + 105	5.40	21.6	78.4
-105	9.70	11.0	89.0

Note: Overall lights fraction is 6.24% in this roll crushed material.

TABLE VII Results of magnetic studies on SALA low intensity wet magnetic separator

<i>Products</i>	% <i>Wt</i>	% <i>Mn</i>	% <i>Fe</i>	<i>Distribution, %</i>	
				<i>Mn</i>	<i>Fe</i>
Magnetic	6.8	41.0	12	6.50	10.8
Middling	2.0	45.6	7.6	2.10	2.0
Non-magnetic	91.2	42.8	7.2	91.4	87.2
Head (calc)	100	42.7	7.56	100	100

separator. The magnetic and non-magnetic products were collected. The non-magnetic fraction was processed once again and the magnetic fraction thus obtained was considered as middling. The three products obtained on SALA low intensity magnetic separator were analysed for Mn and Fe (Table VII).

Wet High Intensity Magnetic Separation

The roll crushed material was further crushed by keeping the minimum possible gap between the rolls and from the resulting product a representative sample was drawn and subjected to magnetic separation on BOXMAG wet high intensity magnetic separator at 12,000 G. The roll crushed material was further ground to 30 and 60 min and this ground material was processed on wet high intensity magnetic separator. All the magnetic and non-magnetic products were analysed for Mn and Fe (Table VIII).

Another set of studies was carried out on this ground product by varying the intensity, so as to ascertain the optimum conditions and the products were analysed for Mn and Fe (Table IX).

TABLE VIII Results of magnetic separation on BOXMAG wet high intensity magnetic separator

<i>Code</i>	<i>Products</i>	<i>%Wt</i>	<i>%Mn</i>	<i>%Fe</i>	<i>Mn/Fe</i>	<i>Distribution, % Mn</i>
A	Magnetic	88.5	46.8	8.9	5.4	93
	Non-magnetic	11.5	28.5	6.1		7
B	Magnetic	77	50.5	8.6	5.87	87
	Non-magnetic	23	24.7	5.0		13
C	Magnetic	74.2	51.1	8.8	5.37	85
	Non-magnetic	25.8	26.6	6.0		15

A: Roll crushed material with $d_{80} \sim 600 \mu\text{m}$.

B: 30 min. ground product with $d_{80} \sim 100 \mu\text{m}$.

C: 60 min ground product with $d_{80} \sim 60 \mu\text{m}$.

TABLE IX Results of magnetic separation on BOXMAG wet high intensity magnetic separator (at various field strength)

<i>Intensity, G</i>	<i>Products</i>	<i>%Wt</i>	<i>%Mn</i>	<i>%Fe</i>	<i>Mn/Fe</i>	<i>Distribution, % Mn</i>
12,000	Magnetic	74.2	51.1	9.0	5.37	85
	Non-magnetic	25.8	26.4	6.1		15
15,000	Magnetic	81.2	51.0	8.9	5.73	95
	Non-magnetic	18.8	15	3.4		5
18,000	Magnetic	84.6	51.1	8.9	5.74	96
	Non-magnetic	15.4	11.0	2.8		4

RESULTS AND DISCUSSION

The high grade material suitable for ferromanganese production is limited (Table I), although the country has vast resources of the manganese ores. The ferromanganese industry in the country is likely to be affected due to this and it calls for an urgent need to augment the ferromanganese grade reserves. In Maharashtra MOIL operates manganese mines both open cast and underground mining. The manganese ores mined from Chikla region contain mostly low grade to medium grade type ores.

Mineralogical studies on various grade ores drawn from Chikla revealed the presence of manganese minerals in three predominant forms: manganese oxides, manganese silicates and as manganese carbonates, while iron is present as hematite and goethite. Braunitz, bixbyite, hussmannite, jacobsonite and coronadite form the major primary oxides, while pyrolusite, cryptomelane and psilomelane are recorded as

secondary oxide minerals. The manganese silicate phases are represented by hedenbergite, spessartite and rhodonite while kutnohorite and rhodocrosite form the carbonates. The gangue minerals mainly include silicates, carbonates, phosphates and sulphate. The silicate minerals occur in a close association with the manganese minerals. The XRD pattern of a medium grade ore sample is illustrated in Fig. 2. Quartz, orthoclase, plagioclase and diopside together form a major portion of the gangue minerals. Calcite and barite appear to be associated with manganese and silicate phases. Calcite occurs as secondary veins. Electron microscopic studies through X-ray image mapping revealed these veins to be rich in phosphorus. The phosphorus content in the ores from Chikla is relatively low and well within the range needed by ferromanganese industry. However, minute grains of manganese minerals within silicates and similar silicate grains within manganese phases pose problems in their liberation.

The distribution of different elements in various size fractions in low grade (Table IVa) and medium grade (Table IVb) run of mine samples

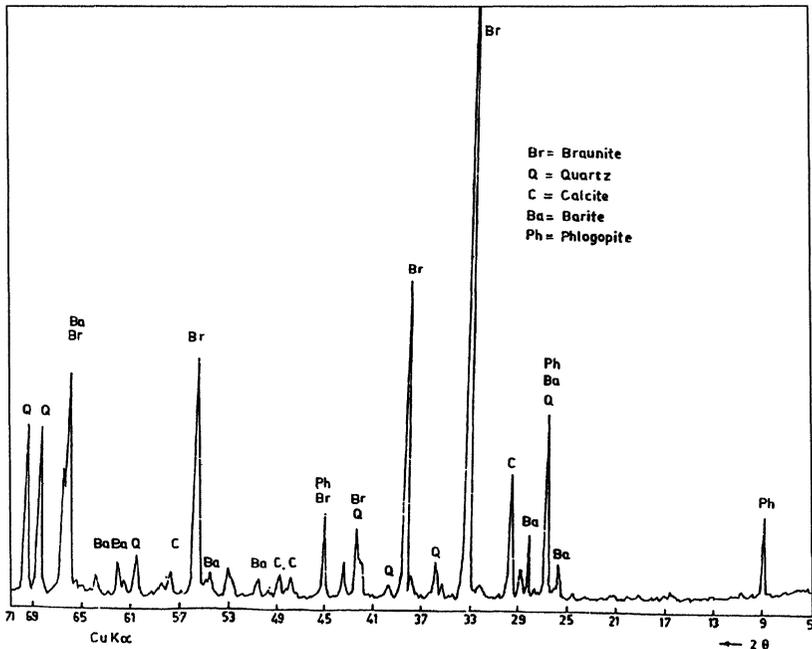


FIGURE 2 XRD pattern of medium grade manganese ore from Chikla

are given in Table IV. These samples were subjected to isodynamic separation and the magnetic products of corresponding fractions were analysed. The analyses indicated substantial improvement in the quality of the magnetic fractions which is largely due to the rejection of silica and calcia content, in addition to the high magnetic susceptibility of the manganese bearing minerals like braunite, bixbyte and husmannite. As the major gangue minerals are quartz and calcium carbonates, the enrichment of manganese by magnetic separation technique may be the ideal process to upgrade the manganese ores of Chikla region.

Another medium grade ore sample (44% Mn, 7.7% Fe, with 20–22% acid insolubles) from the Chikla region was studied for its amenability to beneficiation at the instance of MOIL. The preference of MOIL is to study its response to beneficiation by jigging. Table V indicates the distribution pattern of Mn and Fe in various sieve fractions of the roll crushed material (3 mm rolls gap). The sink and float studies on the size fractions using tetrabromoethane reveal (Table VI) that only 6–7% of the material could be obtained as light fraction which means 6–7% of the material only can be rejected theoretically by jigging. In case the material is subjected to jigging the manganese content can only be raised to around 47% Mn, as against the theoretical possibility of around 55% Mn by rejecting the 20% acid insolubles. Hence the application of jigging to such ores is not considered as a pragmatic approach.

It can be seen from Table VII that the manganese minerals are not prone to enrichment by wet low intensity magnetic separation on SALA drum magnetic separator. As the isodynamic separation studies on a similar medium grade ore revealed its susceptibility to the manganese enrichment, studies were carried out on BOXMAG wet high intensity magnetic separator. Table VIII indicates the possibility of enriching the Mn content to around 51% with 85% recovery. However, the ore needs to be ground to below 100 μm size. Studies carried out by varying the field strength revealed that around 15,000 G may be adequate to enrich the Mn content to around 51% Mn with 95% recovery, which is very close to the theoretically possible enrichment value. As the manganese ores from the Chikla region are the low phosphorus bearing ores, the beneficiated ore can be a potential resource for the ferromanganese industry.

CONCLUSIONS

The manganese ores from Chikla region are by and large of low to medium grade type and low in phosphorus content. Isodynamic separation studies on various ores from this region revealed their susceptibility to high intensity magnetic separation due to the presence of some manganese oxide minerals (bixybite, braunite, husmannite) along with quartz and calcite as major gangue.

The characterisation and beneficiation studies on a medium grade manganese ore sample from Chikla containing 44% Mn, 7.9% Fe and 20–22% acid insolubles revealed that the manganese content can be raised to around 47% Mn by jigging, whereas by grinding the ore to below 100 μm size followed by treatment on wet high intensity magnetic separator the Mn content can be enriched to 51% Mn with 95% recovery. This material having Mn/Fe ratio 5.7 with low phosphorus can be a potential resource for the ferromanganese industry.

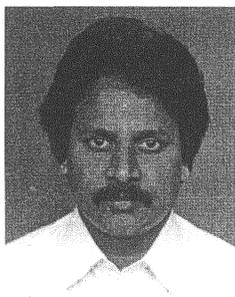
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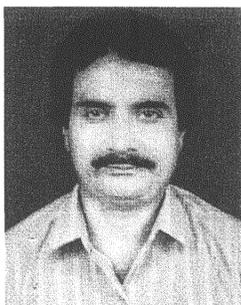
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